MEASUREMENT OF SURFACE FINISH

Surface Roughness

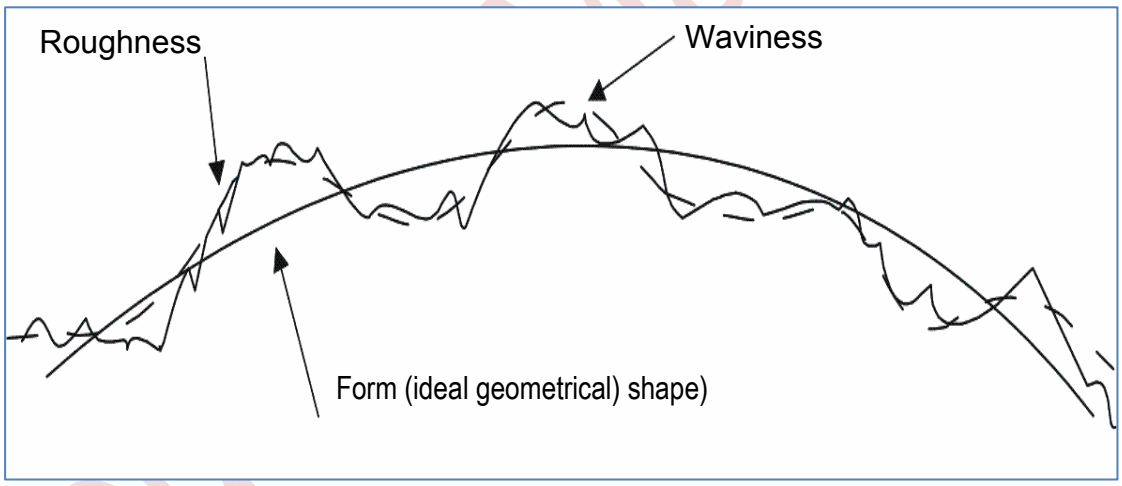
"The irregularities in the surface texture which are inherent in the production process but excuding waviness and errors of form" British Standard 1134

Surface properties:

Engineering surfaces never have an ideal geometrical shape, but instead include different deviations. With regards to the level of approximation they can be considered:

- smooth and even,
- smooth and wavy,
- rough and even,
- rough and wavy.

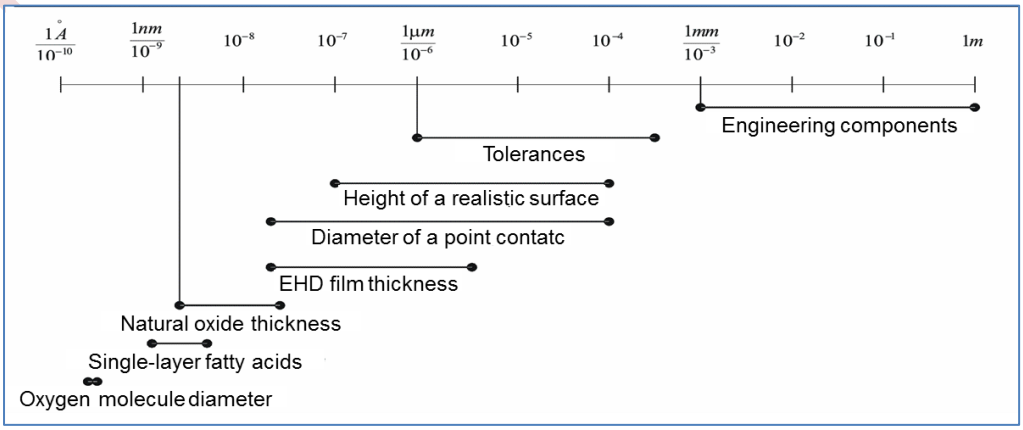
Surface topography



Errors of form:

- **Micro-geometrical deviations – roughness *(important for interaction of surfaces)***
- **Macro-geometrical deviations – waviness**

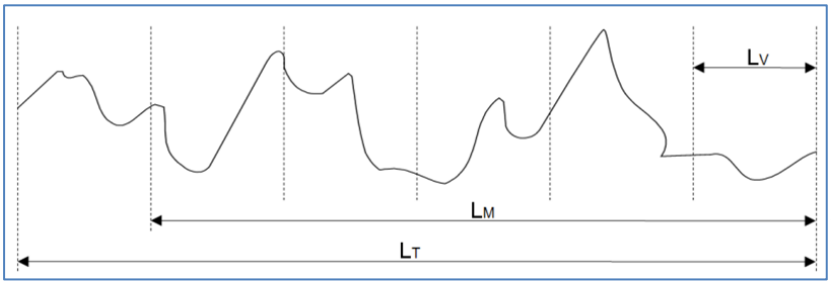
- **What is „rough"?**



Analysis of the measured surface roughness parameters:

Basic element:
surface profile.

$(L_T = L_V + L_M = L_V + 5 \times L_V)$



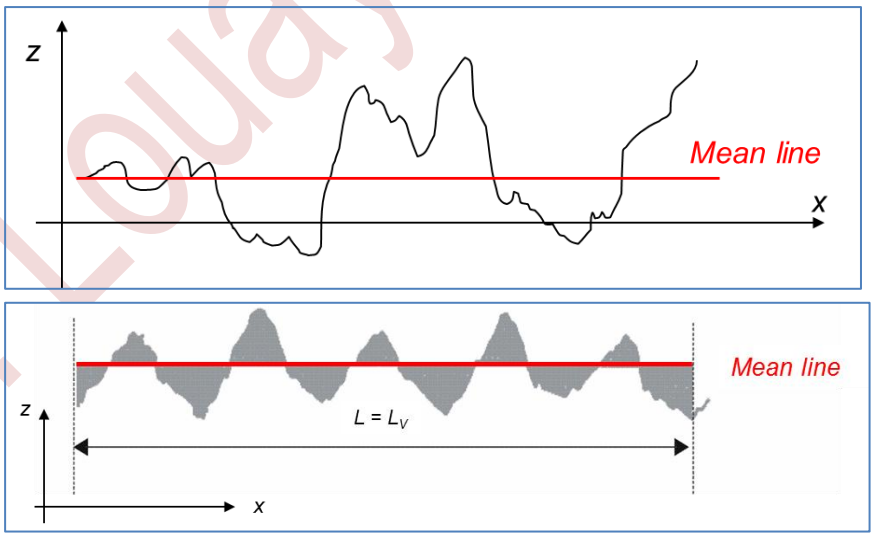
Traversing length is denoted with L_T and represents the distance that is traversed across the surface by the stylus when characterizing the surface, i.e. measurement length.

Assessment length L_M is the length over which surface data is acquired and assessed.

Sampling length (reference length) is denoted by L_V. It is a length of a section inside the assessment length and it is equivalent to wavelength of the filter, λ_C (it distinguishes the roughness from the waviness).

Standardized: important to choose the correct reference length and assessment length, so that the macro-geometrical deviations are excluded from the measurement.

Mean line of the profile is denoted by *m*. It is a line with a shape of geometrical profile (perfect geometric line) and it runs parallel to that profile.
The mean line of the profile is determined so that the <u>sum of squared deviations from this line is the smallest</u>.
...or otherwise: *Surface area above and below the mean line of the profile is the same!*



Average surface roughness produced by standard machining processes

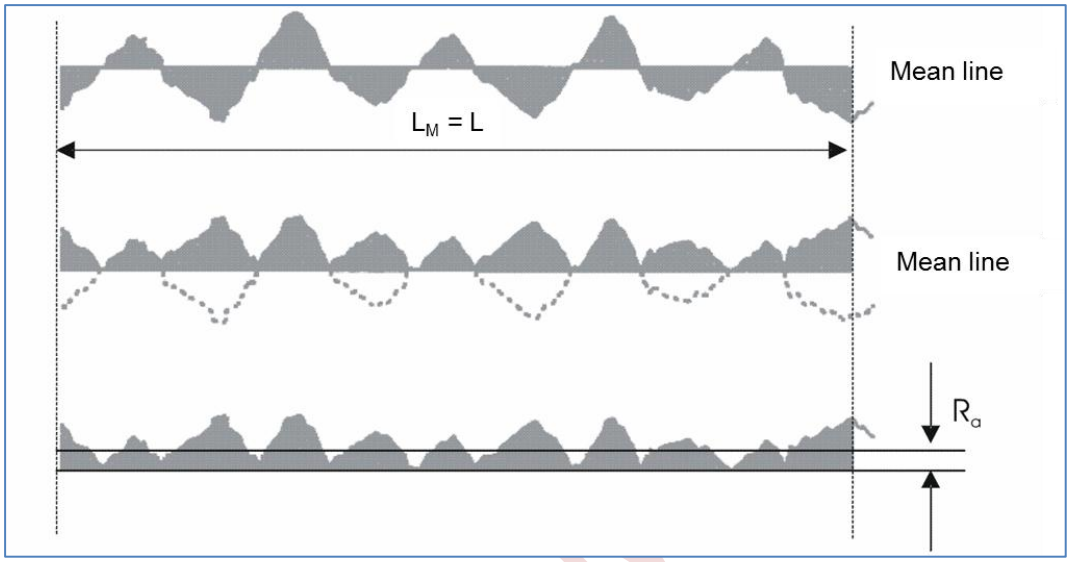
Planning (wood): 2,5 - 25 mm
Milling, drilling: 0,8 - 8 mm
Turning: 0,8 - 2,5 mm
Grinding: 0,25 - 2,5 mm
Honing, lapping: 0,25 mm

Arithmetical mean deviation, R_a:

The most widely recognized and used parameter for surface rougness characterization.

R_a is arithmetical mean deviation of all the measured values in the assesed profile (L_M) from the mean line of that profile.

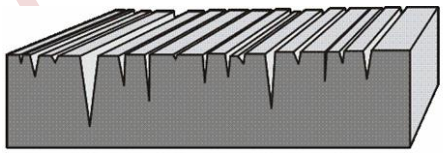
$$R_a = \frac{1}{l}\int_0^l |z(x)|\, dx$$



Arithmetical mean deviation of the assessed profile, R_a:

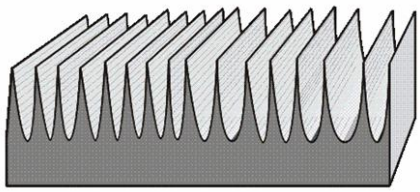
Avareging of data:

- R_a does not differentiate between profile peaks and valleys!!



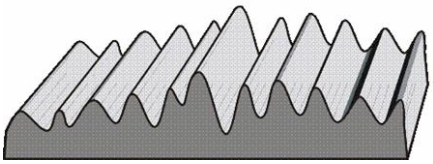
R_a = 2,4 µm

- R_a or any other parameter by itself: not sufficient.



R_a = 2,5 µm

- Additional parameters necessary: more sensitive & able to distinguish between surfaces with different shapes and/or ratios of peaks and valleys.



R_a = 2,4 µm

Dimensions and Tolerances:

- Factors that determine the performance of a manufactured product, other than mechanical and physical properties, include :
  - Dimensions - linear or angular sizes of a component specified on the part drawing
  - Tolerances - allowable variations from the specified part dimensions that are permitted in manufacturing

Dimensions (ANSI Y14.5M-1982):
A *dimension* is "a numerical value expressed in appropriate units of measure and indicated on a drawing and in other documents along with lines, symbols, and notes to define the size or geometric characteristic, or both, of a part or part feature"

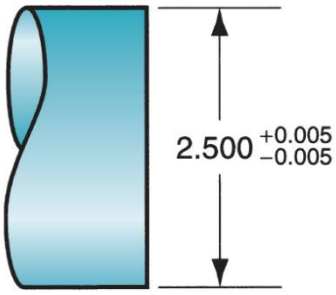
- The dimension indicates the part size desired by the designer, if the part could be made with no errors or variations in the fabrication process

Tolerances (ANSI Y14.5M-1982):
A *tolerance* is "the total amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits"

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

Bilateral Tolerance:

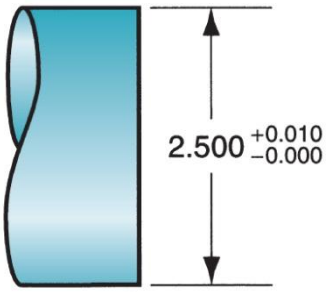
- Variation is permitted in both positive and negative directions from the nominal dimension
- Possible for a bilateral tolerance to be unbalanced
  - Ex: 2.500 +0.010, -0.005



(a)

Unilateral Tolerance:

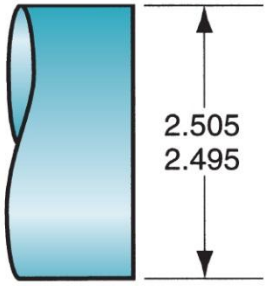
- Variation from the specified dimension is permitted in only one direction
- Either positive or negative, but not both



(b)

Limit Dimensions:

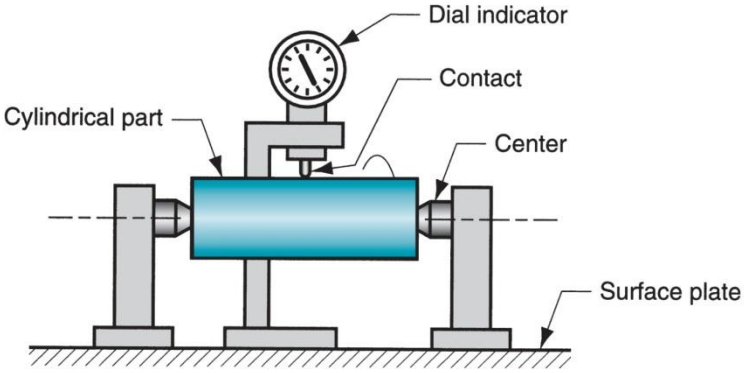
- Permissible variation in a part feature size consists of the maximum and minimum dimensions allowed

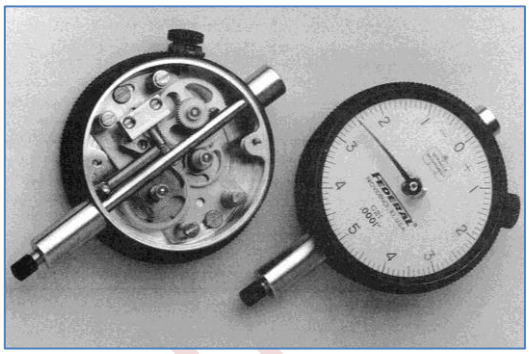


(c)

Dial Indicator:

- Front view shows dial and graduated face; back view shows cover plate removed.
- As part is rotated about its center, variations in outside surface relative to center are indicated on the dial



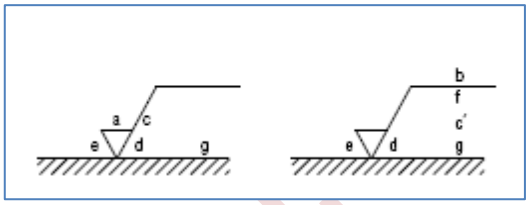


Four Elements of Surface Texture:

1. Roughness - small, finely-spaced deviations from nominal surface
   - Determined by material characteristics and processes that formed the surface
2. Waviness - deviations of much larger spacing
   - Waviness deviations occur due to work deflection, vibration, tooling, and similar factors
   - Roughness is superimposed on waviness
3. Lay - predominant direction or pattern of the surface texture
4. Flaws - irregularities that occur occasionally on the surface
   - Includes cracks, scratches, inclusions, and similar defects in the surface
   - Although some flaws relate to surface texture, they also affect surface integrity

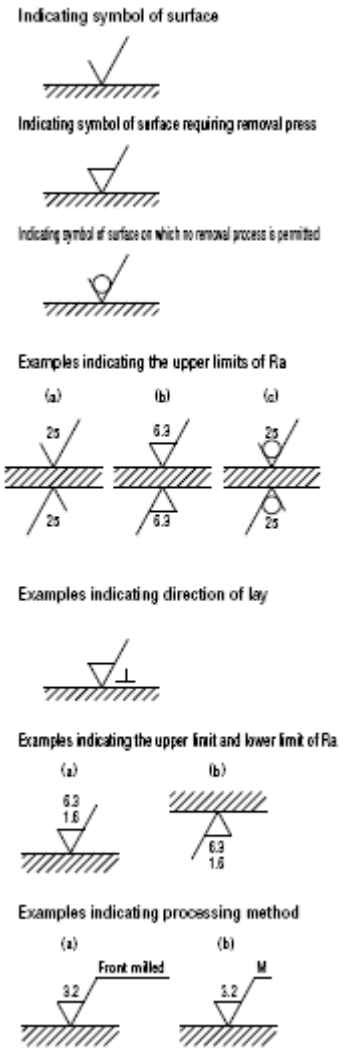
Positions of respective indicating symbols relative to indicating symbol of surface:
Each grain surface position is indicated as shown in Fig. 1.This includes surface roughness, cut-off value or reference length, processing method, symbol of direction of lay, surface waviness, etc.

a: Value of Ra
b: Processing method
c: Cutoff value. Evaluation length
c: Reference length. Evaluation length
d: Symbol of direction of lay
f : Parameter other than Ra(With tp, parameter/cutoff level)
g: Surface waviness(according to JIS B 0610)



Reference: The location of lay of e in Fig. 1.is given as the finish allowance in ISO 1302.

Symbol	Meaning	Figure
=	Parallel to the projected surface on which the direction of lay of the cutting blade is indicated. (ex) Shaped surface	Direction of lay of cutting blade
⊥	Perpendicular to the projected surface on which the direction of lay of the cutting blade is indicated. (ex) Shaped surface (when viewed from the side), machined or cylindrical ground surface.	Direction of lay of cutting blade
X	Intersection of two diagonal lines on the projected surface on which the direction of lay of the cutting blade is indicated. (ex) Honing finished surface	Direction of lay of cutting blade
M	Multidirectional intersection or non-directional point on the projected surface on which the direction of lay of the cutting blade is indicated. (ex) Rapping finished surface, super finished surface, face milled or end milled surface in surfacing feed direction	
C	Concentric circles roughly centered on the same on the surface on which the direction of lay of the cutting blade is indicated. (ex) Facing surface	
R	Radiating shape roughly centered on the same point on the surface on which the direction of lay of the cutting blade is indicated.	



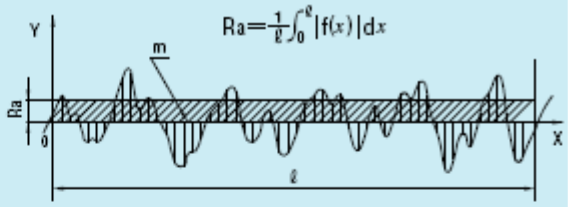
Categories of surface roughness:

Definitions and indications for surface roughness parameters(for industrial products)are specified. They are arithmetical mean roughness(Ra), maximum height(Ry), ten-point mean roughness(Rz), mean spacing of profile irregularities(Sm), mean spacing of local peaks of the profile(S) and profile bearing length ratio(tp). Surface roughness is given as the arithmetical mean value for a randomly sampled area. [Mean center line roughness(Ra)is defined in the annexes of JIS B 0031 and JIS B 0061].

Typical ways for obtaining surface roughness:

Arithmetical mean roughness (Ra)

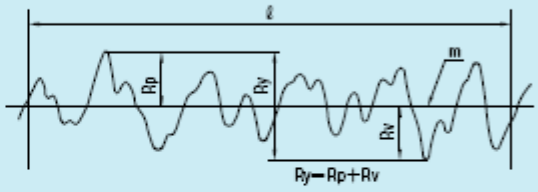
A section of standard length is sampled from the mean line on the roughness chart. The mean line is laid on a Cartesian coordinate system wherein the mean line runs in the direction of the x-axis and magnification is the y-axis.The value obtained with the formula on the right is expressed in micrometer (μm) when y=f (χ).



Maximum peak (Ry)

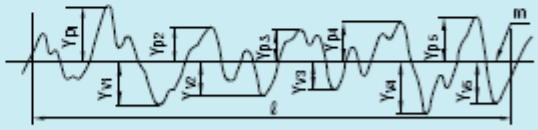
A section of standard length is sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y direction. The value is expressed in micrometer (μm).

Note : To obtain Ry, sample only the standard length. The part, where peaks and valleys are wide enough to be interpreted as scratches, should be avoided.



Ten-point mean roughness (Rz)

A section of standard length is sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y direction.
Then, the average peak is obtained among 5 tallest peaks (Yp), as is the average valley between 5 lowest valleys (Yv).
The sum of these two values is expressed in micrometer (μm).



$$Rz = \frac{|Yp_1+Yp_2+Yp_3+Yp_4+Yp_5| + |Yv_1+Yv_2+Yv_3+Yv_4+Yv_5|}{5}$$

$Yp_1, Yp_2, Yp_3, Yp_4, Yp_5$: Tallest 5 peaks within sample

$Yv_1, Yv_2, Yv_3, Yv_4, Yv_5$: Lowest 5 peaks within sample

Reference: **Relationship between arithmetical mean roughness(Ra)and conventional symbols:**

Arithmetical mean roughness Ra			Max. height Ry	Ten-point mean roughness Rz	Standard length of Ry · Rz ℓ (mm)	Triangular Indication
Preferred number series	Cut-off value λc (mm)	Indication of surface texture on drawings	Preferred number series			
0.012 a	0.08	0.012 ~ 0.2	0.05 s	0.05 z	0.08	▽▽▽▽
0.025 a	0.25		0.1 s	0.1 z		
0.05 a			0.2 s	0.2 z	0.25	
0.1 a	0.8		0.4 s	0.4 z		
0.2 a			0.8 s	0.8 z		
0.4 a		0.4 ~ 1.6	1.6 s	1.6 z	0.8	▽▽▽
0.8 a			3.2 s	3.2 z		
1.6 a			6.3 s	6.3 z		
3.2 a	0.25	3.2 ~ 6.3	12.5 s	12.5 z	0.25	▽▽
6.3 a			25 s	25 z		
12.5 a	8	12.5 ~ 25	50 s	50 z		▽
25 a			100 s	100 z	8	
50 a		50 ~ 100	200 s	200 z		~
100 a	—		400 s	400 z	—	

The evaluation length of Ra, Ry and Rz: Five times the cut-off value standard length respectively.

Symbols for Geometrical Characteristics:

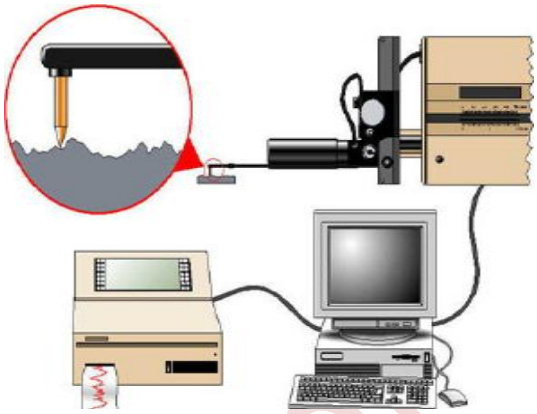
Tolerances	Characteristics	Symbol
Form	Straightness	—
	Flatness	▱
	Roundness	○
	Cylindricity	⌭
	Profile any line	⌒
	Profile any surface	⌓
Orientation	Parallelism	//
	Perpendicularity	⊥
	Angularity	∠
	Profile any line	⌒
	Profile any surface	⌓
Location	Position	⌖
	Concentricity (for centre points)	◎
	Coaxiality (for axes)	◎
	Symmetry	⌯
	Profile any line	⌒
	Profile any surface	⌓
Run-out	Circular run-out	↗
	Total run-out	⌰

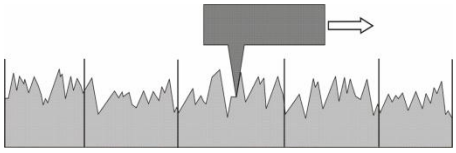
Methods of measuring surface finish:

1. **SURFACE INSPECTION BY COMPARISON MEHODS:** these include:
   i. Touch inspection
   ii. Visual inspection
   iii. Scratch inspection
   iv. Microscopic inspection
   v. Surface photographs
   vi. Micro interferometer
   vii. Wallace surface dynamometer
   viii. Reflected light intensity
   ix. Comparison by standard specimens
2. **Direct Instrument Measurement:**
   i. Intersection method
   ii. Interference method
   iii. Stylus method

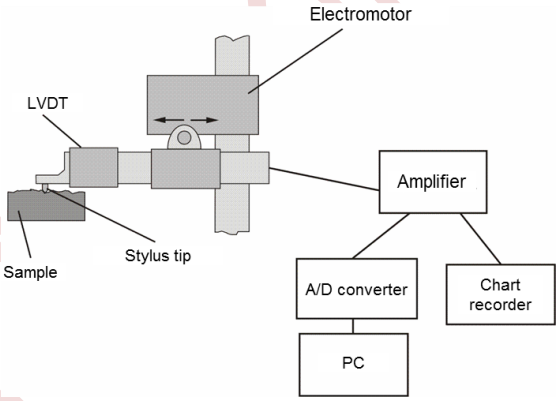
Stylus Instrument Surface scan :

- Maximal measuring area 100x100 mm
- Vertical range 1 mm
- Horizontal resolution 2μm
- Vertical resolution 8 nm





2D Profilo-meter :The resolution depends on the stylus tip and the velocity of scanning.

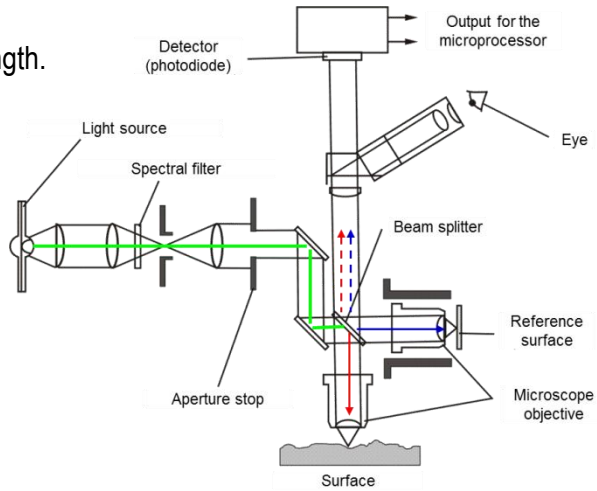


Optical Instruments(Optical interferometer)

PST Micro-Xam Interferometer:

- Maximal measuring area 1.3x1.0 mm
- Vertical range 5 mm
- Horizontal resolution 0.3 μm
- Vertical resolution 0.05 nm

3D:The resolution depends on optics and light wavelength.



Scanning Probe Microscopy SPM

Primary forms

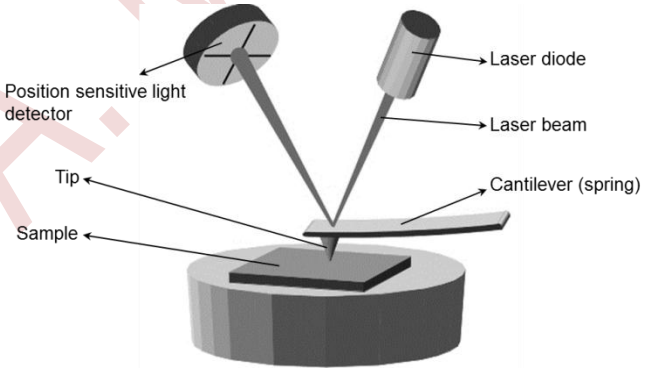
I. Scanning Tunneling Microscopy STM

II. Atomic Force Microscopy AFM

AFM Operation Modes:

- Contact
- Tapping
- Non-Contact

3D:The resolution depends on the laser, scanner, feedback loop, software, probe (tip)…



Dimension 3000 SPM:

- Maximal measuring area 100 x100 µm
- Vertical range 6 µm
- Horizontal resolution 100 pm
- Vertical resolution 10 pm