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A novel lateral shearing interferometer and its anti-vibration characteristic for on-machine precision surface measurement

Liangzhou Chen [a], Xiaojun Liu [a,*], Yongsheng Gao [b]

[a] School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, China
[b] Department of Mechanical Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong Special Administrative Region, China

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ABSTRACT

Based on the self-reference feature of the shearing interference, a lateral shearing interferometer is proposed for on-machine precision surface measurement. This shearing interferometer is based on a specially designed shear generator made of a single birefringence plate. Due to the self-reference feature and a common path polarized interference design which is based on the birefringence shear generator, the interferometer is simple and compact in structure. As a wave interferometer, the design has immunity to mechanical vibrations while it has high accuracy for precision surface measurement. The interferometer is suitable for on-machine precision surface monitoring for quality control. The principle of the proposed interferometer is introduced. Analysis and experimental testing were carried out. The results show that the interferometer has a good anti-vibration performance. The accuracy in RMS is better than λ/80.

1. Introduction

As the technologies in the semiconductor and optics industries advance very rapidly, demands for high quality surfaces, such as optical mold surfaces, wafer surfaces and others for precision equipment, are steadily increasing [1]. Surface quality is usually guaranteed by use of high precision manufacturing equipment and proper manufacturing processes. However, a prerequisite for this is the stability and reliability of the manufacturing system. When manufacturing is in a high precision level, the quality of the processed surface will be very strongly influenced by the operation status of the manufacturing equipment and all the elements, kinematically, dynamically and thermally [2,3]. This makes on-machine monitoring necessary for the machining surface quality assurance and control. Because on-machine quality monitoring can provide direct and real-time quality evaluation and process revision, improve process continuity and reliability of process control, so that reliable quality assurance can be achieved to avoid rejects and re-machining [1,4].

Current on-machine surface quality monitoring methods are mostly indirect methods [5–8], in which it is the operation status of machine tools or manufacturing process parameters but not the quality characteristic of the machining surface that are monitored directly. Then, based on the indirect monitoring results and the relationship models between the surface quality characteristics and machine status or process parameters, necessary compensation or parameter adjustments are conducted for surface quality assurance [5,9–12]. To on-machine surface measurement, the disadvantages of the indirect

* Corresponding author.
E-mail address: mexjl@hust.edu.cn (X. Liu).

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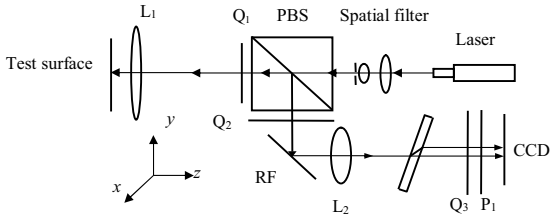

Fig. 1. Schematic diagram of the proposed shearing interferometer.

monitoring and control methods are their low reliability and stability. For efficiency and reliable quality assurance, direct on-machine quality monitoring and control is the desirable choice.

For direct on-machine surface quality monitoring and control, the main problem lies in the lack of effective on-machine precision surface measurement methods in complicated machining circumstances. Laser wave interference methods [13] are high precision and high effective methods for precision surface measurement. However, they are usually very sensitive to external environment vibration and disturbances, and unsuitable to be applied to on-machine precision surface measurement.

Different from general wave interference, shearing interference is a kind of self-reference interference, in which the wave-front under test superposes to interfere with a laterally sheared copy of itself. Hence, a shearing interferometer does not need high precision surface as reference, and usually has good immunity to external vibration, while it provides whole field measurement with high surface measurement accuracy. Various designs of lateral shearing interferometers have been reported for different applications, such as the verification of the laser beam collimation and analysis of optical system [14–16], double-shearing with polarization beam splitting film and lensmeter analysis [17,18], material stress and strain analysis [19,20], precision surface measurement [21], dynamic flow field measurement [22], and work-piece surface quality or deformation evaluations [23,24]. In these designs, wedge prisms [25–27], parallel plates [28], square prisms [29], ronich gratings [23,30,31] and rotatable prism pairs [32] have been adopted as shear generating devices, which are the most important components in shearing interferometers. Although they are extremely useful, wedge prism and parallel plate designs are difficult to perform phase shifting, which are usually necessary for precision interference measurements [13]. Square prisms have very complicated structure for shearing quantity adjustment and phase shifting, which leads to low reliability and stability. Ronich gratings consist of two parallel gratings, however, they are difficult to fabricate, have limited shearing range and requires high precision mechanical motion for phase shifting. These designs are not suitable for on-machine applications.

A lateral shearing interferometer has been investigated for on-machine precision surface monitoring by using a new shear generator made of birefringence crystal. The new interferometer has simple mechanism, common path interference, convenient shear adjustment and phase shifting, and therefore has a good stability and high immunity to external vibration and disturbance while it provides a comparable accuracy to other general wave interferometers. The interferometer is not only suitable for applications mentioned above, but also for on-machine precision surface measurement.

In this paper, the principle of the new interferometer and its anti-vibration capability will be introduced and analyzed. Experimental results are discussed to demonstrate the performance for on-machine precision surface measurement.

2. Proposed shearing interferometer

The proposed shearing interferometer is shown in Fig. 1. SP is the specially designed shear generator made of birefringence crystal. After the light from the laser passes through the spatial filter, polarized beam splitter PBS, a quarter-wave plate Q_1, and the collimated lens L_1, it becomes a standard plane wave. The plane wave incidences onto the test surface and is reflected back to be a wavefront with the aberration information of the test surface. After the wavefront passes through L_1 and Q_1 once again and is reflected by the beam splitting surface of PBS and mirror RF, the wavefront then passes through the collimated lens L_2 and incidences into the shear generator SP. Here L_1 and L_2 consist of a beam expander, by which the aperture can be adjusted for proper scope to match with different objectives. By SP, the wavefront is sheared along y-axis direction into two polarized wavefronts, one with polarized direction in parallel and another in vertical to the page surface. The two sheared wavefronts pass through a quarter wave plate Q_3 whose fast-axis is 45° to the page surface and a polarizer P_1 to come to similar polarized direction to interfere with each other, shear interference therefore takes place. By CCD, the interference patterns corresponding to shear along y direction is obtained. Similarly, after rotating the shear generator by 90° along z-axis, the shear interference patterns corresponding to shear along x direction can also be obtained. The bi-direction shear interference patterns are then sent to a computer for analysis and wave-front reconstruction, and the information of the wave-front shape and hence the test surface aberration can be obtained.

In the interferometer, Q_3, P_1 consists of a polarized phase shifter. When P_1 is rotated to change the polarized direction by an angle α, phase shifting of an angle 2α can be produced [33].