Diffraction Effects In Interferometry

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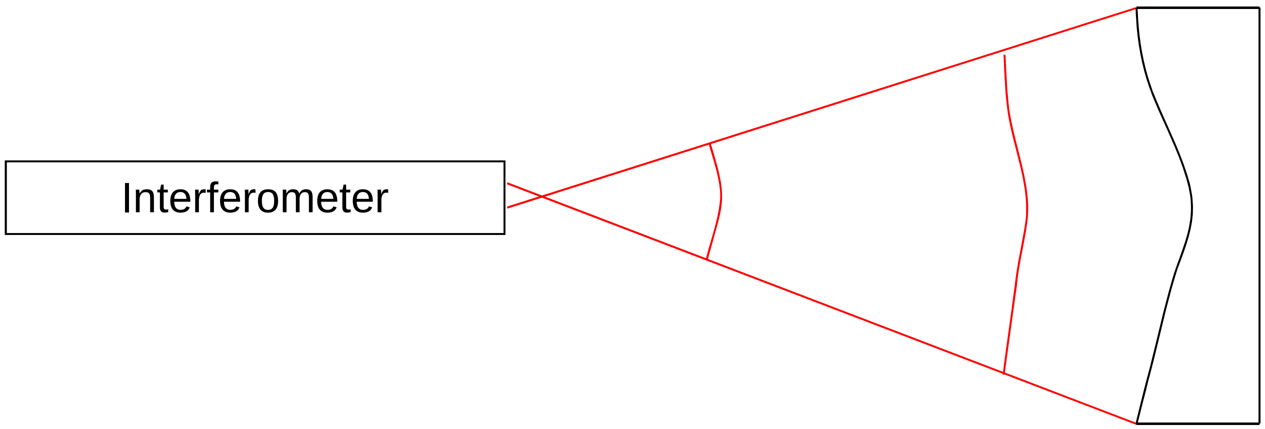
Introduction

- Random errors
- Geometric errors
  - Retrace error
  - Imaging distortion
- Errors due to diffraction effects
  - Phase smoothing
  - Edge diffraction

Errors due to diffraction

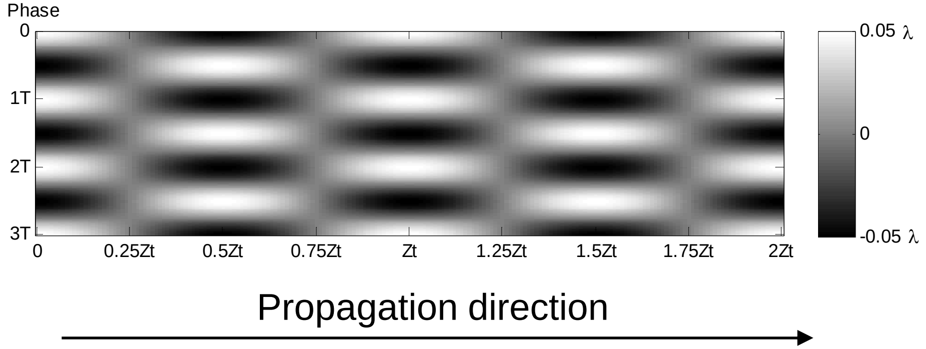
- Wavefront aberrations change as they propagate
- To correctly measure the test surface, the interferometer has to focus on the test surface

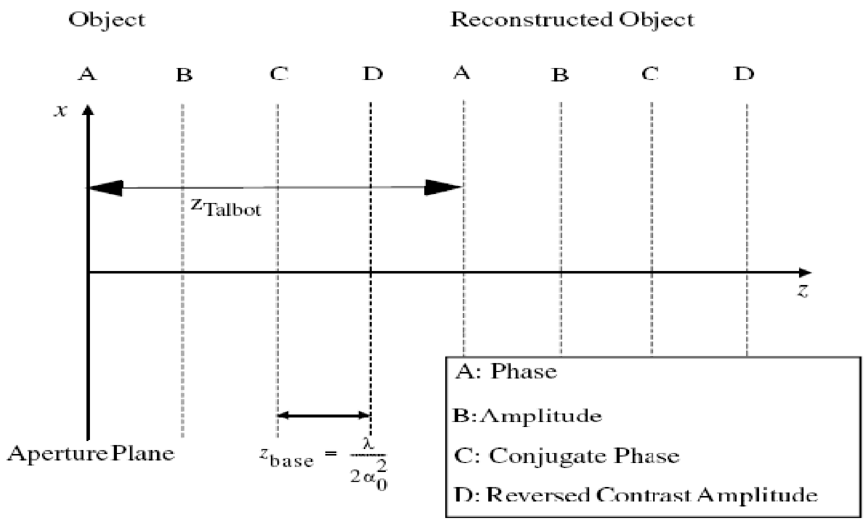


The plane in focus

Use Talbot imaging to study diffraction effect

a sinusoidal phase pattern propagates in a collimated space





Talbot distance: $z_T = \frac{2p^2}{\lambda}$

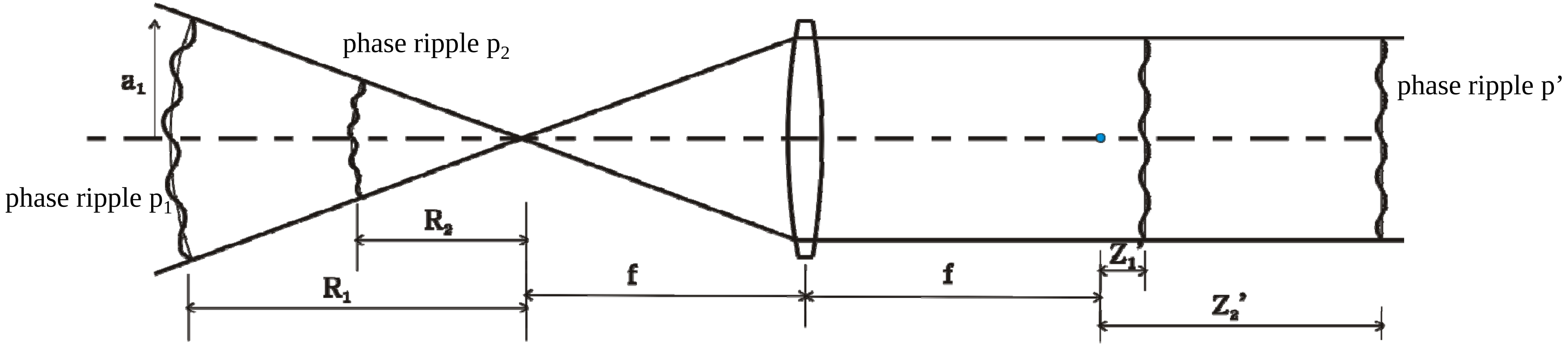
$$W' = W\cos\left(2\pi\frac{z_0}{z_T}\right) = W\cos\left(\frac{\pi\lambda z_0}{p^2}\right)$$

$$TF = \frac{W'}{W} = \cos\left(\frac{\pi\lambda z_0}{p^2}\right)$$

For a converging/diverging wavefront, we can convert it to equivalent propagation in collimated space.

• P. Zhou and J. H. Burge, "Analysis of wavefront propagation using the Talbot effect," submitted to Applied Optics

Phase smoothing in a converging/diverging beam



$$W' = W \cdot \cos\left(\frac{\pi\lambda \cdot \Delta Z'}{p'^2}\right) = W \cdot \cos\left(\frac{\pi\lambda R_1 \cdot (R_1 - R_2)}{R_2 \cdot p_1^2}\right)$$

Effective propagation distance: $L_e = \frac{R_1(R_1 - R_2)}{R_2}$

Normalized frequency: $f_{\text{normalized}} = \frac{2a_1}{p_1}$

Wavefront after propagation: $W' = W \cos\left(\frac{\pi\lambda L_e f_{\text{normalized}}^2}{4a_1^2}\right)$

Fresnel number: $N_f = \frac{a_1^2}{\lambda L_e}$

$$TF = \cos\left(\frac{\pi f_{\text{normalized}}^2}{4N_f}\right)$$

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Diffraction effects in the test wavefront

- Errors in the test wavefront are caused by null optics (if they exist) and the test surface.
- A simple case is to consider only errors in the test surface.
- Interferometer focuses onto the test surface to avoid the diffraction effects.
- If the test surface is not properly imaged on the detector,
  - Phase ripple on the test surface will not be correctly measured.
  - Cause diffraction "ripples" around the edge – edge diffraction.

• P. Zhou, J. H. Burge and C. Zhao, "Imaging issues for interferometric measurement of aspheric surfaces using CGH null corrector," SPIE annual meeting, 2010, August

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Diffraction effects in the reference wavefront

- Errors in the reference wavefront are caused by imperfections from reference surface.
- The reference wavefront suffers from diffraction effects if the reference surface is not in focus.
- Errors from the reference wavefront, including diffraction effects, can be calibrated with an absolute test.
- This requires that the interferometer zoom or imaging lens are not changed between the surface measurement and the absolute test.

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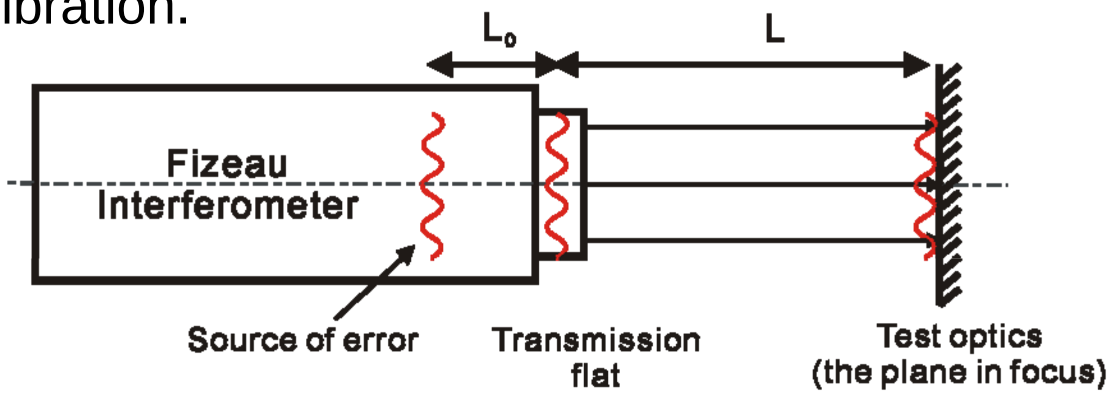
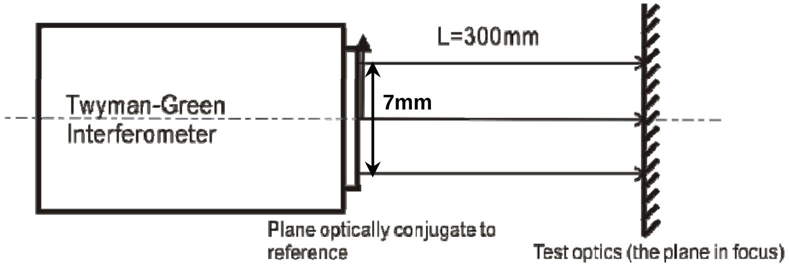
Diffraction effects in the common wavefront

- The common wavefront refers to the wavefront from the illumination optics in an interferometer.
- The common wavefront propagates different distances in the test and reference arms, causing diffraction errors due to different propagation distance.
- Diffraction errors from the common wavefront can be calibrated only if the test surface has the same radius of curvature as the optics used in calibration.



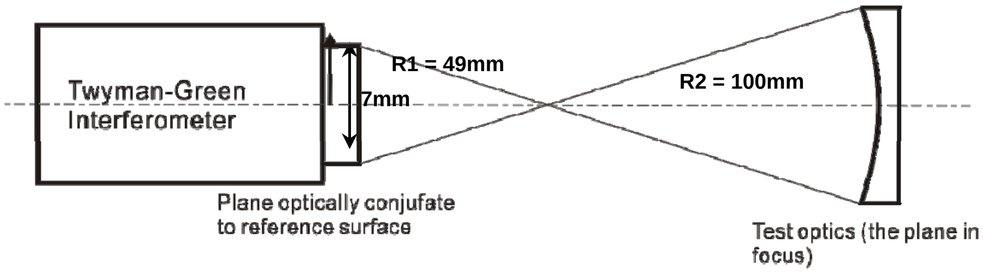
Example – smoothing effect for the reference wavefront

- Test a flat



$$N_f = \frac{a^2}{\lambda L} = \frac{(7/2)^2}{0.633 \cdot 10^{-3} \cdot 300} = 64.5$$

- Test a sphere

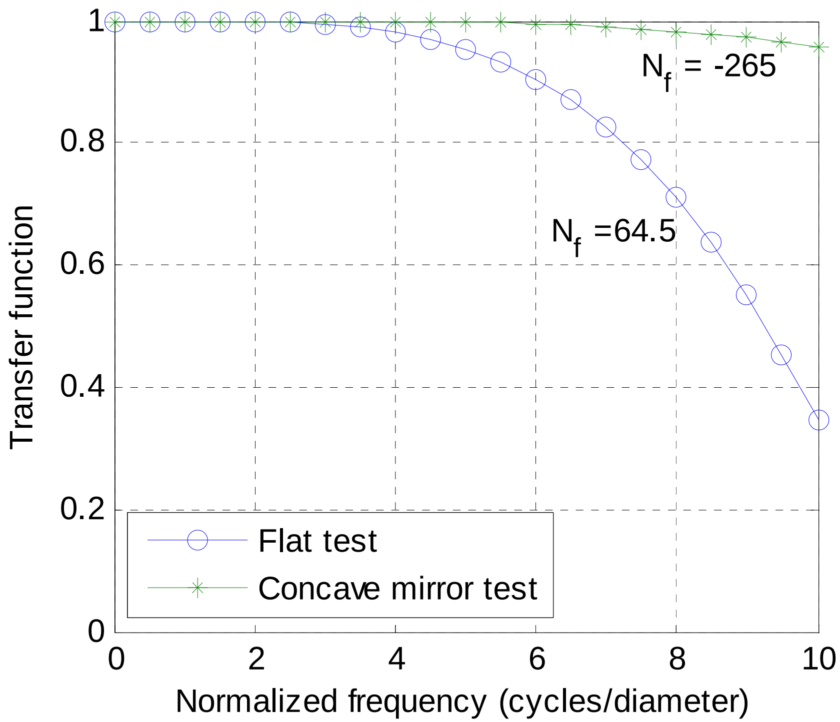


$$L_e = \frac{R_1(R_1 - R_2)}{R_2} = \frac{49 \cdot (49 + 100)}{-100} = -73\text{mm}$$

$$N_f = \frac{a^2}{\lambda L_e} = \frac{-3.5^2}{0.633 \cdot 10^{-3} \cdot 73} = -265$$

$$TF = \cos\left(\frac{\pi f_{normalized}^2}{4N_f} \right)$$

Transfer function for the reference wavefront



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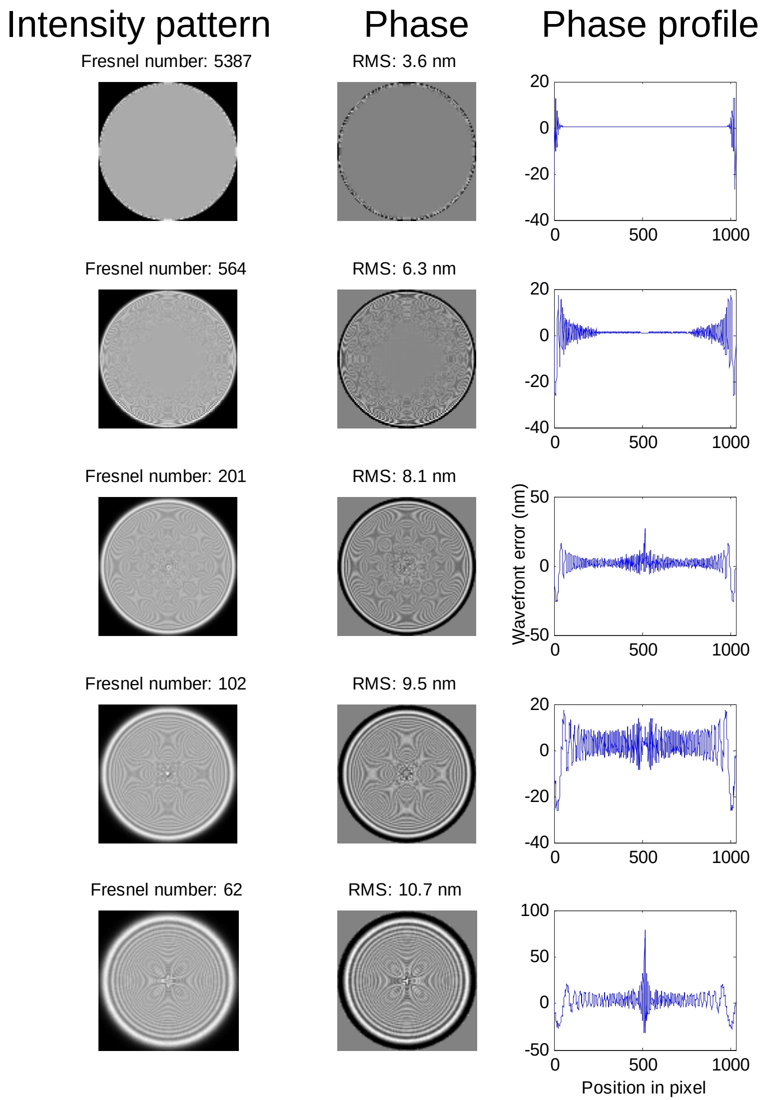
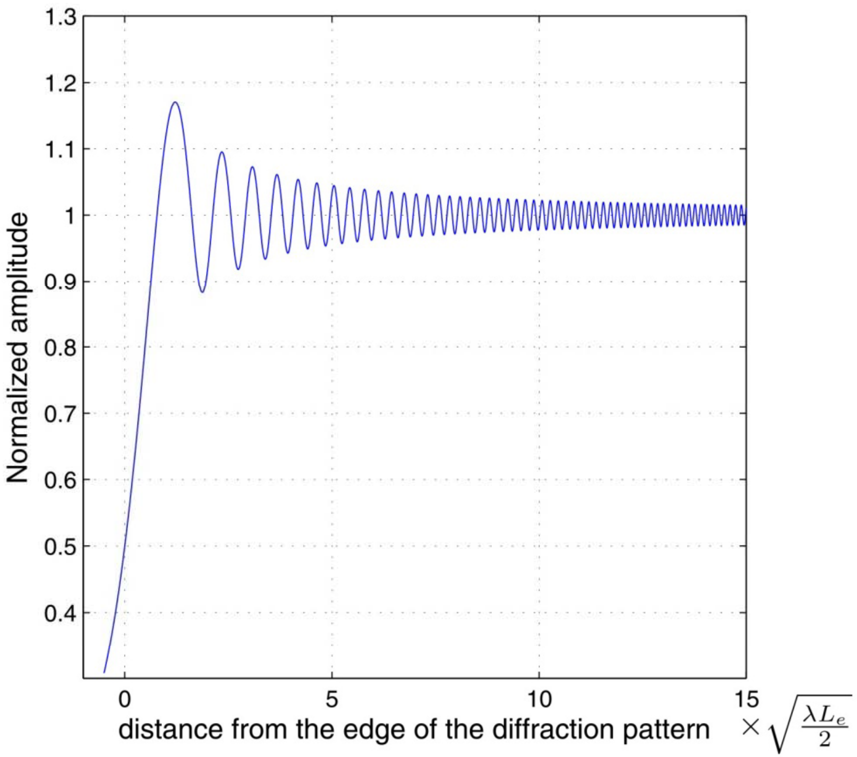
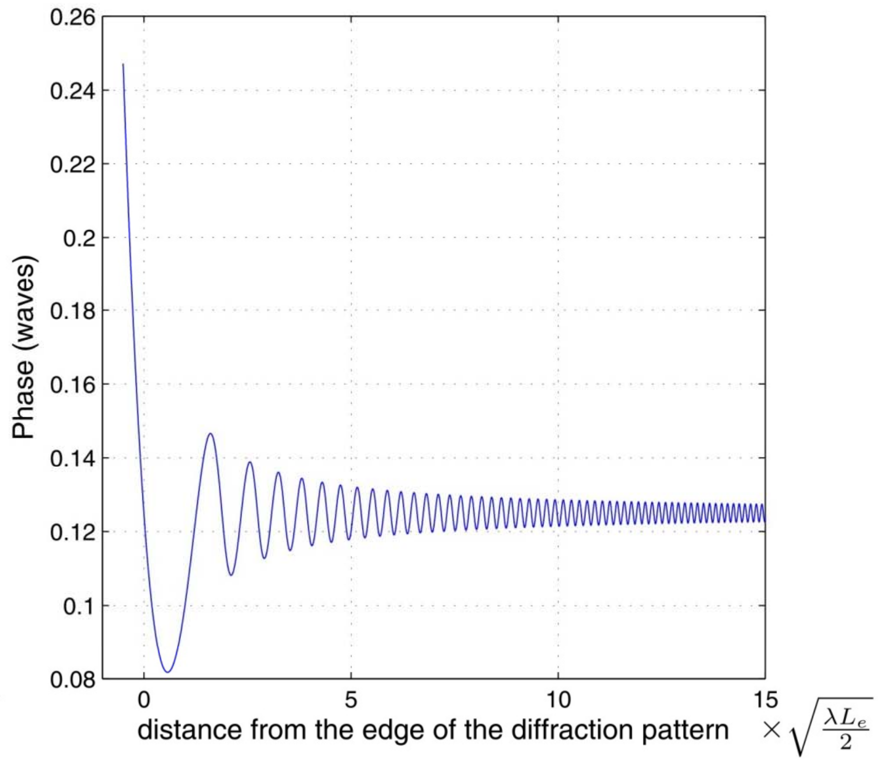
Edge diffraction



Edge diffraction- continued





Conclusion

- Interferometric measurements suffer from errors due to diffraction.
- Diffraction effect causes phase smoothing for middle/high spatial frequency errors. The smoothing effect can be evaluated using the Talbot effect.
- Diffraction effect causes edge diffraction when the aperture stop is not in focus. The edge diffraction can be evaluated using the Fresnel knife-edge diffraction.
- Effective propagation distance can be used to evaluate the phase smoothing and edge diffraction when the wavefront is not collimated.