

Flat Surface Testing

FS-I

An interferometer is used to perform a single pass test of a surface where the surface is illuminated at an angle α . If S is the average fringe spacing and Δ is a deviation from straightness in the fringes, prove that

$$\text{surfaceHeightError} = \frac{\frac{\lambda}{2} \frac{\Delta}{S}}{\cos[\alpha]}$$

Solution

$$\text{OPD} = 2 (\text{surfaceHeightError}) \cos[\alpha]$$

The OPD will change by 1λ in going from one fringe to the next. Therefore,

$$\text{surfaceHeightError} = \frac{\frac{\lambda}{2} \frac{\Delta}{S}}{\cos[\alpha]}$$

FS-2

Show that the classical equation for the Ritchey Common test given below is correct. Δ_{TS} is the distance between the source positions for which the S fan and the T fan are retroreflected, L is the distance from the flat to the center point between the S and T foci, and θ is the angle the flat is tilted from normal incidence, and r_o is the radius of curvature of the "flat".

$$\Delta_{TS} = - \frac{2 L^2}{r_o} \left(\frac{\sin[\theta]^2}{\cos[\theta]} \right)$$

Solution

Let r_T be the radius of curvature for the tangential fan and r_S be the radius of curvature for the sagittal fan. The sag is given by $\frac{\rho^2}{2r_o}$.

For single pass off the flat the OPD is given by

$$\Delta_T = \frac{\rho^2 \cos[\theta]^2}{r_T} = \frac{\rho^2}{r_o} \cos[\theta]$$

$$\Delta_S = \frac{\rho^2}{r_s} = \frac{\rho^2}{r_o} \cos[\theta]$$

Therefore,

$$\frac{1}{r_T} = \frac{1}{r_o \cos[\theta]} \quad \text{and} \quad \frac{1}{r_s} = \frac{\cos[\theta]}{r_o}$$

If s_1 is the distance from the flat to the center of the spherical mirror used in the test,

$$\frac{1}{L_s} + \frac{1}{s_1} = \frac{2 \cos[\theta]}{r_o} \quad \text{and} \quad \frac{1}{L_T} + \frac{1}{s_1} = \frac{2}{r_o \cos[\theta]};$$

Note that these are the well known Coddington Equations.

$$\frac{1}{L_s} - \frac{1}{L_T} = \frac{2 \cos[\theta]}{r_o} - \frac{2}{r_o \cos[\theta]}$$

$$\frac{L_T - L_s}{L_s L_T} = \frac{2}{r_o} \frac{(\cos[\theta]^2 - 1)}{\cos[\theta]}$$

$$\Delta_{TS} = - \frac{2 L^2}{r_o} \frac{\sin[\theta]^2}{\cos[\theta]}$$

FS-3

A 1 meter diameter flat is being tested using a Ritchey Common test at an angle of incidence of 45° . A Frankenian widget is being used to measure the distance between the S and T foci and hence determine the radius of curvature of the so called flat. While we do not study Frankenian widgets in this class, give an estimate as to the maximum radius of curvature that can be measured. Be sure to justify your answer. (I am looking for fundamental limitations in measurement of radius of curvature which are more or less independent of whatever a Frankenian widget is.)

Solution

We need to consider the depth of focus which goes as $\pm 2 \lambda (f\#)^2$.

The distance between the S and T foci goes as $\frac{2 L^2}{r} \frac{\sin[\theta]^2}{\cos[\theta]}$. L is the distance from the surface being measured to the image, r is the radius of curvature, and θ is the tilt angle. Thus, the $f\#$ we are doing the measurement at is $\frac{L}{d \cos[\theta]}$, where d is the diameter. Thus, we want

$$4 \lambda \left(\frac{L}{d \cos[\theta]} \right)^2 < \frac{2 L^2}{r} \frac{\sin[\theta]^2}{\cos[\theta]}$$

$$r < \frac{d^2 \cos[\theta] \sin[\theta]^2}{2 \lambda} / . \{d \rightarrow 1 \text{ m}, \theta \rightarrow 45^\circ, \lambda \rightarrow 0.5 \times 10^{-6} \text{ m}\}$$

$$r < 353553. \text{ m}$$

FS-4

I am testing a nearly parallel plate in a Twyman-Green interferometer to determine the wedge angle.

- Derive the relationship between wedge angle and fringe spacing. Be sure to indicate any assumptions you are making.
- If the plate has a thickness variation, how would you determine magnitude and sign?
- For straight equi-spaced fringes, how can you determine the thin portion of the glass wedge?

Solution

a)

OPD introduced by plate = $2(n-1) \alpha x$, where α is the wedge and x is a linear distance on the plate. We will assume that if the plate is not present a single fringe is present. If S is the fringe spacing, then

$$2 (n - 1) \alpha S = \lambda$$

$$S = \frac{\lambda}{2 (n - 1) \alpha}$$

b)

Each fringe error corresponds to a thickness variation of

$$\delta t = \frac{\lambda}{2 (n - 1)} \left(\frac{\Delta}{S} \right), \text{ where } \left(\frac{\Delta}{S} \right) \text{ is the fractional fringe error.}$$

Sign determined by pushing in on reference mirror to shorten the reference arm of the interferometer and watching the fringe motion. For open fringes, the fringes will move in the same direction that fringes from thicker regions of the plate are displaced.

c)

First assume that a single fringe is present when the plate is removed. For straight equi-spaced fringes, the fringes move toward the thin portion of the wedge when the reference mirror is pushed in to shorten the reference path.

FS-5

I am using an autocollimator to measure the parallelism of some window glass. For some reason the test is not working. I have tipped and tilted the plate properly to reflect the light back into the autocollimator, however I am unable to find an image of the reticle in the returned beam. Explain.

Solution

If the window surfaces are not flat the image of the reticle may be blurred too much to see.

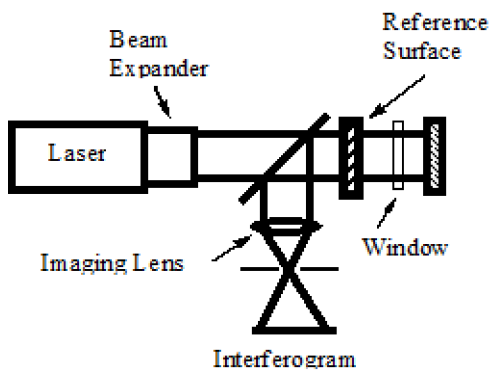
FS-6

A Fizeau interferometer having a HeNe laser as the light source is used to perform a transmission test of windows. Let the reference surface and return flat in the Fizeau be perfect, but the 60 cm diameter collimator lens used in the interferometer has 2 waves of third-order spherical aberration.

- Sketch the setup.
- How would you adjust the collimation of the beam in the interferometer cavity to minimize the OPD error resulting from the spherical aberration?
- Using the collimation given in part (b), what is the approximate maximum OPD error in the test results if the separation between the reference surface and the return flat is 2 meters?

Solution

a)



b)

Defocus should be introduced to minimize the maximum slope. Since 2 waves of third order spherical are present, -3 waves of defocus should be introduced.

c)

$$\Delta w = (2 \rho^4 - 3 \rho^2) \lambda; \text{ slope} = \theta = \frac{(8 \rho^3 - 6 \rho) \lambda}{r_{\max}};$$

$$\theta_{\max} = \frac{2 \lambda}{30 \text{ cm}} \frac{0.633 \times 10^{-4} \text{ cm}}{\lambda}$$

$$4.22 \times 10^{-6}$$

Let d equal cavity length

$$\text{error} = 2 d (1 - \cos[\theta_{\max}]) / d \rightarrow 2 m \frac{\lambda}{0.633 \times 10^{-6} \text{ m}}$$

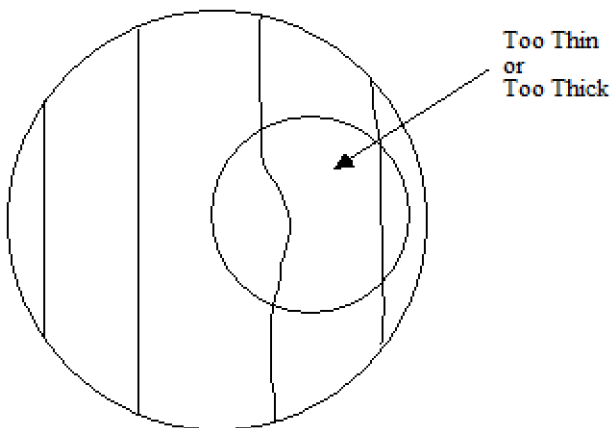
$$0.0000562667 \lambda$$

$$\text{error} = 5.7 \times 10^{-5} \lambda$$

FS-7)

A Twyman-Green interferometer is used with a HeNe laser to evaluate a 5 cm diameter glass window of refractive index 1.5 in double-pass transmission. The interferogram shown below is obtained. Before the window glass was put into the interferometer, the interferometer was adjusted to give a single interference fringe.

- In units of micro-radians, approximately how much wedge is in the glass?
- Pushing on the reference mirror in the interferometer so as to shorten the reference arm of the interferometer caused the fringes to move to the left. Does the region indicated in the photo correspond to a too thin or too thick portion of the glass?
- If before the glass is placed in the interferometer, the interferometer is adjusted to give approximately 5 straight equi-spaced horizontal fringes across the interferogram, approximately what would the interferogram look like after the glass is placed in the interferometer? (State any assumptions you make.)



Solution

a)

Let α be the wedge angle, then

$$\text{OPD} = 4 \lambda = 2 (n - 1) \alpha (5 \text{ cm})$$

$$\alpha = \frac{4 (0.633 \mu\text{m})}{5 \times 10^4 \mu\text{m}} = 5 \times 10^{-5} \text{ rad} = 50 \mu\text{radians}$$

b)

Making the reference arm shorter is equivalent to making the test arm longer. Therefore, making the test arm longer causes the fringes to move to the left. Thus, a fringe deviation to the left would correspond to the glass being too thick. Therefore, for the region shown, the glass must be too thin.

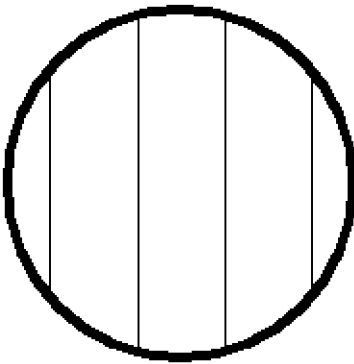
c)

There will be 4 waves of tilt in the x direction and 4 waves of tilt in the y direction (if we assume there are fringes at the top and the bottom of the aperture). Therefore, we will have $4\sqrt{2}$ fringes at ± 45 degrees relative to the x-axis. The thickness variations in the glass will still cause about a quarter fringe deviation from straightness.

FS-8

The interferogram shown below was obtained using a HeNe laser operating at a wavelength of 633 nm and a Twyman-Green interferometer to test a 4 inch diameter piece of window glass of refractive index 1.5. Before the window glass was put into the interferometer, the interferometer was adjusted to give a single interference fringe.

- Approximately how much wedge is in the glass?
- Before the glass is placed in the interferometer, the interferometer is adjusted to give 11 straight equi-spaced horizontal fringes across the interferogram. One of the 11 fringes is at the top edge of the interferogram and another of the 11 fringes is at the bottom edge of the interferogram. What would the interferogram look like after the glass is placed in the interferometer? (State any assumptions you make.)



Solution

a)

Let α be the wedge angle, then

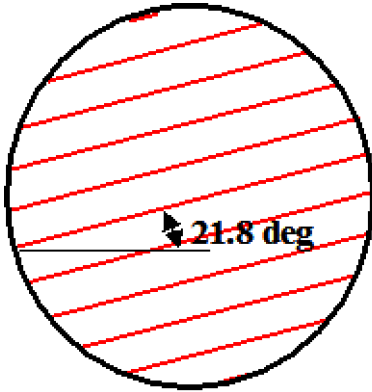
$$\text{OPD} = 4 \lambda = 2 (n - 1) \alpha (10 \text{ cm})$$

$$\alpha = \frac{4 (0.633 \mu\text{m})}{10^5 \mu\text{m}} = 2.5 \times 10^{-5} \text{ rad} = 5 \text{ arcsecond}$$

b)

11 fringes in the vertical direction and 4 fringes in the horizontal direction. There are 10λ of OPD between the 11 fringes. Thus the fringes make an angle, θ , from the horizontal where

$$\tan[\theta] = \frac{4}{10}; \theta = \text{ArcTan}\left[\frac{4}{10}\right] = 21.8^\circ$$



FS-9

A 90 degree prism made out of glass having a refractive index of 1.5 is tested in retro-reflection using a Twyman-Green interferometer. The wavelength is 633 nm. With unit magnification between the prism and the interferogram, the straight parallel fringes in the interferogram have a spacing of 1 mm and 3 mm.

- What is the error in the 90-degree prism angle? State any assumptions you make.
- How could you determine whether the 90-degree angle is too large or too small?

Solution

a)

$4n\epsilon$ = angle between two beams leaving prism.

Let d_1 and d_2 be the fringe spacing for the two parts of the interferogram.

$$d_1 \theta_1 = \lambda \quad \text{and} \quad d_2 \theta_2 = \lambda$$

$$\theta_1 + \theta_2 = 4 n \epsilon = \lambda \left(\frac{1}{d_1} + \frac{1}{d_2} \right)$$

I am assuming the reference beam is between the two beams leaving the prism. If this is not true then $4 n \epsilon = \theta_1 - \theta_2$.

$$\epsilon = \frac{\lambda}{4 n} \left(\frac{1}{d_1} + \frac{1}{d_2} \right) \quad / . \{ \lambda \rightarrow 0.633 \mu\text{m}, d_1 \rightarrow 1000 \mu\text{m}, d_2 \rightarrow 3000 \mu\text{m}, n \rightarrow 1.5 \}$$

$$0.000140667$$

b)

Several possible answers.

If angle is too small beams are going toward each other. If angle is too large beams are diverging from each other. Fluff out fringes on one side to see if beams are going toward or away from each other.

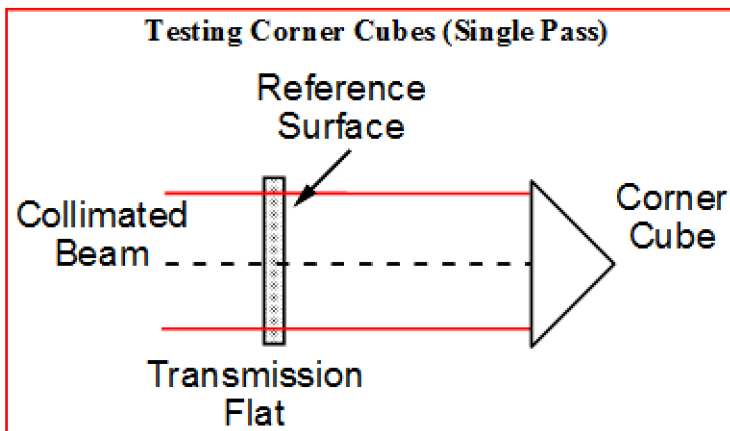
FS-10

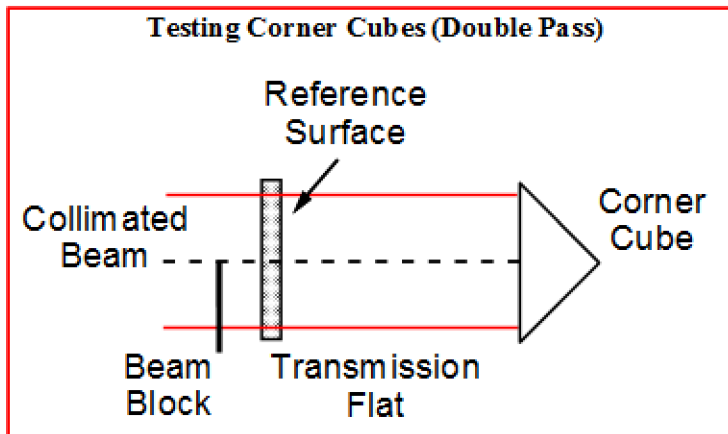
You are given the job of measuring a corner cube.

- a) Sketch both the single pass and double pass interferometric setups.
- b) What is generally more accurate, single pass or double pass? Why?
- c) A perfect corner cube is being measured. Sketch the resulting fringes for both single pass and double pass interferometric test.
- d) If an autocollimator is used to test a corner cube, how many images of the reticle would be observed? What is the major problem you might experience using an autocollimator to test the corner cube?

Solution

a)

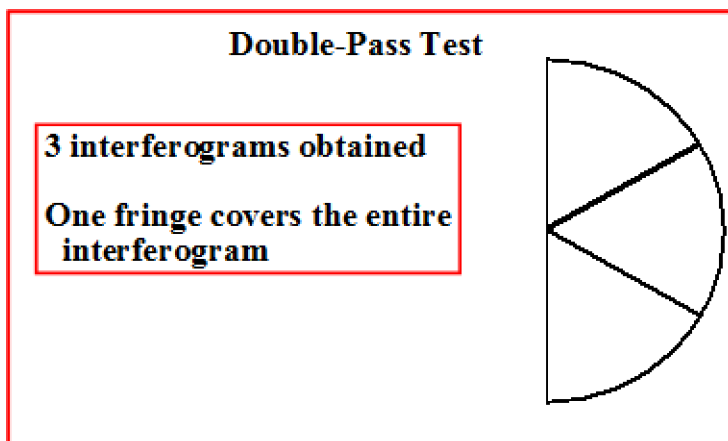
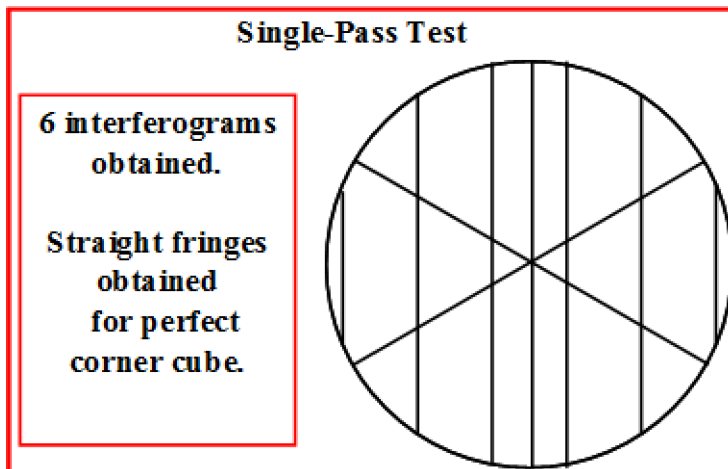




b)

The double-pass setup is more accurate because the collimated beam is not flipped over and errors in this beam cancel, at least to first order.

c)



d)

Six images of the reticles are obtained and their contrast is low.

FS-I I

A laser based Fizeau interferometer is used to test a corner cube.

a) Give two possible advantages of the double pass test compared to the single pass test

b) If the double pass test is used and the corner cube has a diameter of 5 cm, how many tilt fringes will be introduced into the interferogram if the reference flat is tilted 4.5 arc-seconds. The wavelength is 633 nm.

Solution

a)

Errors in the collimator tend to cancel out and the two interfering beams have nearly the same intensity without the introduction of an attenuator.

b)

None.

FS-I2

I am considering making a wire grating for picking off a small portion of a high power CO₂ laser beam. The grating will be used with collimated 10.6 micron "light" and will produce a first-order diffraction angle of 1°. The grating must introduce a peak wavefront error of no more than $\lambda/10$ (at 10.6 μm) into the first diffraction order. To meet this requirement, the grating wires must be nearly straight and nearly equi-spaced.

a) What is the maximum allowable departure that any given wire can be from this straight, equi-spaced condition if we are to satisfy the $\lambda/10$ peak wavefront error specification (at 10.6 μm)?

b) If the grating just satisfies the $\lambda/10$ peak wavefront error specification at 10.6 μm , how much peak error will the same grating introduce into the first diffracted order when the wavelength of the incident radiation is 9.6 μm .

Solution

a)

Maximum allowable departure is 1/10 of the grating line spacing.

$$d = \frac{\lambda}{\sin[\theta]} \quad / . \{ \lambda \rightarrow 10.6 \mu\text{m}, \theta \rightarrow 1^\circ \}$$

$$607.366 \mu\text{m}$$

Maximum allowable departure = 60.7 μm .

b)

Still $\lambda/10$.

FS-I3

I am using a Twyman-Green interferometer to test a 200-line/mm diffraction grating. If the +1 diffraction order is interfered with the reference beam the interferogram shows a peak to valley error of 1/4 fringe at a wavelength of 633 nm.

- How large is the peak to valley error in the position of the grating lines?
- What is the peak to valley error in the interferogram if the light source has a wavelength of 488 nm?
- What will be the peak to valley error in the interferogram if the +2 diffraction order is interfered with the reference beam and the wavelength is 633 nm?

Solution

a)

The grating spacing is 5 μm .

$$\text{Error} = \frac{1}{4} (5 \mu\text{m}) = 1.25 \mu\text{m}$$

b)

$\frac{1}{4}$ fringe. The error does not depend upon λ .

c)

The error will be twice as much, or $\frac{1}{2}$ fringe.