THE UNIVERSITY OF ARIZONA.

College of Optical Sciences

10.0 Absolute Measurements

Computers make it possible to perform measurements more accurate than the reference surface

10.0 Absolute Measurements

- 10.0 Absolute Measurements
  - 10.1 Flat Surfaces
  - 10.2 Spherical Surfaces
    - 10.2.1 Three Measurements of Spherical Mirror
    - 10.2.2 Ball Averager
  - 10.3 Surface Roughness
    - 10.3.1 Perfect Mirror
    - 10.3.2 Generate Reference
    - 10.3.3 Absolute rms Measurement

Absolute Surface Shape Measurement

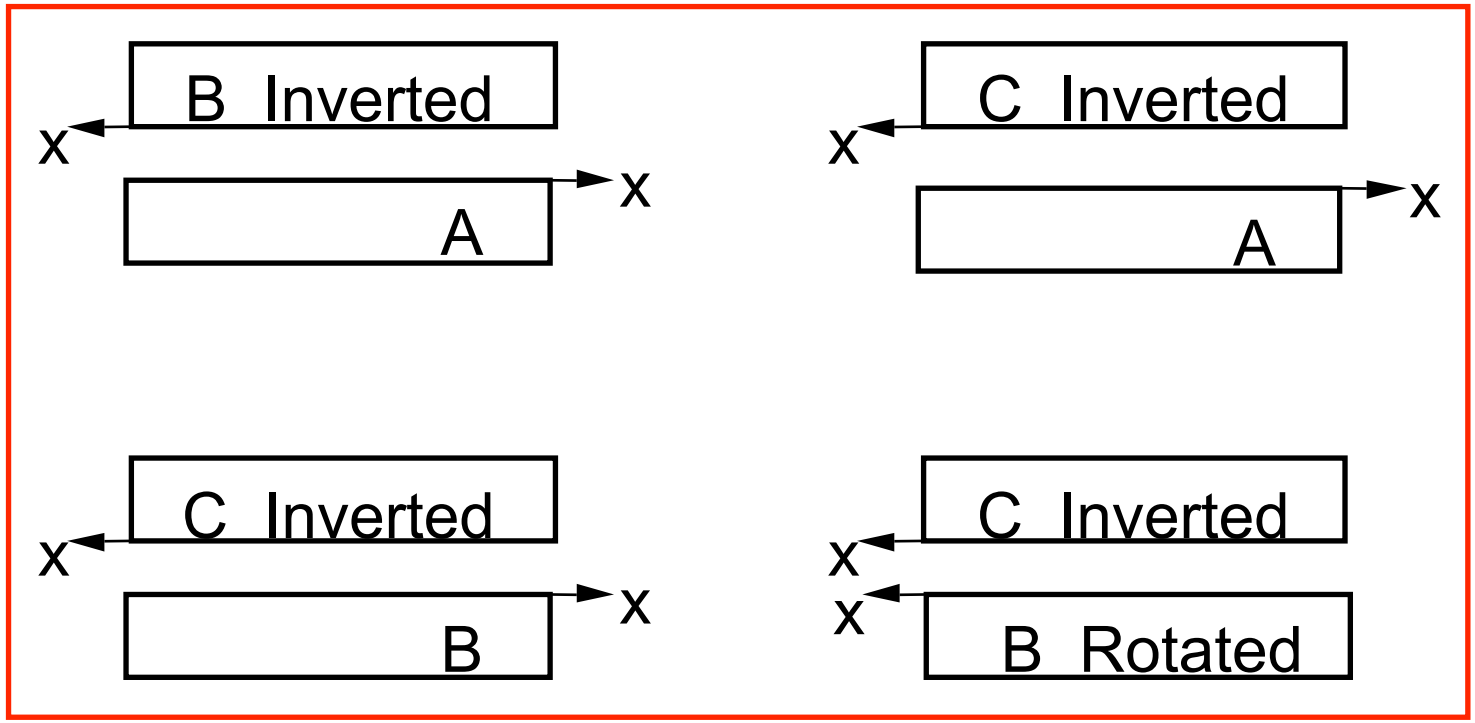
- Perform measurements more accurate than the reference surface
- Removing system aberrations & reference surface effects
- Improves measurement accuracy
- Tests for
  - Flats
  - Spheres
  - Surface roughness

THE UNIVERSITY OF ARIZONA

10.1 Flat Surfaces

- For an absolute measurement of flat surfaces need at least three flats
  - Compare flat A with flat B
  - Compare flat A with flat C
  - Compare flat B with flat C
- Can get null test for all three measurements all three flats must indeed be flat.

Measurements Required for Three-Flat Test



Three-Flat Test Equations

Make 4 Measurements

$$G_{AB}(x,y) = f_A(x,y) + f_B(-x,y)$$

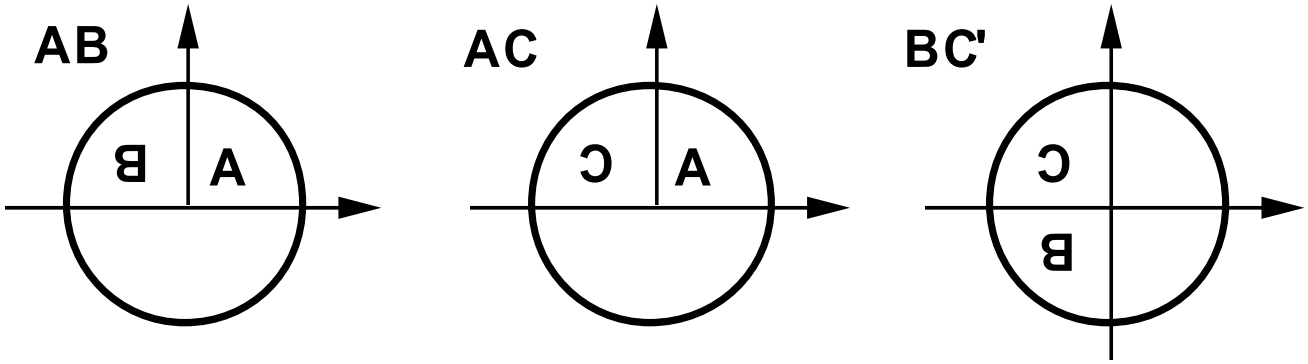
$$G_{AC}(x,y) = f_A(x,y) + f_C(-x,y)$$

$$G_{BC}(x,y) = f_B(x,y) + f_C(-x,y)$$

$$G_{BC'}(x,y) = f_B(-x,-y) + f_C(-x,y)$$

THE UNIVERSITY OF ARIZONA

Three-Flat Test - X Line

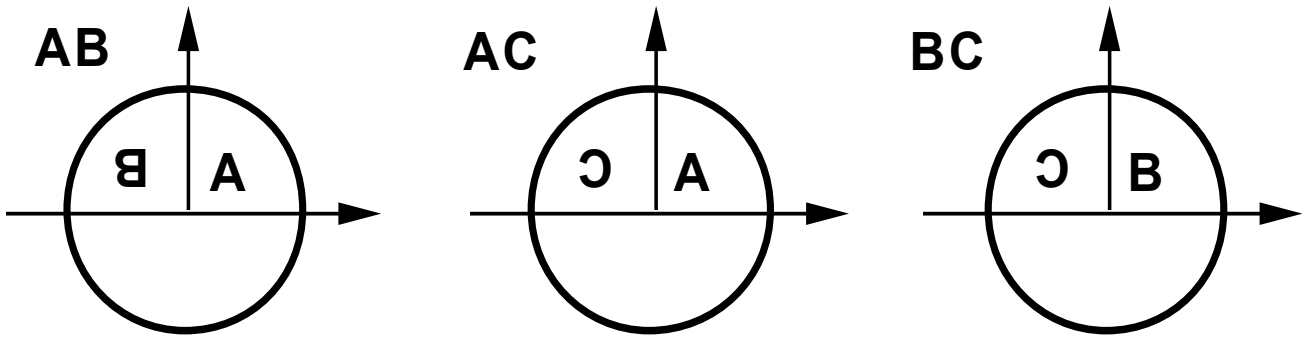


$$f_A(x,0) = \frac{G_{AB}(x,0) + G_{AC}(x,0) - G_{BC'}(x,0)}{2}$$

$$f_B(x,0) = \frac{G_{AB}(x,0) - G_{AC}(x,0) + G_{BC'}(x,0)}{2}$$

$$f_C(x,0) = \frac{-G_{AB}(x,0) + G_{AC}(x,0) + G_{BC'}(x,0)}{2}$$

Three-Flat Test - Y Line



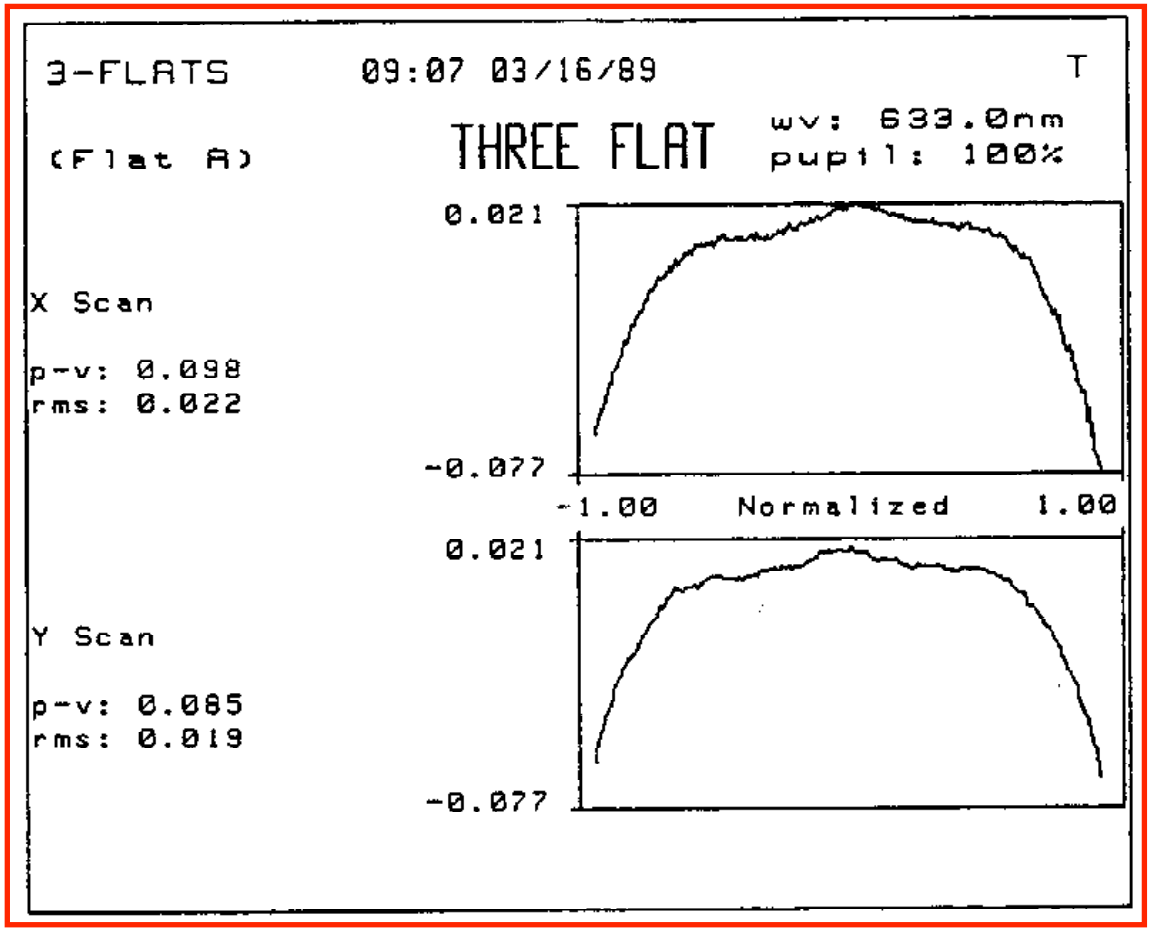
$$f_A(0,y) = \frac{G_{AB}(0,y) + G_{AC}(0,y) - G_{BC}(0,y)}{2}$$

$$f_B(0,y) = \frac{G_{AB}(0,y) - G_{AC}(0,y) + G_{BC}(0,y)}{2}$$

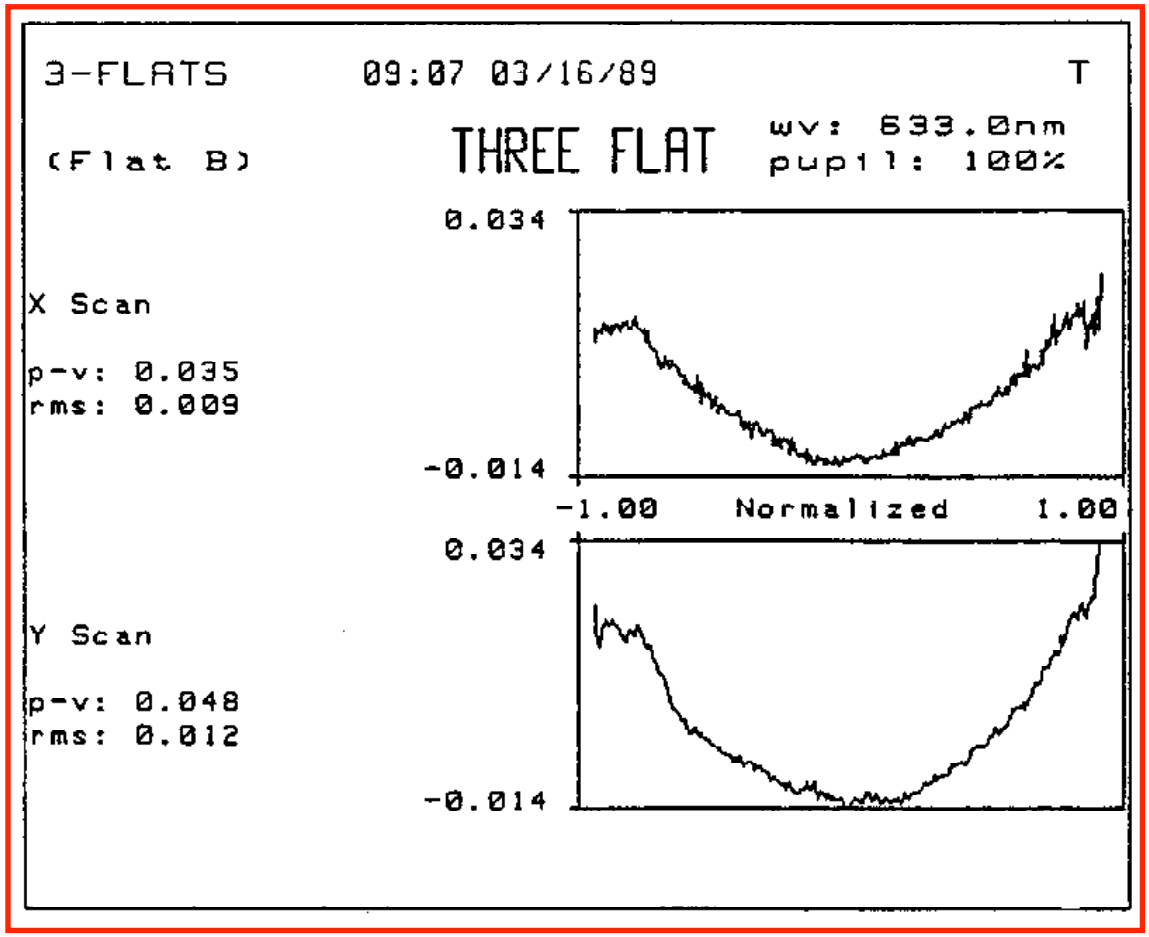
$$f_C(0,y) = \frac{-G_{AB}(0,y) + G_{AC}(0,y) + G_{BC}(0,y)}{2}$$

THE UNIVERSITY OF ARIZONA

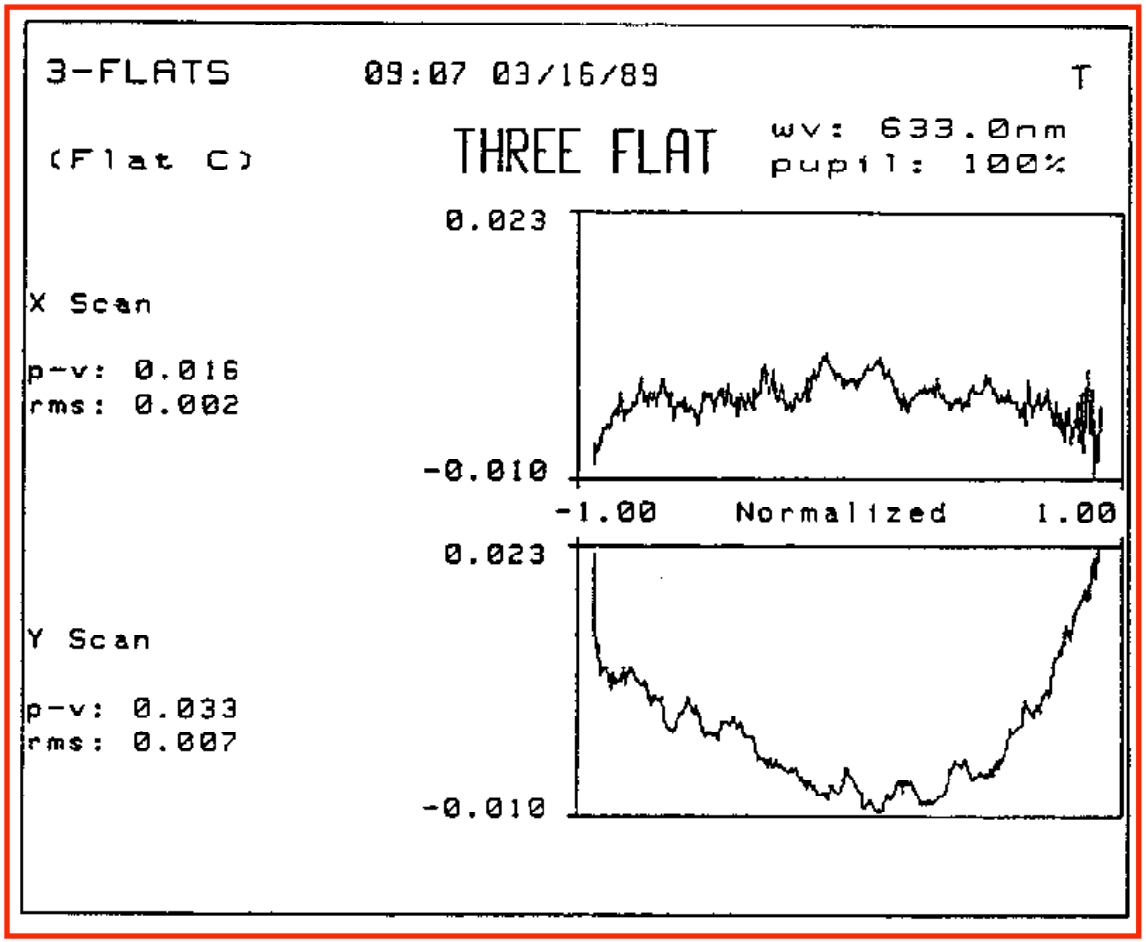
Three-Flat Test - Flat A



Three-Flat Test - Flat B



Three-Flat Test - Flat C



THE UNIVERSITY OF ARIZONA

Question

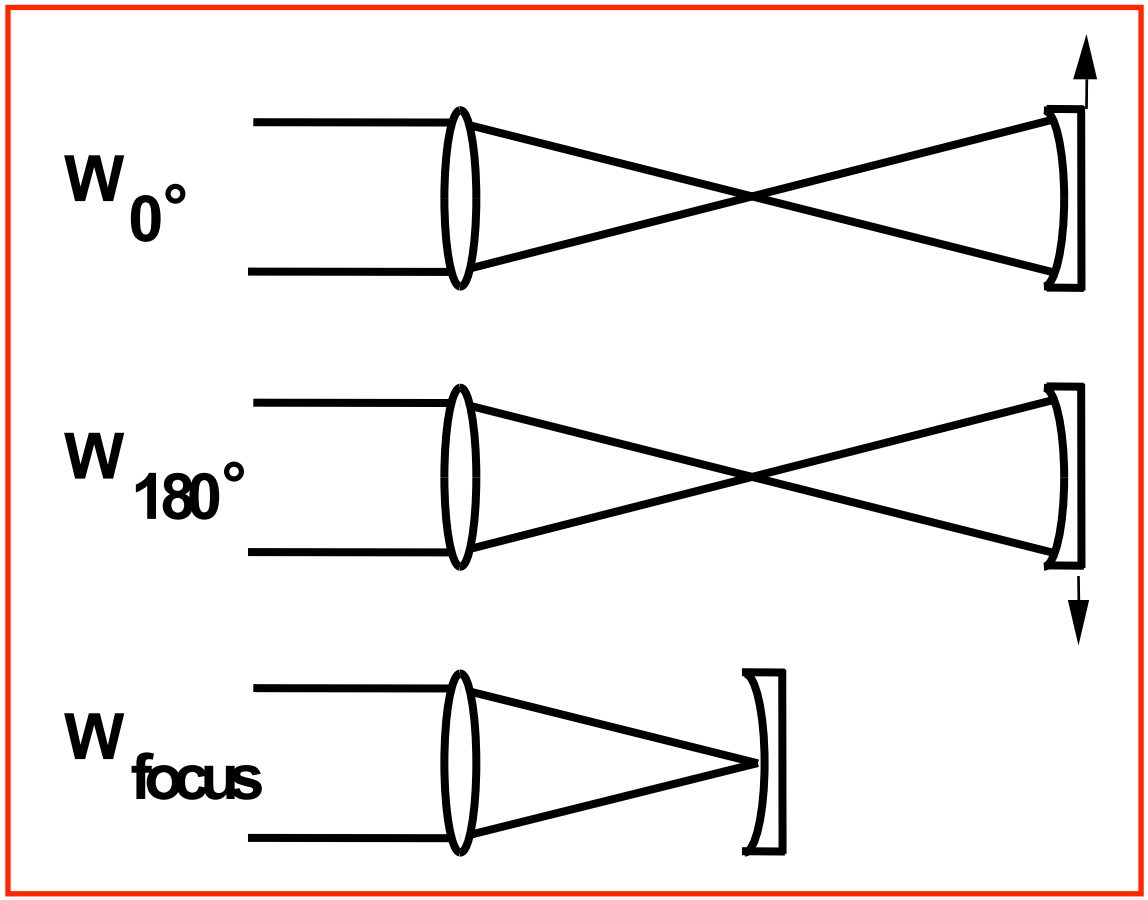
What is wrong with the following approach for performing an absolute measurement of a flat??

1. Measure a flat in a Twyman-Green or laser based Fizeau interferometer.
2. Move the flat a small distance in the horizontal direction and make a second measurement.
3. Subtract these two measurements. All the errors coming from the interferometer for the two measurements are common and subtract out and we are left with the equivalent of a lateral shear interferogram for the flat.
4. This could be repeated to obtain a lateral shear interferogram having orthogonal shear.
5. Analyze the two lateral shear interferograms to determine the errors in the flat.

10.2 Absolute Sphere Testing

- 10.2.1 Three Measurements of Spherical Mirror
- 10.2.2 Ball Averager

10.2.1 Three Measurements of Spherical Mirror



Absolute Sphere Testing (Equations)

$$W_0[x,y] = 2W_{surf}[x,y] + W_{ref}[x,y] + 2W_{div}[x,y]$$
$$W_{180}[x,y] = 2W_{surf}[-x,-y] + W_{ref}[x,y] + 2W_{div}[x,y]$$
$$W_{focus}[x,y] = W_{ref}[x,y] + W_{div}[x,y] + W_{div}[-x,-y]$$

Combining the three measurements yields

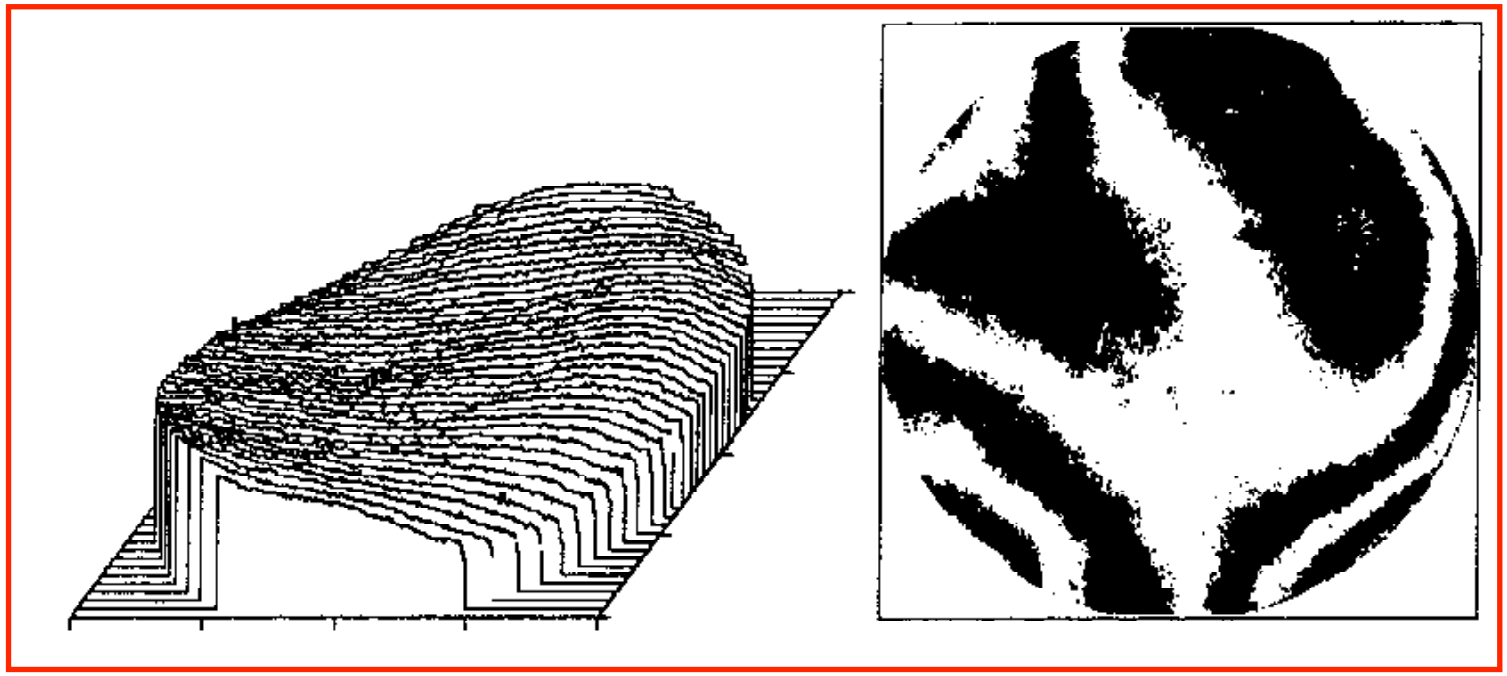
$$W_{surf}[x,y] = \frac{1}{4}\left(W_0[x,y] + W_{180}[-x,-y] - W_{focus}[x,y] - W_{focus}[-x,-y]\right)$$

[-x, -y] in the last equation means we are rotating the data 180° in the computer.

THE UNIVERSITY OF ARIZONA

Single Measurement of Sphere

TILT, POWER REMOVED
INTERVAL = 0.025
RMS = 0.014 WAVES
P-V = 0.121 WAVES

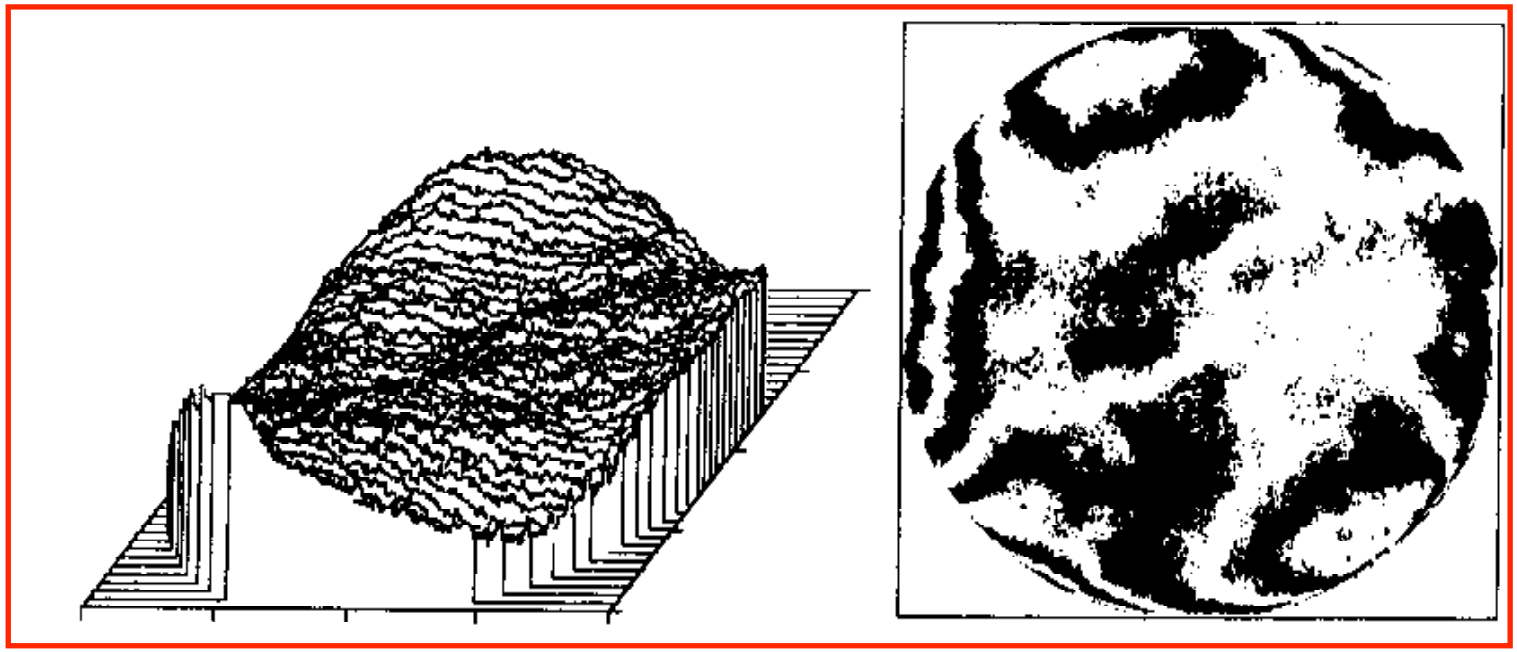


FIZEAU INTERFEROMETER, F/1.1 REF. SPHERE

THE UNIVERSITY OF ARIZONA

Flat at Focus f/1.1 Diverger

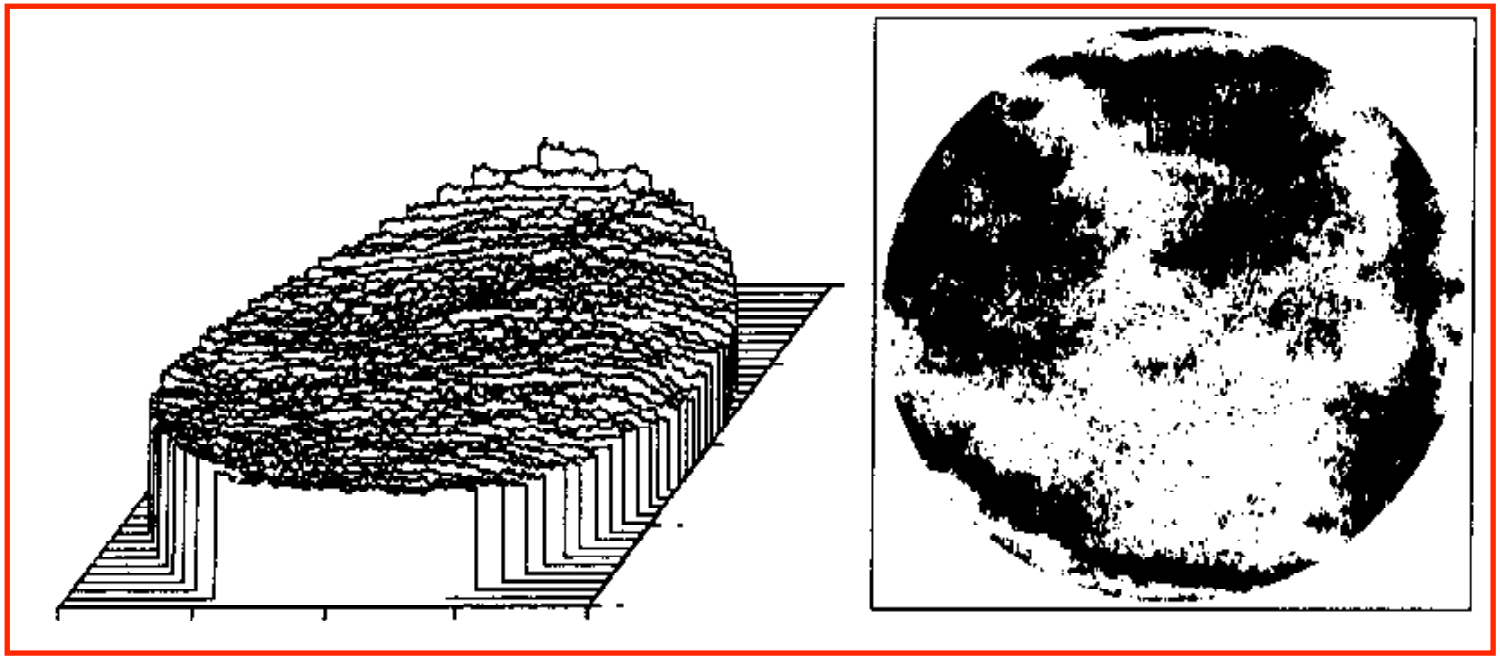
TILT, POWER, COMA REMOVED
INTERVAL = 0.05
RMS = 0.027 WAVES
P-V = 0.243 WAVES



THE UNIVERSITY OF ARIZONA

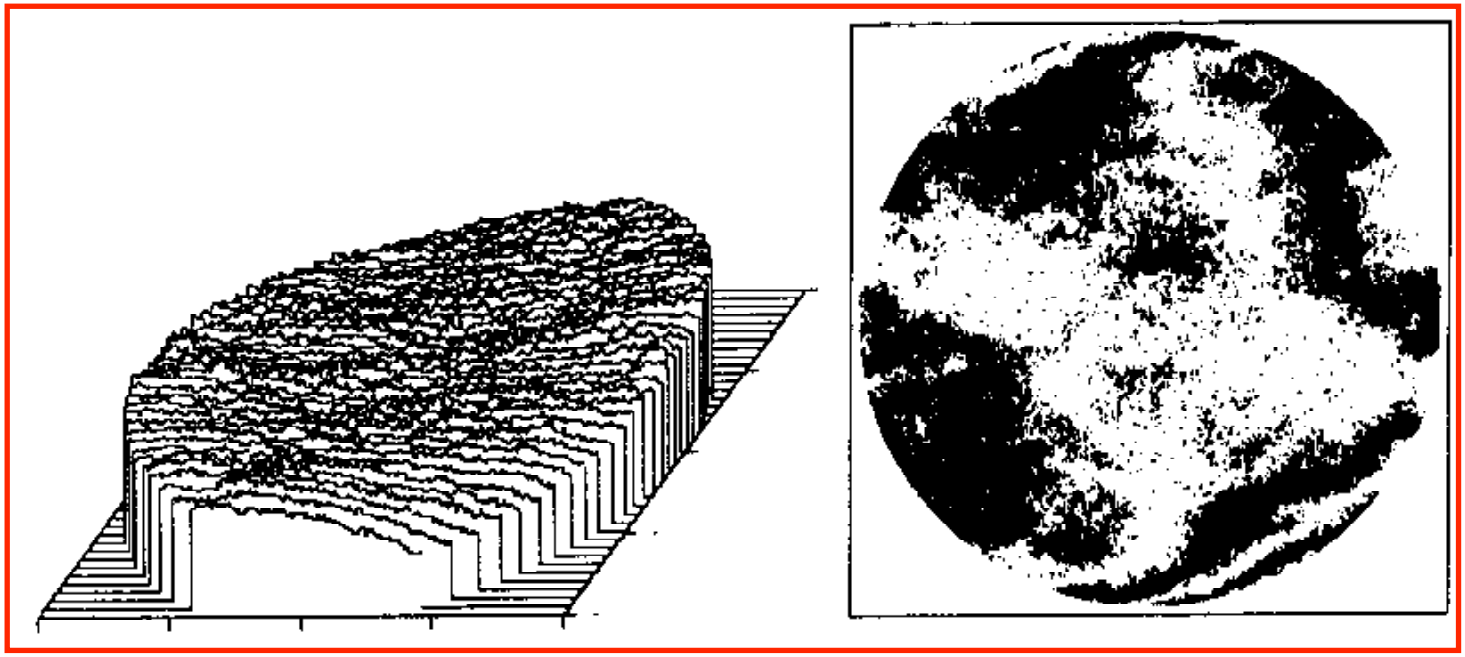
Absolute Reference

TILT, POWER REMOVED
INTERVAL = 0.025
RMS = 0.010 WAVES
P-V = 0.084 WAVES



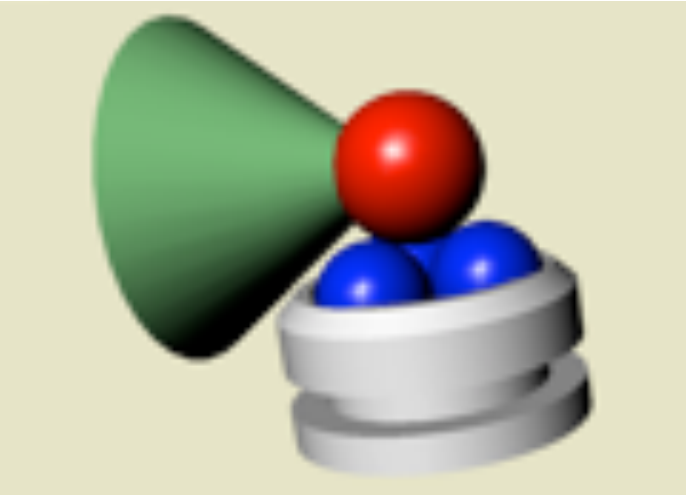
Absolute Measurement of Sphere

TILT, POWER REMOVED
INTERVAL = 0.025
RMS = 0.011 WAVES
P-V = 0.081 WAVES



THE UNIVERSITY OF ARIZONA

10.2.2 Absolute Sphere Testing Using Ball Averager



Calibration ball sitting on a three point kinematic mount with the green cone representing the light from the transmission sphere focused at the center of the ball.

Actual Hardware

Take many measurements for different rotations of ball and average results to average out errors in the ball.

THE UNIVERSITY OF ARIZONA

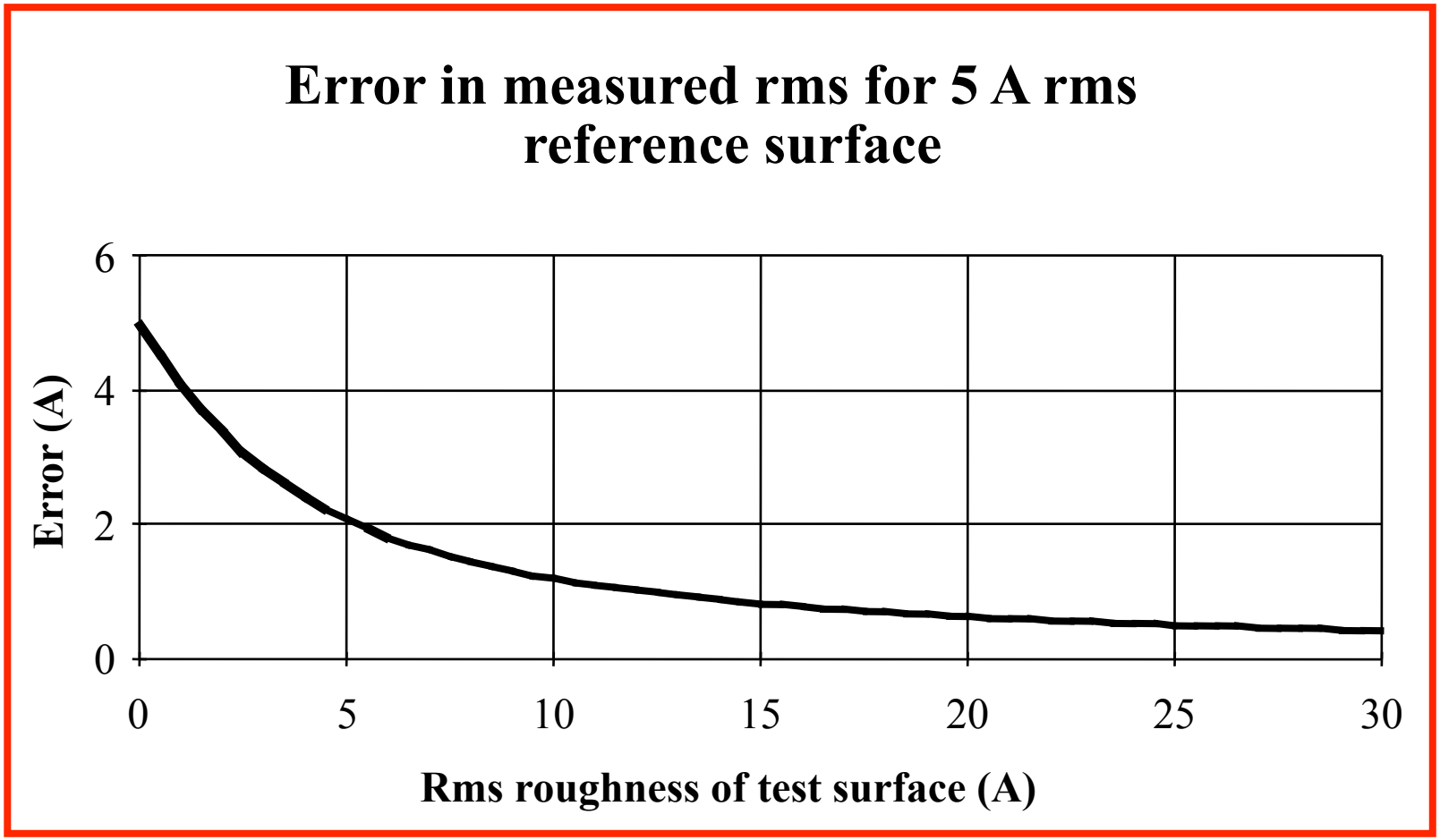
10.3 Absolute Measurement of Surface Roughness

- 10.3.1 Perfect mirror
- 10.3.2 Generate reference
- 10.3.3 Absolute rms measurement

Absolute Surface Roughness Measurement Assumptions

- Surface height is random
- Statistics do not vary over surface
- Each measurement = Test + Reference
- Test and reference uncorrelated

Effect of Reference Surface on Measurement



THE UNIVERSITY OF ARIZONA

10.3.1 Perfect Mirror

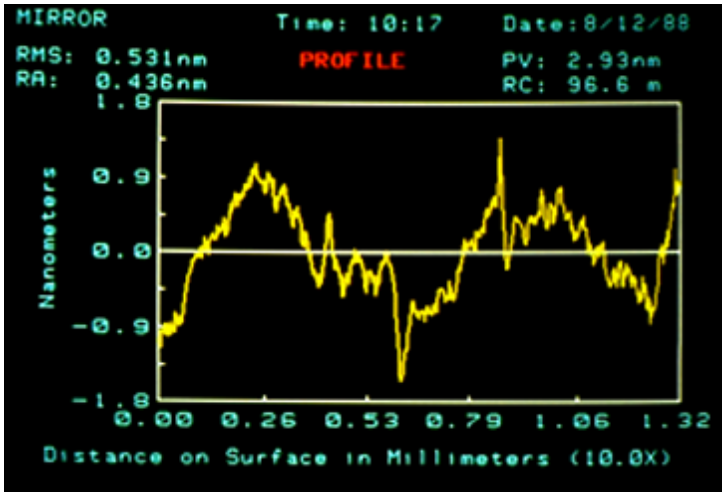
I have never seen a perfect mirror, but if we could get one we could measure it to calibrate the system.

10.3.2 Generate Reference

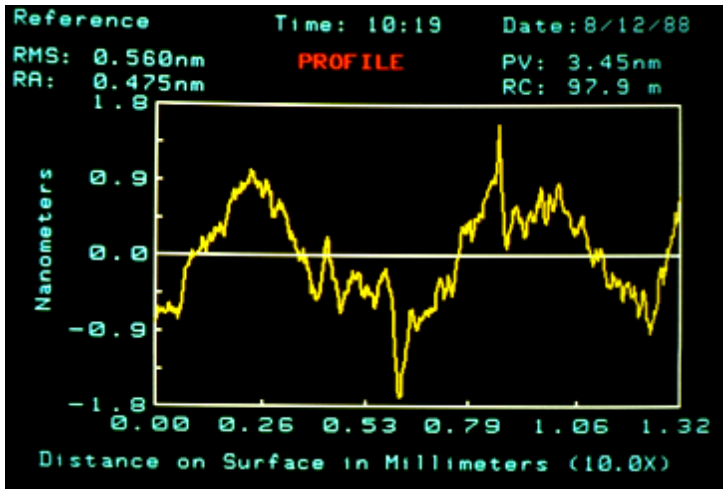
- Average many measurements
- Move random surface > correlation length between measurements
- Effects of random surface reduce as square root of number of measurements

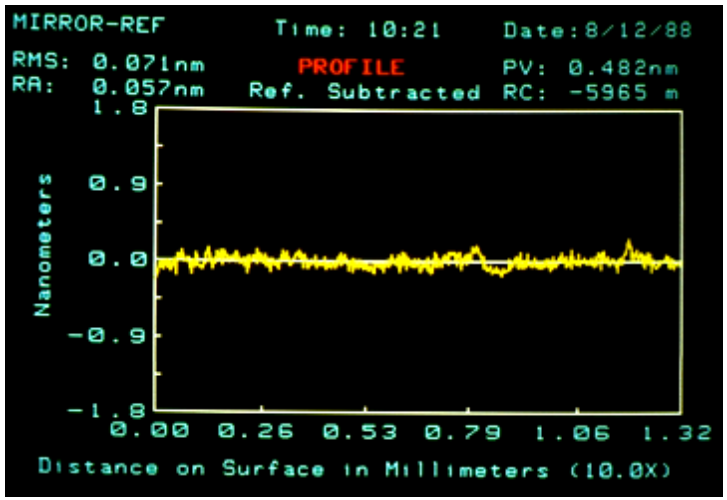
Generate Reference and Subtract

Surface + Reference



Reference





Surface (0.071 nm)

THE UNIVERSITY OF ARIZONA

10.3.3 Absolute RMS Measurement

- Make 2 measurements where surface moved > correlation length between measurements
- Subtract measurements and divide by square root of 2
- Reference cancels and obtain
- RMS of test surface

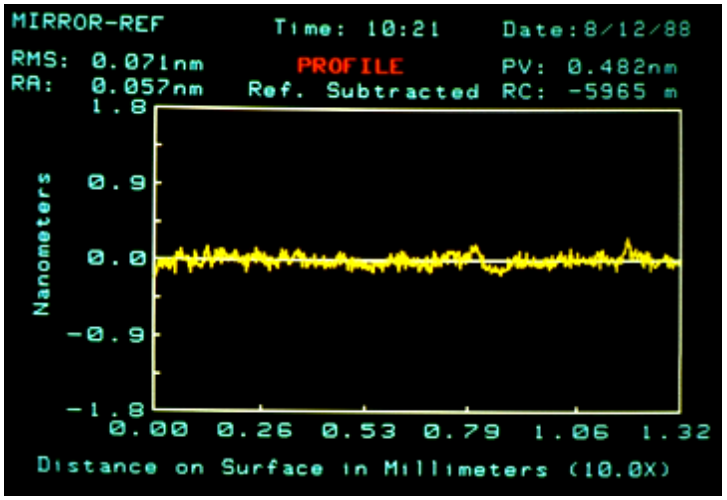
$$Diff = Test_1 + (-Test_2)$$

$$RMS_{Test} = \frac{1}{\sqrt{2}} RMS_{Diff}$$

THE UNIVERSITY OF ARIZONA

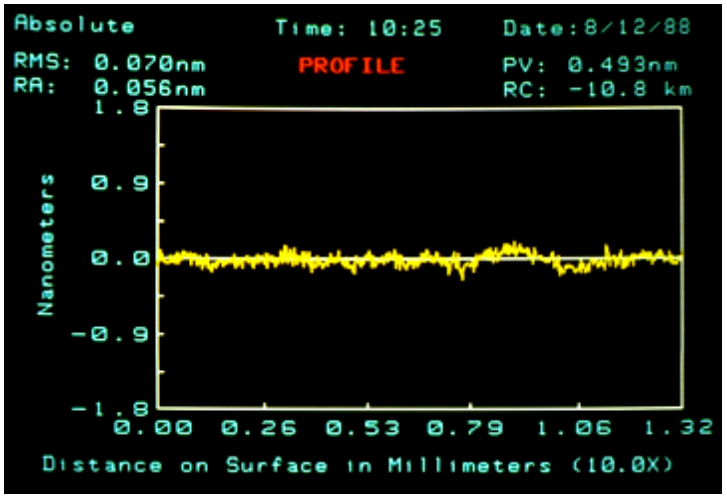
Generate Reference and Absolute RMS Comparison

Generate Reference



RMS = 0.071 nm

Absolute RMS



RMS = 0.070 nm

THE UNIVERSITY OF ARIZONA