

Sensitivity Analysis of a Cylindrical Interferometer

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I. Introduction

A grazing incidence cylindrical interferometer for the measurement of cylindrical parts has been designed and manufactured by the Tropel Corporation.^{1,2,3} During the measurement, the instrument interferometrically maps a cylindrical artifact onto a fringe annulus. Since the axial length of the cylinder is compressed into a smaller radial image distance, this leads to the question of what is the axial spatial frequency sensitivity of the instrument. To test the interferometer for axial instrument transfer function⁴, cylindrical artifacts having azimuthally symmetric surface errors with a sinusoidal dependence on axial position were diamond-turned. The parts were measured with an upgraded Mahr MFU-7 and an early version of the Tropel CM25 cylindrical interferometer. Because of the lower resolution optical transfer function of this version of the instrument, it was a good platform to study instrument response. The measured waveform amplitudes from the interferometer were compared in frequency space to measurements from the mechanical roundness instrument.

II. Measurement Artifacts and Analysis

Three nominally 30-mm long brass parts were diamond turned using a Precitech Nanoform 350 diamond turning machine. Each artifact had a 1.0 μm amplitude sinusoid turned along the part axis with a corresponding 15.0, 6.0 and 3.75 mm axial wavelength. An upgraded Mahr MFU-7 at the UNC Charlotte metrology lab measured straightness of each part. Twelve straightness measurements 30 degrees azimuthally apart were taken along a 20 mm axial trace starting 5 mm from the bottom of each artifact. Each trace consisted of 2000 data points and was taken with a 3 mm stylus tip and a stylus force of 3 grams. For each straightness trace, a Fourier transform of a centered measurement window equal in length to an integer multiple of waves was calculated. For each part, the results of the Fourier transform were averaged and the magnitudes of the spatial frequencies from 1 to 10 oscillations per window were calculated. The average of the twelve straightness traces along with the magnitude of the amplitude of each spatial frequency term is shown in Figures 1, 2 and 3. The dominant sinusoid amplitude of the 15 mm wavelength part was 0.87 μm ; for the 6 mm wavelength part, the dominant sinusoid amplitude was 0.99 μm ; and for the 3.75 mm wavelength part, the dominant sinusoid amplitude was 0.96 μm . Based on a statistical evaluation of 12 data sets, the standard uncertainty of the dominant spatial frequency amplitude was 40 nm for the 15 mm wavelength part, 5 nm for the 6 mm wavelength part., and 15 nm for the 3.75 mm wavelength part. For the 15 mm wavelength part, the window length was equal to one period. This may have increased the magnitude of taper removal aliasing errors that contributed to a larger uncertainty. For the other parts the window was equal to three and four oscillations respectively and aliasing errors relating to taper removal would be reduced.

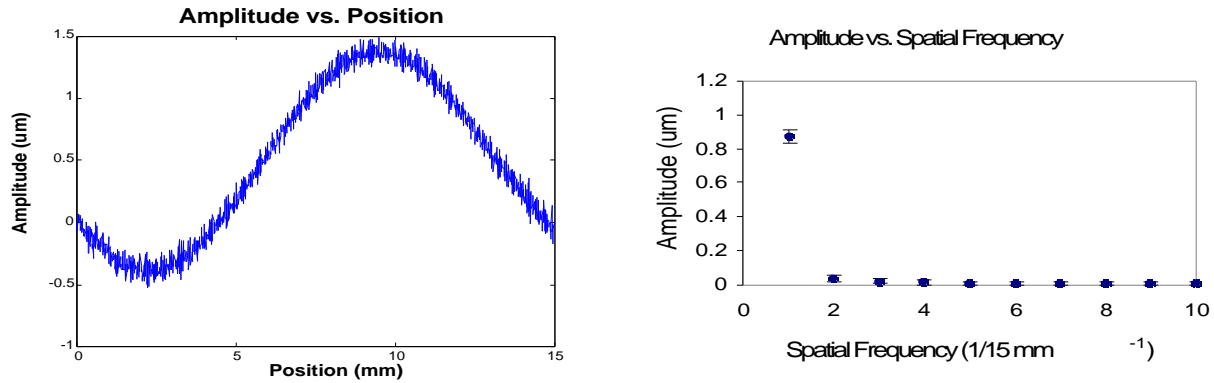


Figure 1: Average of 12 straightness traces of 15 mm window with taper removed taken by a Mahr MFU-7 for nominal 15 mm axial wavelength, 1.0 μm amplitude artifact. Also, amplitude of each spatial frequency shown.

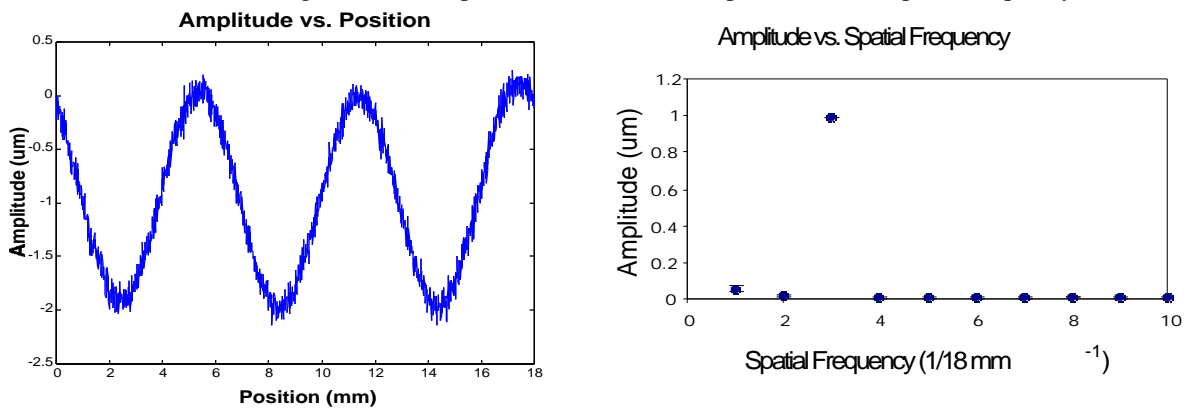


Figure 2: Average of 12 straightness traces of 18 mm window with taper removed taken by a Mahr MFU-7 for nominal 6 mm axial wavelength, 1 μm amplitude artifact. Also, amplitude of each spatial frequency shown.

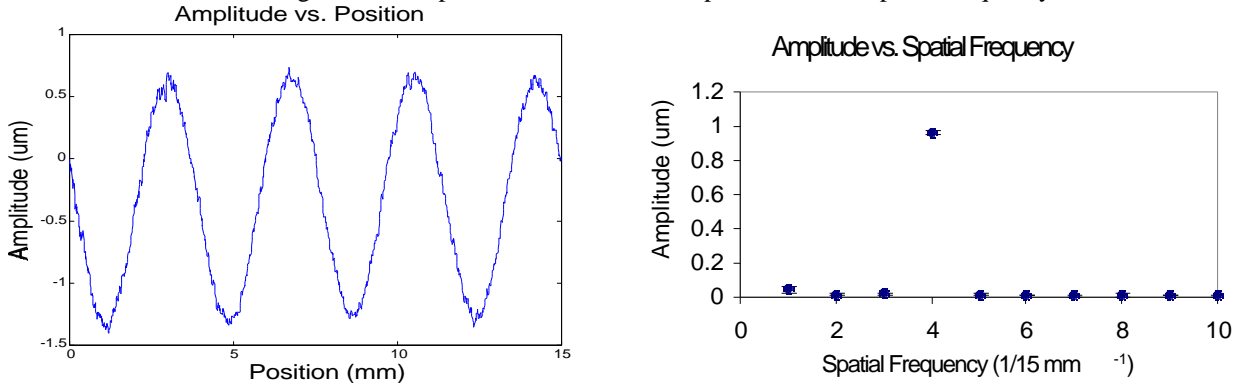


Figure 3: Average of 12 straightness traces of 15 mm window with taper removed taken by a Mahr MFU-7 for nominal 3.75 mm axial wavelength, 1 μm amplitude artifact. Also, amplitude of each spatial frequency shown.

III. Optical Measurements and Analysis

Each axial sinusoid artifact was measured by the Tropel CM25 cylindrical interferometer with a shortest wavelength straightness cutoff filter of 0.8 mm. The measurement resulted in 256 straightness data sets evenly spaced around the artifact. For these parts, the straightness data sets were composed of 42 data points with a resolution of 1.58 pixels/mm. For the 15-mm and the

3.75 mm wavelength part, a 15.2-mm window that corresponded to 24 pixels of data was sampled from each straightness measurement. For the 6-mm wavelength part, a 18.2-mm window corresponding to 28 pixels of data was sampled from each straightness measurement. The measurement window for each part sampled the same axial length for both the mechanical and optical measurements. All straightness data sets for each window of straightness data and artifact were Fourier transformed and averaged. The straightness data sets with taper removed from the cylindrical interferometer data along with the amplitude of each spatial frequency term are shown in Figures 4, 5, and 6. The statistical uncertainty evaluation of the amplitude of each spatial frequency term was less than 2 nm. For the 15 mm wavelength part, the interferometer measured the part at the nominal part amplitude. As the wavelength of the axial sinusoid of nominally one micron amplitude decreased to 6 mm then to 3.75 mm, the magnitude of the response of the interferometer decreased. This may be a function of the interferometer reflecting light off the surface at grazing incidence shortening the axial profile causing larger slopes more difficult to resolve.⁵

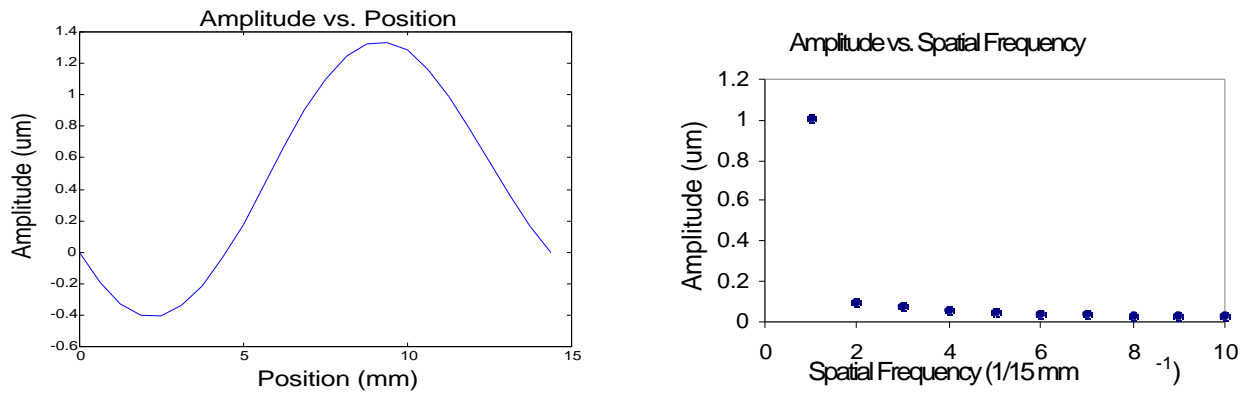


Figure 4: Average of 256 sets of axial data points of a 15 mm window from data taken by a Tropel CM25 cylindrical interferometer for nominal 15 mm axial wavelength, 1 um amplitude artifact. Also, Fourier transform of data shows amplitude of each spatial frequency.

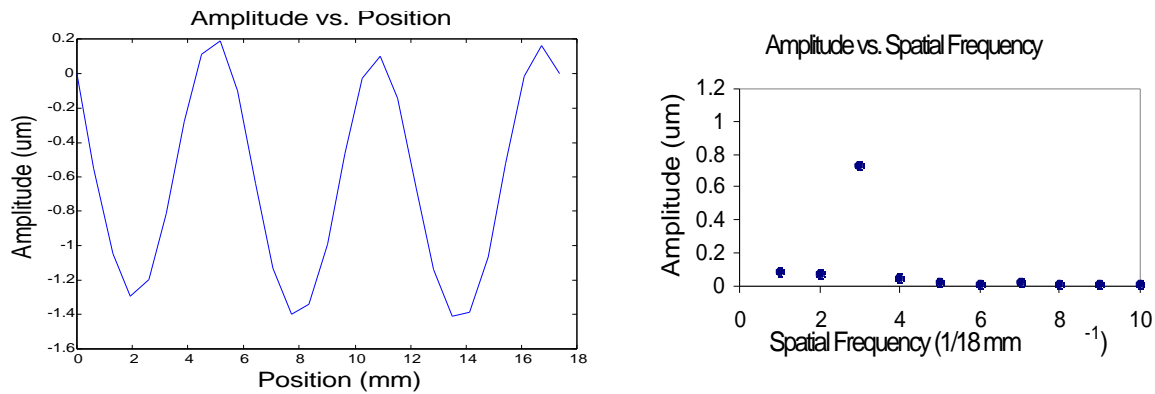


Figure 5: Average of 256 sets of axial data points of a 18 mm window from data taken by a Tropel CM25 cylindrical interferometer for nominal 6 mm axial wavelength, 1 um amplitude artifact. Also, Fourier transform of data shows amplitude of each spatial frequency.

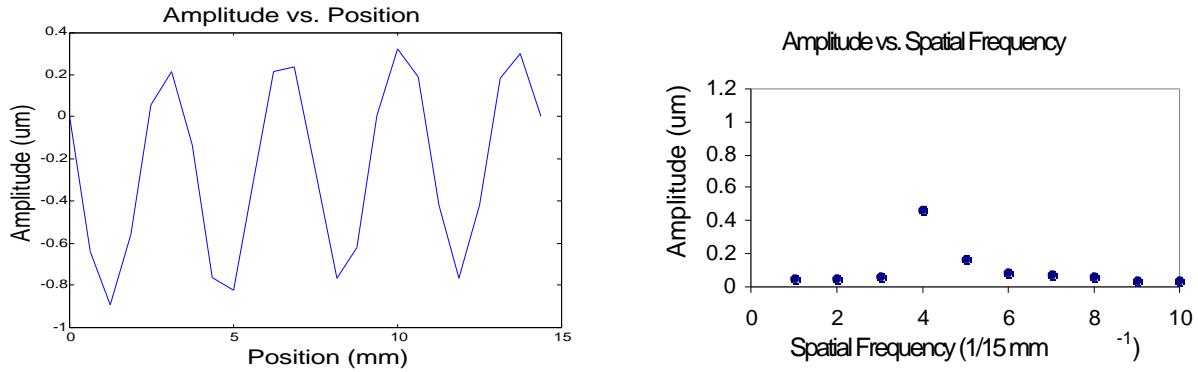


Figure 6: Average of 256 sets of axial data points of a 15 mm window from data taken by a Tropel CM25 cylindrical interferometer for nominal 3.75 mm axial wavelength, 1 μm amplitude artifact. Also, Fourier transform of data shows amplitude of each spatial frequency.

IV. Conclusions

Three axially sinusoidal cylindrical artifacts of differing spatial wavelength and nominally similar amplitude were diamond turned and measured for axial straightness with both a mechanical and interferometric instrument. Based on the mechanical measurements, the sinusoid amplitude was nominally one micron for each artifact. At a one micron amplitude, as the spatial wavelength of the parts became shorter, the amplitude response of the cylindrical interferometer decreased. This effect appeared to be slope dependent, which would also make the response a function of both sinusoid amplitude and spatial frequency. This may be due to the interferometer reflecting light off the surface at grazing incidence shortening the axial profile,⁵ the number of pixels in the axial direction sampling the artifact, or the optical modulation transfer function of the optical imaging system. Further work includes measuring the parts on the new, high-resolution version of the Tropel CM25 and investigating the response of the cylindrical interferometer as a function of artifact spatial slope.

V. References

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