A PORTABLE GRAZING INCIDENCE INTERFEROMETER FOR MEASURING THE FLATNESS OF SLIDEWAYS AND SURFACE PLATES

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ABSTRACT
The flatness of machine slideways and surface plates is often critical to the precision of machined surfaces or the accuracy of measurements. Yet there are very few viable methods or techniques for measuring this important parameter. The most common methods use auto-collimators or electronic levels to measure angular deviations in the surface to arrive at an estimation of the flatness. These methods are time-consuming and result in a limited number of data points. The error motions of an assembled machine tool or metrology instrument can also be measured using conventional methods, but the contribution due to the slideway flatness is difficult to determine directly. A prototype grazing incidence interferometer capable of performing these measurements has been designed, built and tested at Tropel. Results of measurements of a variety of surfaces are given in order to illustrate the prototype instrument’s capabilities. In particular, the results of measurements from a machine tool slideway and a granite surface plate are provided.

1. INTRODUCTION
For many years, grazing incidence interferometry has been used to accurately measure the flatness of precision machined surfaces. Recently, the principle has been extended to measure the cylindricity and diameter of inside or outside diameter cylinders. The principle of grazing incidence allows one to obtain high contrast interference fringes from relatively rough and diffuse surfaces. Furthermore, the large angle of incidence increases the fringe spacing, resulting in a much greater dynamic range than normal incidence interferometry. Finally, the application of digital phase measuring techniques allows one to greatly improve the accuracy and resolution of the measurement over visual evaluation of a fringe pattern. Until now, this method has been limited to measuring the flatness of individual components, up to about 200mm in diameter. In many cases, such as with machine slideways and surface plates, it is useful to know the flatness of a surface over an area which is only a part of a much larger structure. In these cases, it is necessary to bring the metrology instrument to the part, instead of the part to the metrology instrument.

2. DESIGN
The optical layout of the portable grazing incidence interferometer is given in Figure 1.

Figure 1. Optical layout of portable grazing incidence interferometer.
A fiber-coupled helium-neon laser is used as the source for the interferometer. This allows the heat from the laser to be located away from the interferometer. A 40mm diameter doublet lens produces a collimated wavefront which is
directed to the first diffraction grating by a right angle prism. The interferometer uses two linear diffraction gratings to split and recombine the light into test and reference beams. The first order diffracted light from the first grating reflects off the surface at a grazing angle and serves as the test beam. The zero order diffracted light passes parallel to the surface and serves as the reference beam. The two beams are then recombined at the second grating. An interference pattern indicative of the surface height variations is imaged by the viewing lens and CCD camera. A linear translation of one of the gratings introduces a phase shift into the interferogram. Finally, a computer collects the phase shifted interferograms and calculates the surface flatness. Multiple measurements can be stitched together to measure the flatness of a much larger area.

Figure 2. Photograph of portable grazing incidence interferometer measuring the flatness of a surface plate.

A photograph of the prototype interferometer is given in Figure 2. This prototype instrument measures an area approximately 1 inch wide by 15 inches long, and can easily be carried by hand to the surface to be measured. All of the optical components are mounted on an aluminum I-beam. The I-beam provides a stiff mounting structure while maintaining a low mass. The entire instrument weighs approximately 15 pounds. The source and viewing arms of the interferometer are located on the top half of the beam and the diffraction gratings are located on the bottom half. Three fine adjustment screws are located on the outside of the beam to permit fine alignment of the fringe pattern and repeatable placement of the instrument on the surface to be measured. Located next to each adjustment screw is an air dash-pot to reduce the likelihood of damage to the surface. The pitch of each diffraction grating is 10 microns, resulting in a fringe sensitivity of 5 microns per fringe. A translation of the first grating by 10 microns in a direction perpendicular to the grating lines results in a phase shift of one fringe. This motion is accomplished with a micro-stepping motor and an eccentric cam.

3. MEASUREMENTS

Figure 3 shows the results of a measurement of an 18" optical flat. This flat has been separately verified to have a figure error of less than 0.1 microns over the measured area. The top of the figure includes a photograph of the fringe pattern and an isometric view of the surface height map. The square image results from the geometric distortion caused by the grazing incidence angle. This distortion can be compensated for in software to display the measurement in the correct aspect ratio. The remaining plots in Figure 3 are contour and line profiles of the same measured area. The figure indicates a systematic interferometer error of less than 2 microns, including a periodic error due to grating imperfections. This measurement is stored and used as a reference file to be subtracted from subsequent measurements.
Figure 3. Measurement results from the 18” reference flat.

Figure 4. Fringe patterns obtained from a surface plate and a machine slideway. The first fringe pattern in Figure 4 corresponds to the measurement of a granite surface plate. This fringe pattern does not appear significantly different than that of the reference flat. This indicates that there is little form error in
this region of the surface plate. Figure 5 below shows the contour and line profile measurements from the surface plate after the reference file has been subtracted. The flatness in this region is measured to be less than 0.5 microns.

![Image of surface plate measurement](image.png)

Figure 5. Measurement results from the granite surface plate.

The second fringe pattern in Figure 5 corresponds to the measurement of a machine tool slideway. The instrument has been placed over the edge of the slideway to illustrate the flatness along the edge. Higher order form variations are clearly evident in the fringe pattern. Figure 6 below shows the contour and line profile measurements of the slideway after the reference file has been subtracted. The flatness in this region is measured to be greater than 10 microns.

![Image of slideway measurement](image.png)

Figure 6. Measurement results from the machine slideway.

4. SUMMARY

In this paper, the design of a portable grazing incidence interferometer for flatness measurements of slideways and surface plates has been presented. The results of measurements of a variety of surfaces has been presented in order to illustrate the prototype instrument’s capabilities. In particular, measurements of a machine tool slideway and a granite surface plate were demonstrated. Future work will include the stitching of multiple measurements together to measure the flatness of an entire surface plate and the comparison of this measurement with conventional methods.

5. REFERENCES