Double-pass point diffraction interferometer for qualitative optical analysis

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We propose a new point diffraction interferometer for qualitative optical analysis. Point diffraction is made two times to generate interfering waves with a single pinholed polarizer. Diffraction from a pinholed polarizer makes reference and measurement waves with a double-pass configuration. A quarter-wave plate rotates their polarization angles after reciprocation. The interferogram between the diffracted-undiffracted measurement wave and the Undiffracted-diffracted reference wave is vibration-insensitive due to a common-path configuration. We examined its capability by changing the pinhole size and divergence angle of the diffracted wave for test optics with various numerical apertures. Application to the alignment of an off-axis parabolic mirror is also presented. The optical parts comprising the interferometer are bonded together into a monolithic component and integrated with a readily available laser diode. The whole system is small and inexpensive to embed permanently into alignment critical targets for repetitive use. We installed the double-pass point diffraction interferometer on a target wheel for thermal imaging system alignment.

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1. Introduction

Optical testing systems evaluating the modulation transfer function (MTF) and other imaging-related parameters require a precise alignment between imaging optics and target objects. Various targets can be placed on a rotating wheel in the case of infrared (IR) optics [1]. Positioning those targets at a predefined plane requires a qualitative interferometric measurement. Previously we used a commercial optical testing interferometer to align the imaging optics and placed a spherical ball at the interferometer's beam focus to get null fringes. Then we used a coordinate measuring machine (CMM) to position the imaging targets at the ball center. This procedure needed three additional alignment steps: setting up the interferometer, the spherical ball and the CMM, which is cumbersome and time consuming. If we could embed a small interferometer into the target, the alignment would be quite simple and easy. Speer et al [2] and Smartt et al [3] proposed point diffraction interferometers (PDI) which have features like common-path and operational wavelength adaptability. Variations of PDI have been reported for phase shifting using crystals [4-6], a diffraction grating [7], a halfwave plate [8] and a Mach-Zehnder configuration [9]. PDI using fiber optics are also reported [10, 11]. They are vibration-insensitive and compact in size. Also they do not need any precision reference optics. Those features meet the requirements for embedding an alignment interferometer in the target. In this paper, we present a new double-pass point diffraction interferometer (DPDI) for qualitative optical analysis and optical system alignment. We used a polarizer with a pinhole and a quarter-wave plate (QWP) to manipulate polarization. Point diffraction is made two times to generate interfering waves with a single pinholed polarizer. Diffraction from a pinholed polarizer makes reference and measurement waves with a double-pass configuration. Interference between the diffracted-undiffracted measurement wave and the undiffracted- diffracted reference wave is stable due to the common-path principle. Wang et al reported an interferometer using a pinholed polarizer and a single-mode fiber [12]. They need an additional spherical wave source other than a pinholed polarizer to illuminate the test optics. But the DPDI just uses one pinholed polarizer with a double-pass setup to illuminate the test optics and make reference and measurement waves. The novelty of the DPDI is the double-pass principle used in point diffraction, which is the first to our knowledge. This advantage removes a well-defined source part and enables the whole interferometer optics to be assembled as a monolithic body. Calibration of the interferometer is unnecessary as the composing optics are minimal. Also the manufacturing cost is low and size can be minimized to be embedded permanently into other parts. This paper presents the principles of the DPDI and examines its capability with different-sized pinholes.

2. Principles

Figure 1 shows the principle of the DPDI. A linearly polarized laser source is collimated by a lens (CL) and redirected by a polarization beam splitter (PBS). A temporally low coherent laser source having a wide spectral bandwidth is preferred to minimize spurious noise from multiple reflections. We used a laser diode (LD) with a wavelength of 635 mm in this study. Most of the beam is reflected by the PBS as the LD is rotated to match the reflective polarization direction. Then, part of the beam is point-diffracted by a pinholed polarizer which has the transmission axis at 45° and becomes a measurement wave. And the rest is undiffracted, becoming a reference wave afterwards. A QWP with its fast axis at 0° is attached onto the pinholed polarizer to make circularly polarized waves. Upon reflection from the test optics, the diffracted and undiffracted waves change their linear polarization angles after the QWP. So the diffracted measurement wave is transmitted through the pinholed polarizer undiffracted, and the undiffracted reference wave is diffracted by the pinhole. The interference fringe between reference and measurement waves is captured by a screen after the PBS for qualitative analysis. The alignment of the test optics and the object plane is accomplished when a null fringe is made.

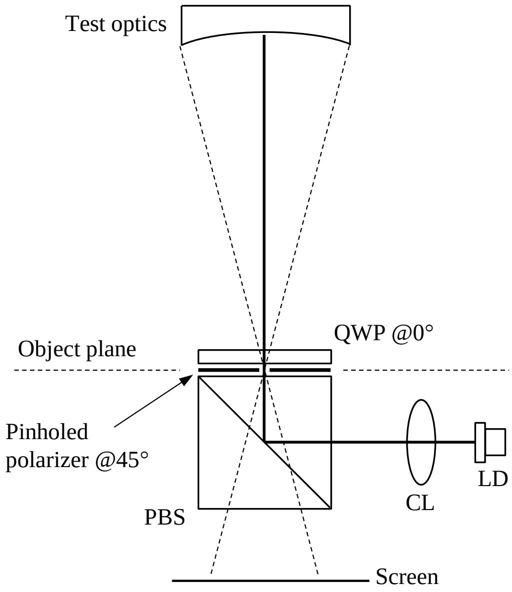

Fig. 1 Principles of the DPDI: QWP, quarter-wave plate; PBS, polarization beam splitter; CL, collimating lens; LD, laser diode.

4. Results and Conclusions

We verified the principles of the DPDI on a laboratory optical bench with various pinhole sizes before making a compact assembly for real applications. We used a LD with a wavelength of 635 nm (Coherent® Radius-635) and a 25mm cube PBS. The diameter of the collimated beam is 1 mm in the $1/e^2$ intensity output. A zero-order QWP is used to mitigate the angular dependence of polarization. The film polarizer is 30 μm thick and has several pinholes with different radii (10, 15, 25, 50 μm). The test optics is a spherical concave mirror the curvature radius of which is 250 mm and the size is 25 mm square. We used a fiber optic taper (Schott® size ratio 25:8 mm) to capture the interference fringe with a photographic camera for demonstration. We obtained the interference fringes created on the fiber optic taper by pinholes with different sizes: (a) R = 10μm, (b) R = 15μm, (c) R = 25μm and (d) R = 50μm. Patterns have intentional tilt fringes to distinguish them from diffraction rings by adjusting the tilt angle of the test optics. The diffraction pattern is dominant as the pinhole size becomes larger. Interference fringes over the Airy rings inform the status of the test optics such as optical aberration and misalignment. The diffraction rings are distracting for this purpose and should be avoided. Determination of the pinhole size depends on the F-number or NA of the test optics, but 10 or 20 μm pinhole radius proved to be sufficient for slow optics. As a conclusion, we proposed a new DPDI for qualitative optical analysis and optical system alignment. And we verified the principles of the DPDI on a laboratory optical bench with various pinhole sizes before making a compact assembly for a real application. We are planning to install the DPDI on a target wheel for thermal imaging system alignment.

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