Synopsis of Technical Report for Opti 521 Graduate Report 1
by Jun Zhang, November 1, 2009

"**Phase-shifting birefringent scatterplate interferometer**"

By Michael B. North-Morris, Jay VanDelden and James C. Wyant
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In this paper the authors introduced a new phase-shifting scatterplate interferometer by exploiting the polarization characteristics of a birefringent scatterplate. The common-path design was used in this interferometer, and thus, no high-quality optical components were required in the test setup. The theory of the interferometer was presented, and the procedure for the fabrication of the birefringent scatterplate was described. This new interferometer could be used for quick and accurate measurements of the test surface, such as concave mirrors.

1. Introduction

Phase-shifting interferometer records a series of interferograms while the reference phase is changed. The wave front is encoded in the irradiance distribution of the fringe pattern, and a simple point-by-point calculation in the computer recovers the phase. Accuracies of the order of 1/1000 of a wave are achievable. For phase-shifting interferometry the limiting error is usually movement caused by vibrations and index variations in the optical path.

Common-path interferometers are one possible solution to the environment limitations. Unfortunately, it is difficult to separate the test and reference beams for phase shifting. A few groups have phase shifted common-path interferometers with varying success by using gratings, microspheres with liquid-crystal layers and quarter-wave plates. In this paper, a birefringent scatterplate is used to separate the test and reference beams. And liquid crystal retarder is used to produce a variable phase shift.

2. Conventional Scatterplate Interferometer

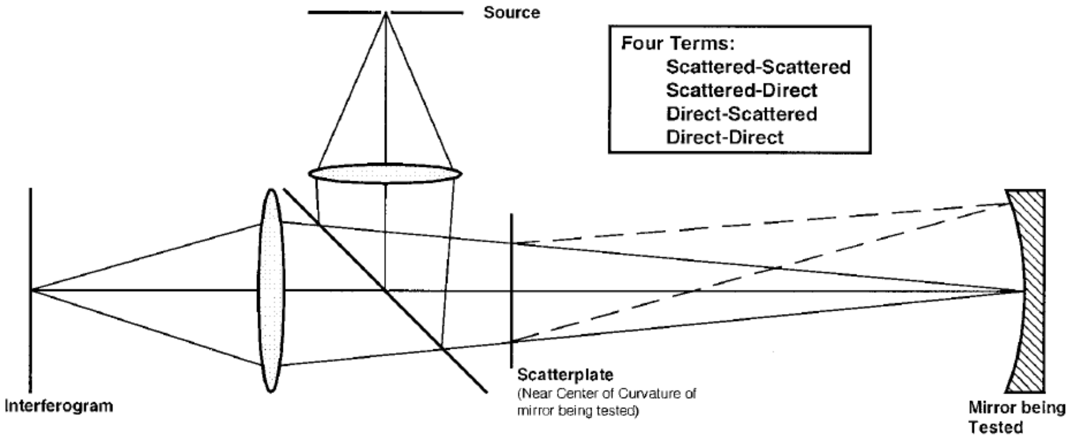


Fig. 1. Scatterplate interferometer for the testing of concave mirrors.

Because of its common-path design and unique ability to average many measurements at one time, the scatterplate interferometer is the ideal choice for a phase-shifting common-path interferometer. The advantages of common-path interferometers are: 1) reduced sensitivity to vibrations and air turbulence, 2) no precision auxiliary optics required, and 3) a white-light source can be used. In addition, the scatterplate interferometer has the unique property of averaging many measurements at one time. Thus, any small spatial phase variations present in the beam incident on the scatterplate will be averaged, significantly reducing the errors associated with them.

The configuration of a conventional scatterplate interferometer for testing a spherical mirror is shown in Fig. 1. A focusing lens is used to image the source onto the test mirror by way of a beam splitter that removes the source from the path of the return beam and a scatterplate. The scatterplate is placed at the center of curvature of the test mirror. Each time the light encounters the scatterplate, some of it is scattered and a portion passes directly through the plate. Because the scatterplate is traversed twice, there are four permutations of the beam that arrive in the image plane: 1) scattered-scattered, 2) scattered-direct, 3) direct-scattered, and 4) direct-direct. The direct-direct beam passes directly through the scatterplate both times it is encountered, forming an image of the source called the hot spot in the image plane. The scattered-scattered beam does not play a role in the formation of interference fringes. And it produces background irradiance in the image plane. The direct-scattered beam is the reference beam of the interferometer. The scattered-direct beam serves as the test beam of the interferometer.

In general, the process described above would not produce interference fringes; however, Burch came up with the solution: The scatterplate must have inversion symmetry, as shown in Fig. 2. The effect of misalignment of the scatterplate is also discussed. Lateral movement of the scatterplate produces tilt in the contour fringes. Similarly, longitudinal misalignment of the scatterplate adds defocus to the contour fringe pattern.

Fig. 2. Inversion symmetry designed into a binary scatterplate.

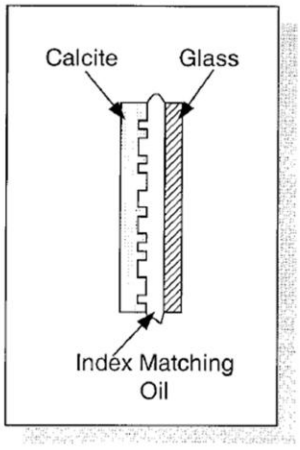


Fig. 3 Birefringent scatterplate.

3. Phase-shifting Scatterplate Interferometer

In the phase-shifting scatterplate interferometer, the goal is to control when the test and reference beams are scattered. Here the birefringent scatterplate shown in Fig. 3 provides the desired control. The appropriate aperiodic pattern with inversion symmetry is etched into a calcite retarder with a chemical etching process. An index-matching oil chosen to match the ordinary index of the crystal is then pressed between the calcite and a glass slide. The end result is that, for light polarized along the ordinary axis of the crystal, the index of the oil and the index of the crystal appear the same and the light passes directly through the scatterplate, whereas light polarized along the extraordinary axis of the crystal sees an index difference and is scattered by the rough surface.

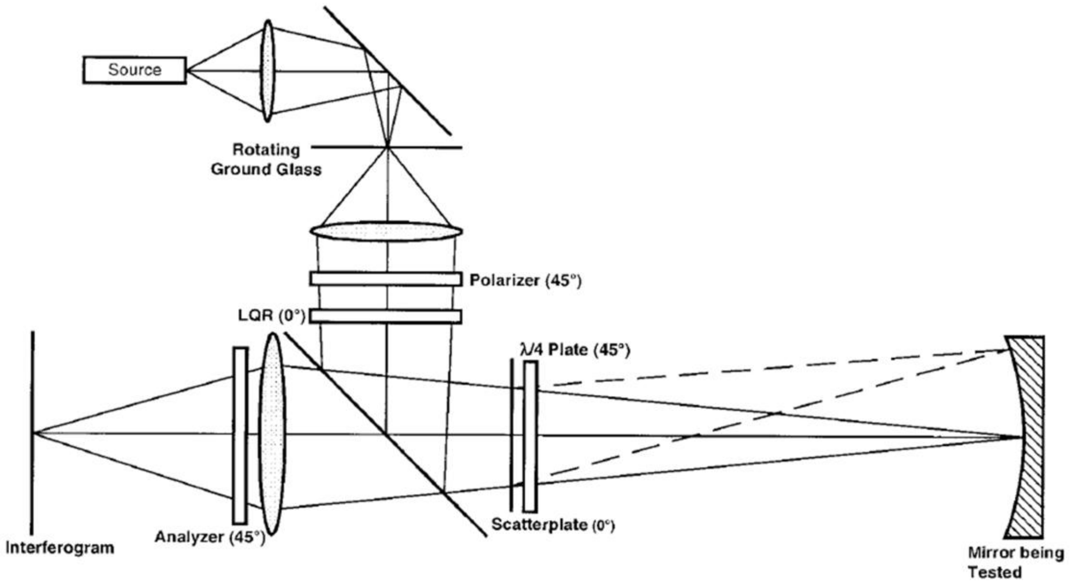
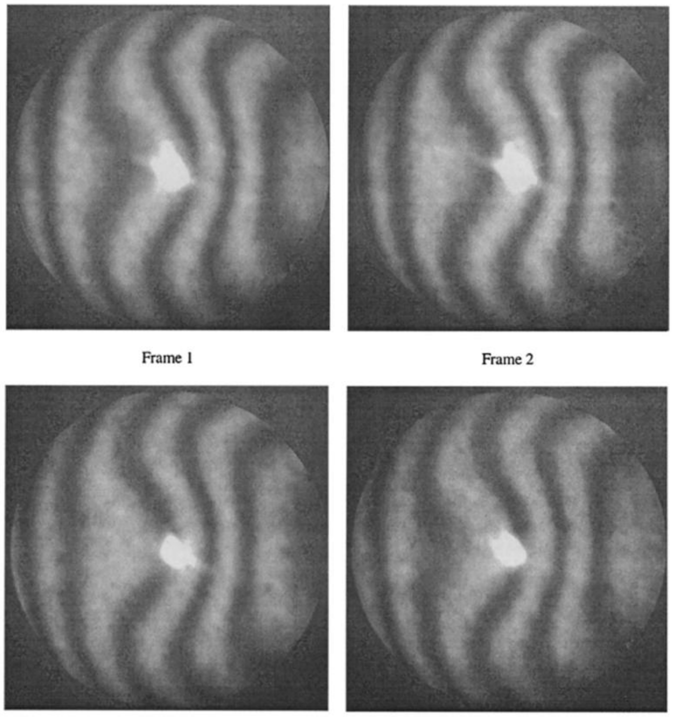


Fig. 4 Phase-shifting scatterplate interferometer. LQR, liquid-crystal retarder.

The schematic diagram of the phase-shifting scatterplate interferometer is shown in Fig. 4. The polarizer passes linearly polarized light oriented at 45° with respect to the optic axis of the calcite scatterplate, providing equal amplitudes for the component of the beam polarized along the optic axis and the component polarized orthogonal to the optic axis. The component parallel to the optic axis will see the extraordinary index of the crystal, and the perpendicular component will see the ordinary index. A liquid-crystal retarder produces a variable phase shift between the two orthogonal components of polarization, and the rotating ground glass plate reduces the speckle in the interferogram because it effectively enlarges the apparent source size. And the result is an extended source, made up of incoherent point sources, that is, the same size as the beam incident on the ground glass plate. Both the scattered and the direct beams pass through a quarter-wave plate twice producing a 90° rotation in the direction of polarization of each. As a result, on the second pass through the scatterplate the beams change roles: The one that traveled directly through on the first pass is now scattered, and the one that was scattered now passes directly through. The outcome is a scattered-direct and direct-scattered beam with orthogonal polarization. Finally, the test mirror is imaged onto a CCD array through an analyzer, which serves to combine the test and reference beams for observation of interference fringes. The end result is that we can phase shift the interference fringes by applying a voltage to the liquid-crystal retarder. Fig.5 contains a series of four shifted interferograms.



Frame 1 Frame 2

Frame 3 Frame 4

Fig. 5 Phase-shifted fringe patterns.

4. Scatterplate Manufacture

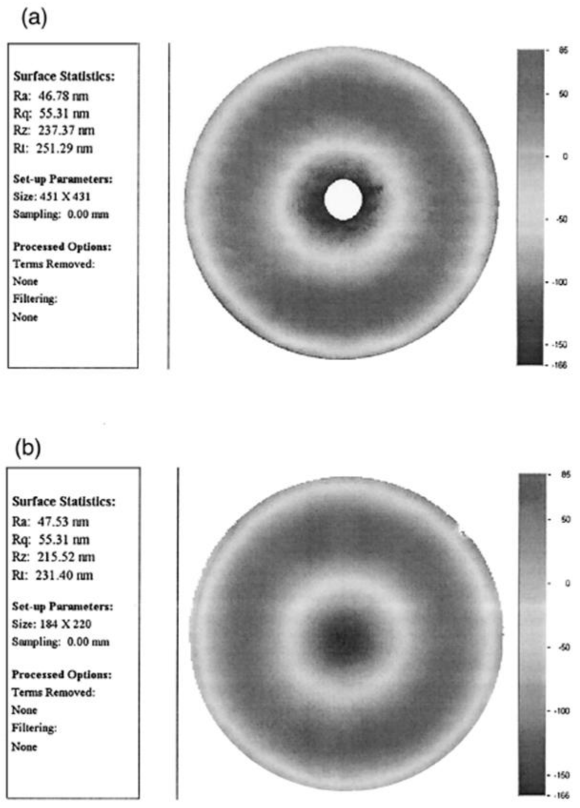
The birefringent scatterplate is the key component of the phase-shifting scatterplate interferometer presented in this paper. There are many issues to be considered, including pattern generation, average feature size, inversion symmetry, and etching rates.

The birefringent scatterplate is made by a six-step etching process. First, a good quality wave plate made with calcite is cleaned in four stages with acetone, isopropanol, deionized water, and a plasma chamber. The next step is to spin coat the sample with photoresist. After coating, the sample is soft baked on a hot plate for 1.5min at 100 ℃ to solidify the photoresist. The scatterplate pattern is then exposed into the photoresist by use of either a speckle pattern or a photomask. Developing removes the photoresist from the calcite only in the regions that are exposed wit flux levels above 150mJ/cm^2. After developing, the sample is hard baked for another 1.5min on the hot plate. The birefringent scatterplate is then chemically etched with an extremely weak solution of hydrochloric acid. Finally, the photoresist is removed by the same cleaning process used to clean the blank substrate.

Two ways can be used to expose scatterplates: Holographic exposure and Photomask. In the holographic exposure method, a ground glass is illuminated with an expanded laser beam, and then a speckle pattern can be exposed on the photoresist. Rotation of 180 ° is required for the inversion symmetry. The advantage of using holographic exposure is that we can easily create low f/number scatterplates. The disadvantage is the elaborate setup required for each exposure and the possible errors from rotating of scatterplate. Photomask is a better way to expose the scatterplate. With one photomask many scatterplates can be rapidly exposed. As a rule of thumb, a scatterplate should be designed such that the minimum f/number is one half of the f/number of the test mirror.

5. Experimental Results

An f/6 mirror with a focal length of 90.93cm was measured by the phase-shifting scatterplate interferometer. The measurement result is compared with a commercial phase-shifting Fizeau interferometer. In double pass, the possible peak-to-valley error in the measurements was 0.073 waves. The rms difference between two consecutive measurements was found to be of the order of 0.0025 waves.



Surface Statistics:
Ra: 46.78 nm
Rq: 55.31 nm
Rz: 237.37 nm
Rt: 251.29 nm

Set-up Parameters:
Size: 451 X 431
Sampling: 0.00 mm

Processed Options:
Terms Removed:
None
Filtering:
None

Surface Statistics:
Ra: 47.53 nm
Rq: 55.31 nm
Rz: 215.52 nm
Rt: 231.40 nm

Set-up Parameters:
Size: 184 X 220
Sampling: 0.00 mm

Processed Options:
Terms Removed:
None
Filtering:
None

Fig. 6 (a) Surface measurement taken with a phase-shifting scatterplate interferometer. (b) Surface measurement taken with a Wyko 6000 phase-shifting Fizeau interferometer.

6. Conclusion

A new phase-shifting scatterplate interferometer is introduced in this paper. The interferometer separates the test and reference beams by exploiting the polarization characteristics of a birefringent scatterplate. The birefringent scatterplate was manufactured with the pattern etched into a good quality calcite wave plate. The scatterplate scatter only the component of polarization oriented along the extraordinary axis of the crystal. Together with two polarizers and a quarter-wave plate, the birefringent scatterplate produces test and reference beams with orthogonal polarizations. A variable phase shift is induced between the beams by use of a liquid-crystal retarder. The performance of this interferometer was admirable compared with commercial Fizeau interferometer. The repeatability is also very excellent.

7. References

1). M. B. North-Morris, J. VanDelden, J. C. Wyant, “Phase-shifting birefringent scatterplate interferometer”, Applied Optics, Vol. 41, Page 668, 2002