Precision Metrology 23 : Surface Metrology

Importance of Surface Quality

1. Functionality: Fitness, corrosion, wear, internal strength, conductivity, resistance, optical property, lubrication, coating, plating, painting

Functional Applications:

-Moving parts in machinery (gear, bed, guide,piston,axis)

-Sealing (piston ring, valve, cylinder)

-Reference (Gage block, micrometer)

-Cutting edge(Lazor)

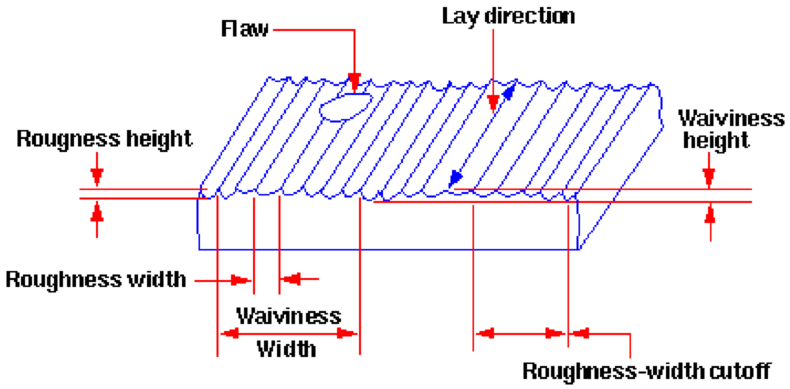
-Electric contact(switch, distributor)

-Optics (mirror, lens)

2. Appearance: Flaws, defects, scratch, cracks, pits
3. Cost: Cost-effective manufacture for appropriate surface quality

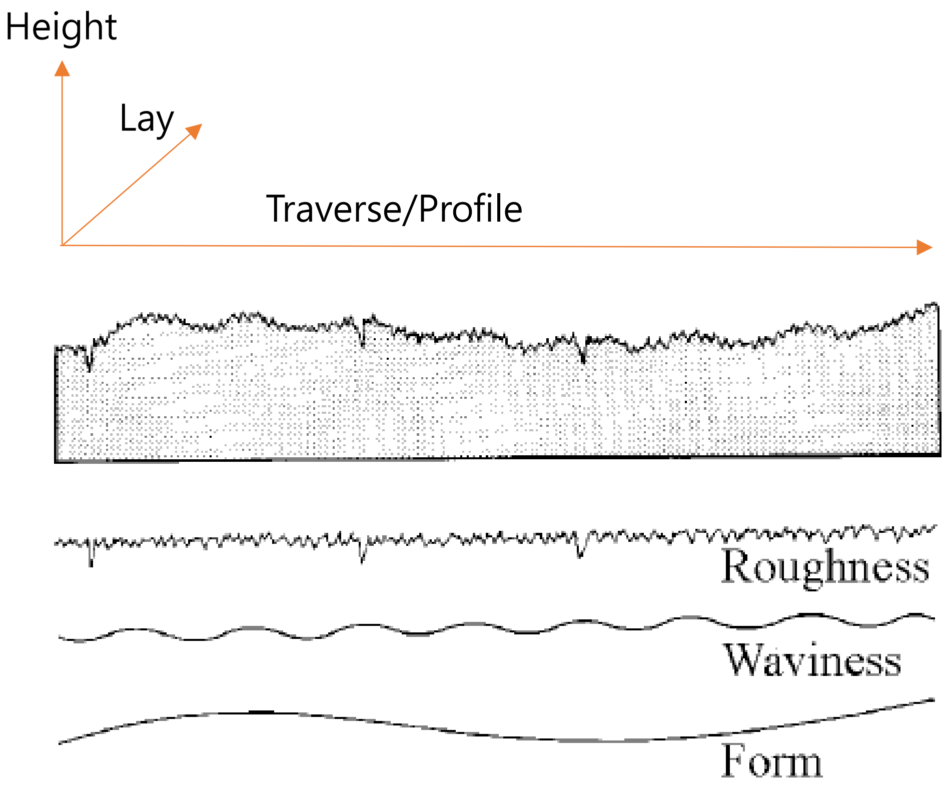
Ex) Cost $\propto$ 1/surface finish^2

Terminology in Surface Metrology



Surface characteristics (Courtesy, ANSI B46.1 - 1962)

Source: www.mfg.mtu.edu



Source: P.Ettl etal. Roughness parameters and surface deformation measured by Coherence Radar

Lay: Dominant pattern in the direction of Processing/Tooling, and the direction of profiling/traversing is set perpendicular to the Lay direction

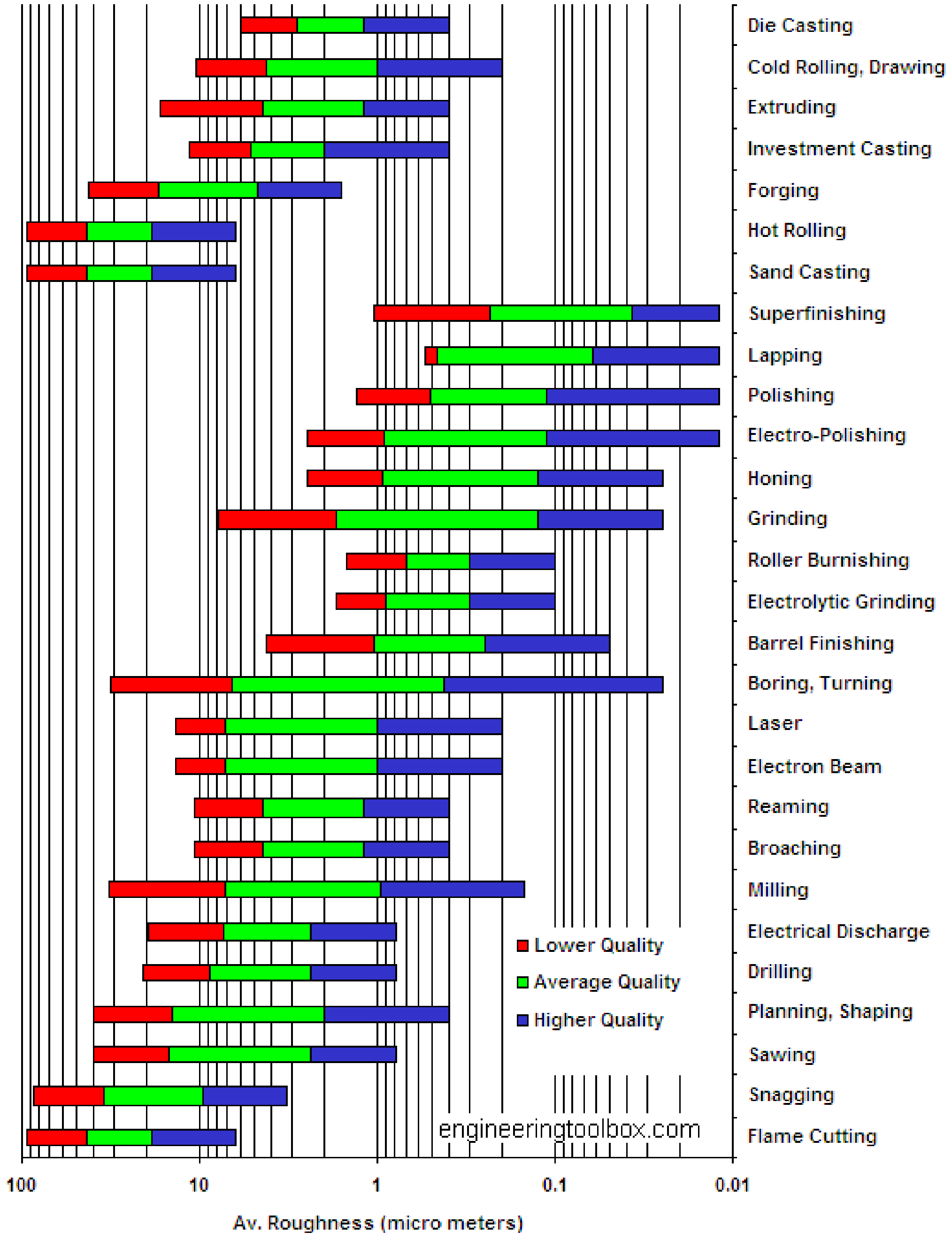
Flaws: Irregularities such as cracks, pits, scratch

Roughness: Closely spaced irregularities due to processing conditions, tool marks, grits of grinding/lapping stones. Depending on Process/Manufacture for surface ("Finger print of process")

Waviness: Widely spaced irregularities, due to deflection, vibration, tool run-outs, chatter, tool eccentricity

Form error: Long period or non-cyclic deviation due to geometric error in guideway

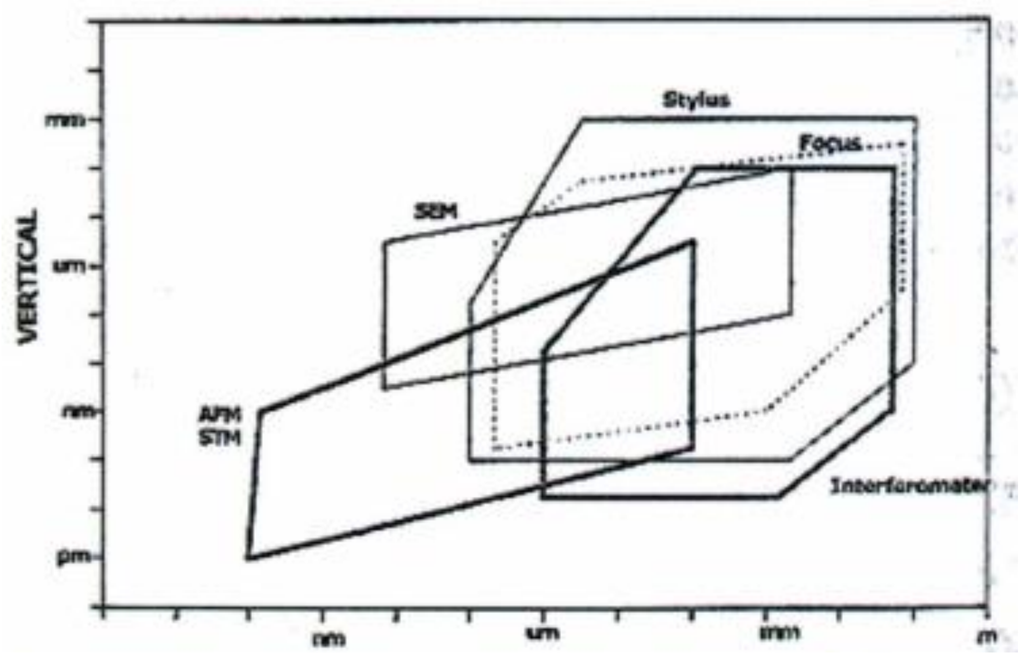
Mechanical Processing and surface roughness



Source: www.engineeringtoolbox.com

Surface Measurement Techniques

Vertical vs. Horizontal resolution for surface profiling techniques



HORIZONTAL

Source: HJ PAHK etal. 3D surface profiling system with nanometer accuracy, ISIST 2002

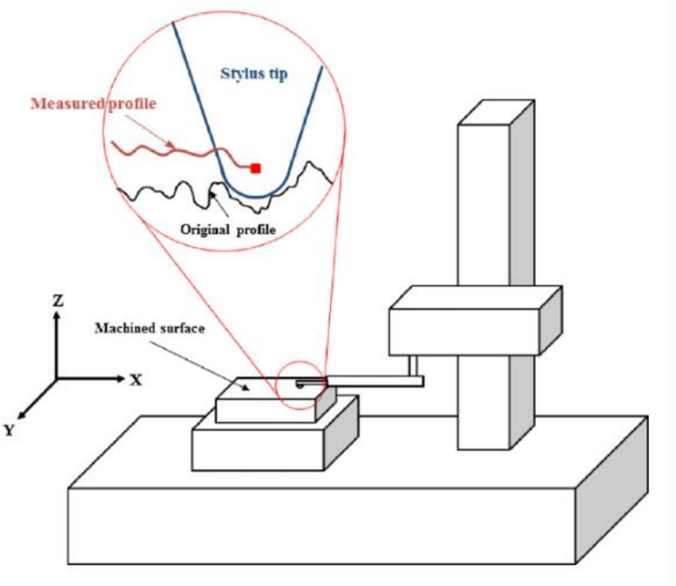
1. Mechanical stylus method, or Stylus profilo-meter

:Reference Measurement Method

-Stylus pick-up traverses a surface

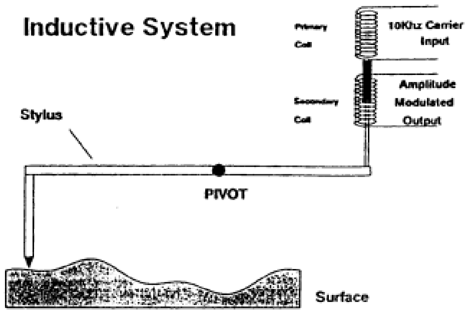
-Vertical motion of stylus converts into electrical signal

-2D/3D measurements with traversing table



Source: DH Lee, 'Assessment of surface profile data acquired by a stylus profilemeter'

Stylus Pick-up in detail



Source: A comparative study on the 3D surface topography for the polished surface of femoral head, H.J.Pahk, Int. J. Advanced Manufacturing Technology, Vol16, 564-570, 2000

Advantage: A reference/standard technique

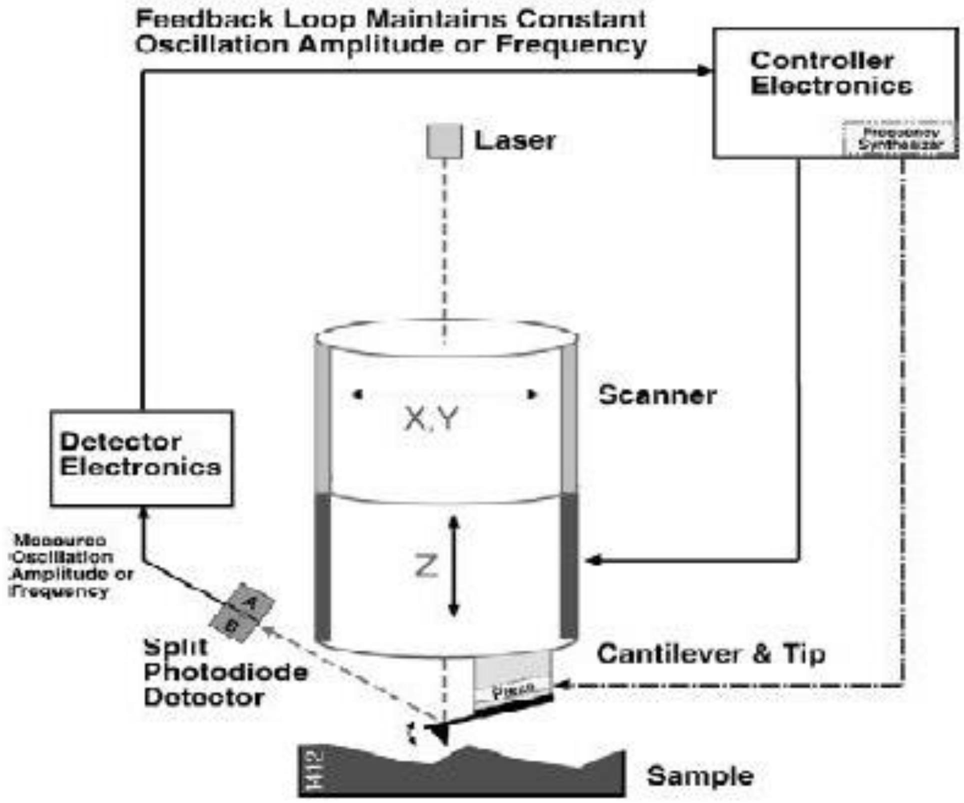
Disadvantage: Stylus can damage or scratch the surface

Size of stylus tip limits the sharp surface pits measurement

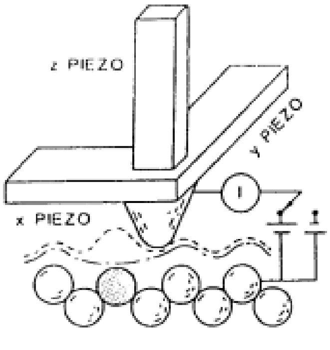
(Typical tip radius ranges from 0.1um to few um)

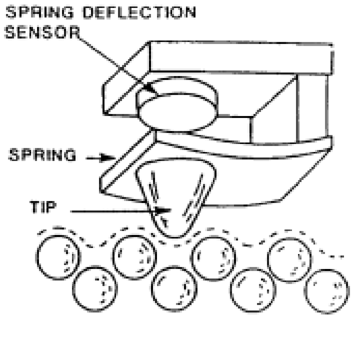
2. AFM(Atomic Force Microscope), STM(Scanning Tunneling Microscope)

Source:wikipedia



Tips for STM and AFM





STM:

-Conducting probe tip

-Electron tunnels across the gap("Tunneling Current")

-Constant current feedback and rastor scanning

-XYZ motions provided by PZT stacks

-Strict control for vibration/temperature is required

-Typical measurement range is 100umX100umX5um

-Only possible to measuring conducting surface

AFM:

-Van der Waals force between the tip and surface

-Deflection of cantilever can be detected

-XYZ motions provided by PZT stacks

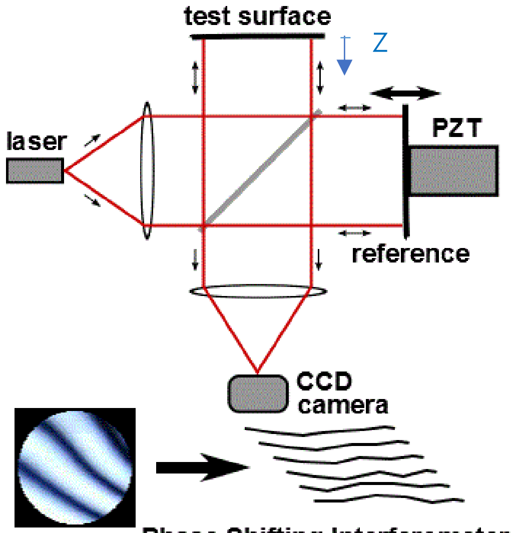
-Feedback control with cantilever movement

-Non-conducting, organic, biological surface can be measured

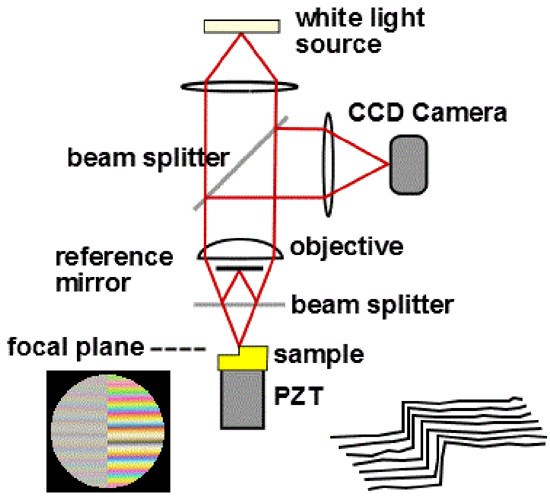
-Strict control for vibration/temperature is required

-Typical measurement range is 100umX100umX5um

3. Interferometric microscope



Phase Shifting Interferometer



Vertical Scanning Interferometer

Source:wikipedia

Beam Path1 from the reference,

Beam Path2 from the specimen;

Two beams meet and interfere at the Beam Splitter(BS);

W_1, W_2: Light waves of Beam1, Beam2

Let L be the path length of each beam initially the same.

When the specimen has Z height in vertical direction, the beam2 path is shortened by 2Z, while the beam1 path is not changed. Thus

$W_1=a[\cos 2\pi L/\lambda+j\sin 2\pi L/\lambda]$

$W_2=b[\cos 2\pi(L-2Z)/\lambda+j\sin 2\pi(L-2Z)/\lambda]$

When the two beams meet and interfere,

the combined Intensity, I, is

$\mathbf{I=|W_1+W_2|^2}$

$=[a\cos 2\pi L/\lambda+b\cos 2\pi(L-2Z)/\lambda]^2+[a\sin 2\pi L/\lambda+b\sin 2\pi(L-2Z)/\lambda]^2$

$=a^2+b^2+2ab\cos 2\pi L/\lambda\cos 2\pi(L-2Z)+2ab\sin 2\pi L/\lambda\sin 2\pi(L-2Z)/\lambda$

$=a^2+b^2+2ab\cos[2\pi L/\lambda-2\pi(L-2Z)/\lambda]$

$=a^2+b^2+2ab\cos 4\pi Z/\lambda=(a^2+b^2)[1+2ab/(a^2+b^2)\cos 4\pi Z/\lambda]$

$=I_0(1+K\cos 4\pi Z/\lambda)$; eq(1)

=Bright, when $4\pi Z/\lambda=0,2\pi,4\pi\ldots$, that is $Z=0,\ \lambda/2,\ \lambda\ldots$

=Dark, when $4\pi Z/\lambda=\pi,3\pi,5\pi\ldots$, that is $Z=\lambda/4,\ 3\lambda/4,\ 5\lambda/4\ldots$

Phase Shifting Interferometry and “Bucketing”

:To calculate the height information, Z(x,y) from the Intensity measurement, I(x,y)

From eq(1), let $4\pi Z(x,y)/\lambda=\ \psi(x,y)$=phase at (x,y)

$I_1(x,y)=I_0[1+K\cos 4\pi Z(x,y)/\lambda]=I_0[1+K\cos\psi(x,y)]$; eq(1′)

Move the reference mirror by $+\lambda/8$ (≒79 nm for Laser source), then W1 beam path is increased accordingly, thus

$I_2(x,y)=I_0[1+K\cos 4\pi\{Z(x,y)+\lambda/8\}/\lambda]$

$=I_0[1+K\cos\{4\pi Z(x,y)+\pi/2\}]=\ I_0[1-K\sin\psi(x,y)]$; eq(2)

Move the reference mirror by $+2\lambda/8$, similarly,

$I_3(x,y) = I_0[1+K\cos 4\pi\{Z(x,y)+2\lambda/8\}/\lambda]$

$= I_0[1+K\cos\{4\pi(x,y)+\pi\}] = I_0[1-K\cos\psi(x,y)]$; eq(3)

Move the reference by +3λ/8, similarly,

$I_4(x,y) = I_0[1+K\cos 4\pi\{Z(x,y)+3\lambda/8\}/\lambda]$

$= I_0[1+K\cos\{4\pi(x,y)+3\pi/2\}] = I_0[1+K\sin\psi(x,y)]$; eq(4)

From eq(1′) to eq(4)

$I_1-I_3=2I_0K\cos\psi(x,y)$; $I_4-I_2=2I_0K\sin\psi(x,y)$

$\therefore\psi(x,y)=\tan^{-1}[I_4-I_2]/ [I_1-I_3]$

$\therefore Z(x,y)=\psi(x,y)\lambda/4\pi$

Thus, the height, Z, can be measured at (x,y) location on the specimen

Drawbacks: Phase ambiguity, thus only for smooth surface having steps less than λ/4 height; wavelength accuracy dependent

White Light Interferometry

or Vertical Scanning Interferometry

:To use the white light as the light source, and the objective lens (such as Mirau optics) is configured to form the focal plane on the specimen surface.

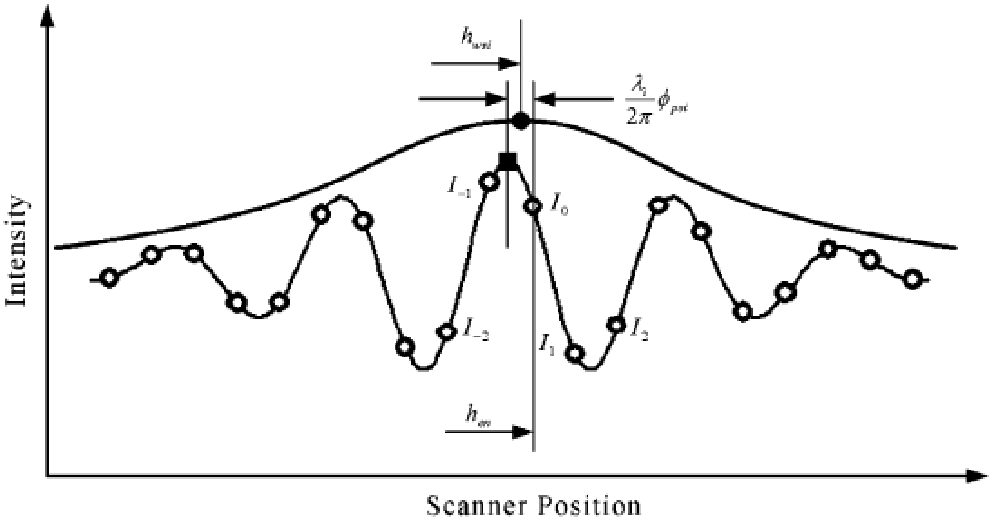
The interference is observed during the very short coherence length of few wavelength, typically 3-4um (or 6-8 wavelengths of white light)

As the sample is moved by the precise PZT scanner, the measured intensity or the visibility is formed as in the figure.

Thus the Z height can be measured as the scan position that gives the maximum intensity of the visibility, by calculating the envelope curve of the visibility function.

The advantage is that the phase ambiguity can be reduced, making the surface having higher steps measurement possible, while the phase shift interferometry is only possible for the smooth surface not having steps of more than λ/4 height.

Drawbacks: Scanner positioning accuracy dependent, phase error, weak to vertical vibration



Source: New algorithm of white-light phase shifting interferometry pursing higher repeatability by using numerical phase error correction schemes of pre-processor, main processor, and post-processor, Jung-Hwan Kim, Sung-Won Yoon, Jeong-Ho Lee, Woo-Jung Ahn and Heui-Jae Pahk, Optics and Lasers in Engineering, Volume 46(2), 140-148, 2008