COMPARISON OF THE FRINGE VISIBILITY CREATED BY ZERO AND FIRST ORDER DIFFRACTED BEAMS IN A DISPERSIVE INTERFEROMETER

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ABSTRACT

Interferometery is an important technique which can provide high resolution measurement of surface topography. In this paper an interferometer with a dispersive probe, sourced by a super-luminescent diode is considered. One important parameter for the effective operation of such an interferometer is the fringe visibility. In this paper the fringe visibility of the first order diffracted light is compared with the reflected (zero order) light from the grating. This is done by modulating the reference beam of the interferometer and recording the fringe modulation on a CCD array. The fringe visibility formed from the first order beam was found to be lower than the zero order, resulting from the efficiency of the diffraction grating.
Keywords surface metrology, interferometer, phase shifting, dispersive probing

1 Introduction

SLD (Super Luminescent Diode) as a broadband white light source is widely used in optical coherence tomography techniques. SLD has properties such as high output power, wide broadband and very high optical gain in the active region [1]. White light interferometery techniques depend on the development of modern electronic devices such as computers, CCD cameras and software making it a very powerful technique used in optical surface profiling. White light has a short coherence wavelength making it difficult to find the interference fringes. White light interferometery can provide powerful and correct surface profile measurement [2,3]. Optical interferometery has been used for surface measurement because the optical probe does not contact the specimen (surface under test). Non-contact methods such as optical instruments have many advantages when compared to stylus instruments. They do not contact the surface being measured and thus cannot damage the measured surface [4-6]. Non-contact methods offer invariably fast and high accuracy interrogation. However, there are many factors that strongly affect the signal collected in an optical profiler such as mechanical vibration, temperature drift and air turbulence.
Wang et al [7], presented attempts to generate a robust and miniature measurement device for future development into a multi-probe array measurement system by using both fibre optic interferometery and wavelength division multiplexing techniques. The optical probe and the optical interferometer are located remotely and a fast surface scan can be carried out, allowing ease of use for on-line measurement. Martin and Jiang have presented and implemented an on-line rapid phase-shifting fibre interferometer with optical stylus to obtain real-time phase information from a fibre interferometer which is insensitive to; polarization state evolution the reference interferometer stability as well as the measurement interferometer around several points [8].
The phase shift interferometery technique is one of the most popular methods to calculate phase [9]. Recently, phase shift interferometery has become widely used in the field of surface metrology. The basic method for PSI calculation is based on the calculation of phase values from numerous phase modulation measurements from the intensity of CCD camera frames.

2 Phase Shift Interferometery

The principal concept behind the interferometeric method is the reference and object beams interference after a reflection from the object. The intensity of the resultant interference beam is detected by; a solid state device such as a CCD camera, photographic film or photo-detector. The interference signal as an equation can be described as

$$I = I_r + I_o + 2\sqrt{I_r I_o}\cos(\phi) \tag{1}$$

Where I_r and I_o are the irradiance reflected from the reference mirror and object respectively and ϕ is the phase shift between them. The fringe visibility is defined as

$$V = |\gamma_{ro}| = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \tag{2}$$

Where γ_{ro} is the fringe contrast or visibility and I_{max}, I_{min} are the maximum and minimum intensity respectively. Phase Shifting Interferometery (PSI) is a well established technique to provide areal characterisation of surface profiles. This method is used to analyse collected intensity data to determine the phase. The intensity pattern changes as the phase in the reference arm is changed. The recorded interferograms are analysed electronically and a suitable algorithm recovers the phase. Examples of these algorithms are Carré, Schwider-Hariharan, and the 3-step/5-step method although many more have been developed [10, 11]. The Carré algorithm is potentially the most useful for the experimental apparatus in this work, because it does not require a specific value of phase shift, it only requires each shift to be identical.

$$\phi(x) = \tan^{-1}\left\{\frac{\left\{\left[3(I_2 - I_3) - (I_1 - I_4)\right]\left[(I_1 - I_4) + (I_2 - I_3)\right]\right\}^{1/2}}{(I_2 + I_3) - (I_1 + I_4)}\right\} \tag{3}$$

The intensities detected by pixels (x) of the CCD camera that correspond to one point on the test surface can be expressed by this equation

$$I(x) = I_r + I_o + 2\sqrt{I_r I_o}\cos(\phi + \delta) \tag{4}$$

Where the, ϕ is the phase interference signal and δ is the phase shift, from equation (4) (OPD) will is proportional to the amount of phase shift for a given wavelength λ,

$$h(x) = \frac{\lambda}{4\pi}\phi(x) \tag{5}$$

From equation (5), the surface height can be calculated for any continuous phase distribution. The phase difference between two interference beams can be calculated by evaluating the fringes intensity. For typical PSI algorithms, the phase change must be 90^{o} .Determining the phase requires at least 3 intensity measurements because there are three unknown parameters in (4). Often a piezo-electric translator (PZT) is used in the reference arm to shift the phase, although these have problems such as the non-linearity and hysteresis, which tend to introduce some error into the actual value of the phase shift. The PZT moves the reference mirror several in the experimental apparatus as shown in figure (1) block (4).

3 Experimental Setup

The proposed apparatus to be studied uses spatial light-wave scanning to replace mechanical stylus scanning for the measurement of surface topography. The basic principle is based on measuring the phase of a reflected optical signal. A low coherence light source is used together with diffraction grating to disperse light along a profile on the surface. The fringe visibility is an important parameter as it defines the signal to noise ratio, and as such directly affects the metrology result. This apparatus comprises several parts: Gratings, CMOS camera, SLD and PZT. Figure (1) shows the experimental apparatus. The measurement system is composed of a Michelson interferometer. The proposed apparatus in this experimental setup will allow spatial light-wave scanning to replace mechanical stylus scanning for the measurement of surface topography, but in the present work to calculate the visibility for 1st order. A block diagram representation of the proposed measurement system is shown in figure (2). The focus of this paper is on blocks 1, 3 and 4. Block 1 is the light source, this comprises a laser diode (632nm) used for alignment, and a SLD as the source to the Michelson interferometer as shown in block 2. The beam from the SLD (Exalos EXS8310-8411) has an output power of 2 mW, bandwidth of 30 nm (FWHM). The centre wavelength is approximately 820 nm; BS1 and BS2 are used as beam combiners for two rays Block (3) as dispersive optical probe. The dispersive optical probe method depends on the angular dispersion of the SLD light beam. The light is dispersed by the grating. The diffraction grating is in a configuration with the objective lens such that the light is collimated onto the specimen under test, as shown in figure 3. The main equation (6) for a diffraction grating is:

$$m\lambda = d\left(sin\alpha + sin\beta\right) \tag{6}$$

Where *m* is an integer number, d is the grating pitch; λ is the wavelength of the incident light. α, β are the incident and diffracted angles respectively. The 1st order is the diffracted beam is work on the surface under test (mirror) and focused by the objective lens. The scanning ranges of surface can represent in the equation (7)

$$S = f.\frac{\Delta\lambda}{d\cos\beta} \tag{7}$$

Where *f* is the focal length of the objective lens and the diffraction grating is operating in the 1st order. Intensities are detected by CMOS camera for each pixel(x) that relates to one point on the specimen surface by way of the spectrometer and as such and, equation (1) can be used to calculate the phase. In this paper an experiment to determine the visibility of the interference fringes is described.

4 EXPERIMENTAL RESULTS

This experiment measured the visibility of interference fringes for the 0-order (reflected) and 1st order light from the diffraction grating. The interferometer as shown in figure (1) is precisely adjusted so the reference and measurement (zero and first order) mirrors are normal to the optical axis. A PZT behind the reference mirror is used to generate vibration on the reference arm to changed the field of view from bight to dark fringes and record the frames for each 0-order and 1st order pattern. The experimental results are analyzed according compare the visibility of the interference from the zero order beam and reference with that of the first order interference beam and reference. Which depends on the grating efficiency.

The fringes for 0-order and 1st order have intensity that varies in time as shown in figure (4) and figure (5). The computer is recorded the intensity *I(x)* by using successive CMOS camera frames.

The PZT was vibrated sinusoidally at 5 Hz. The applied voltage to the PZT is 20V peak to peak. For 10V, the piezo can move up to 1.5um. Figures 4 and 5 show that five fringes have been moved which is approximately 2 um movement for both the zero and first orders interference. Figure 6 shows the combined results on one graph. During the PZT movement from (0) point to maximum travel displacement (5) the fringes has been moved in one direction, then when the PZT return back to the 0 position the fringe is moved in reversed direction by the same amount. Point (A) represents the travel end if the start point is (0-point), the bending in the starting or travel end point might be a voltage polarity change or the voltage has reached to its maximum and dropped down toward the zero. From figure (6) is clear to observe that the 1st order visibility is less than 0-order intensity and the period for one cycle is 6.48 ms for 0-order and 6.60 ms for 1st order. The corresponding frame captures period was 0.022 s.

From the diffraction grating specifications, the intensity of diffracted light after is reduced by approximately 20% from its original intensity. From the general diffraction equation (8), note that the angle of incidence equals angle of reflection for the zero-order, so the reflected light from grating becomes as mirror for zero-order where the angle of incidence is equal to the reflection angle (approximately 70^{o}). For the 1st order the diffracted light angle was equal to about 27^{o}.

4 CONCLUSIONS

The fringe visibility is a key factor for the effective operation of any interferometer, as it directly affects the signal to noise ratio, and thus the resolution of the instrument. In this paper a phase shifting interferometer is considered, having a dispersive probe which laterally disperses broadband laser light over a profile. An important aspect of developing this instrument is to optimising the fringe visibility formed by the diffracted first order light, returning from the specimen under test, and the reference beam. In this paper, the fringe visibility was measured by modulating length of the reference arm using a PZT while the fringe intensities were recorded using a CCD line array. The visibility of the fringes formed using the first order and zero order were compared. The zero order visibility was substantially higher as was expected because of the diffraction grating efficiency. Improving the visibility and thus the signal to noise ratio of the system will be an important part of future work for this project.

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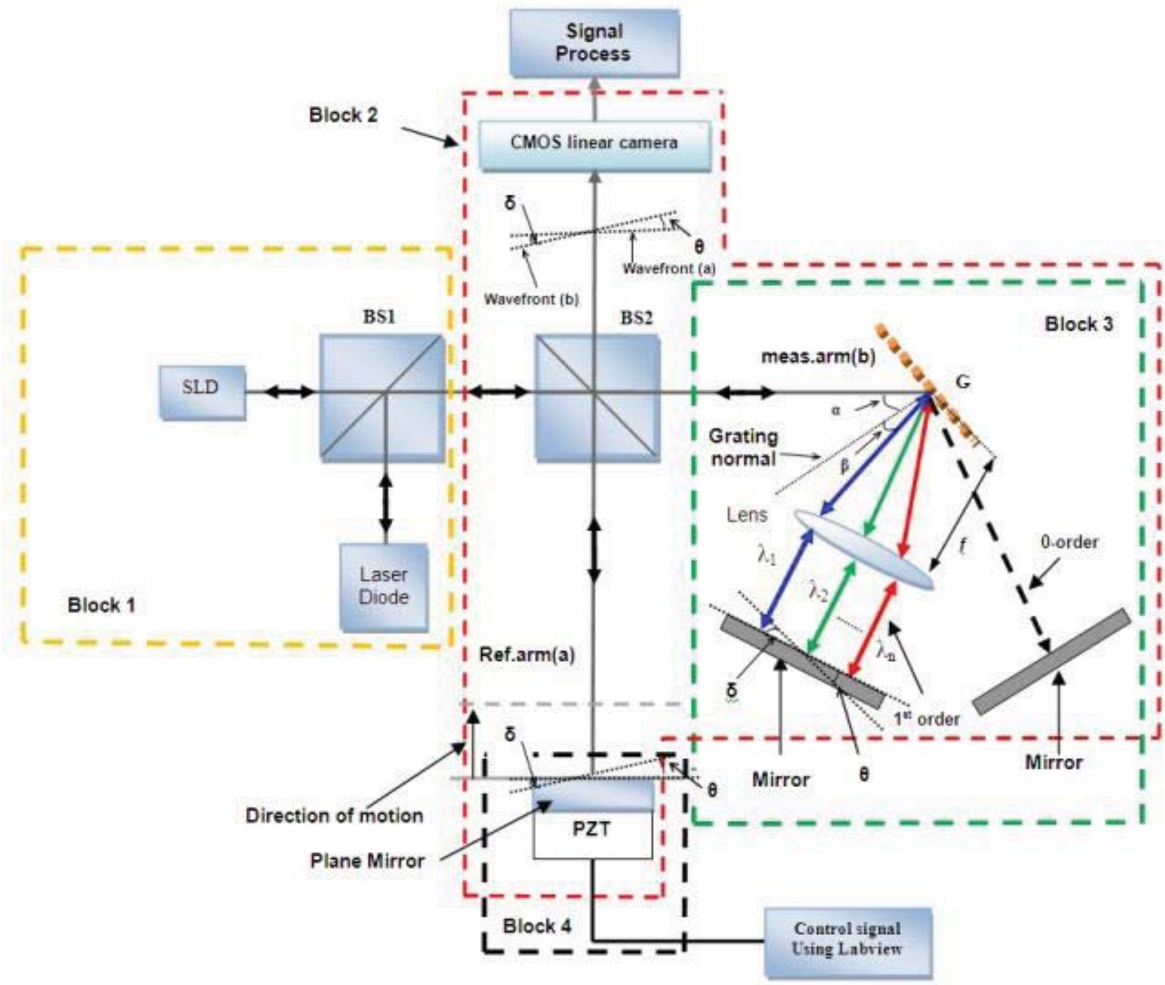
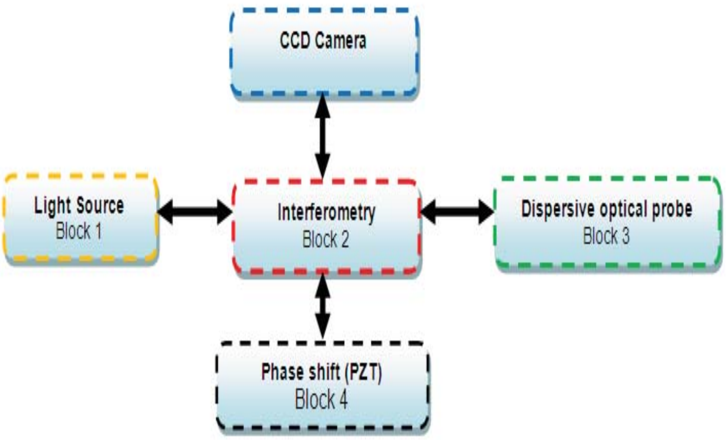


Figure (1): is shown all experiment setup.



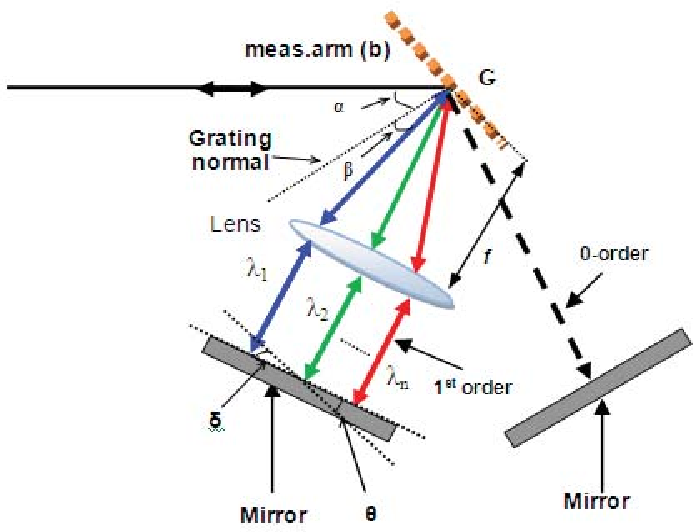


Figure (2): Schematic diagram experiment as blocks.

Figure (3): measurement arm with grating represents the dispersive orders.

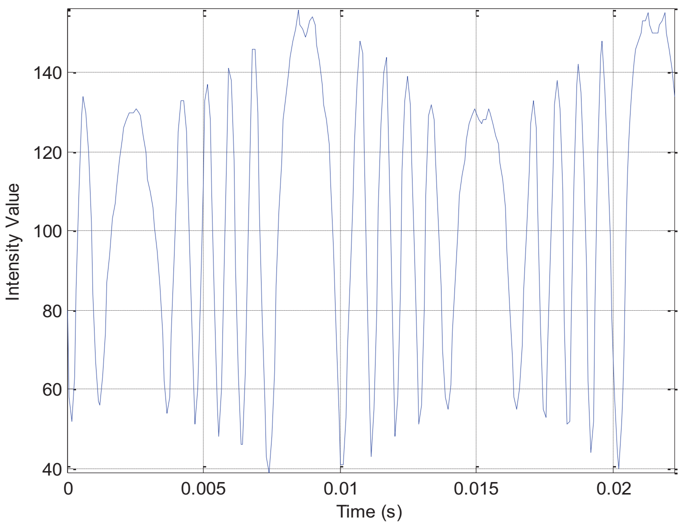


Figure (4): is representing relationship between 0-order intensity with capturing time.

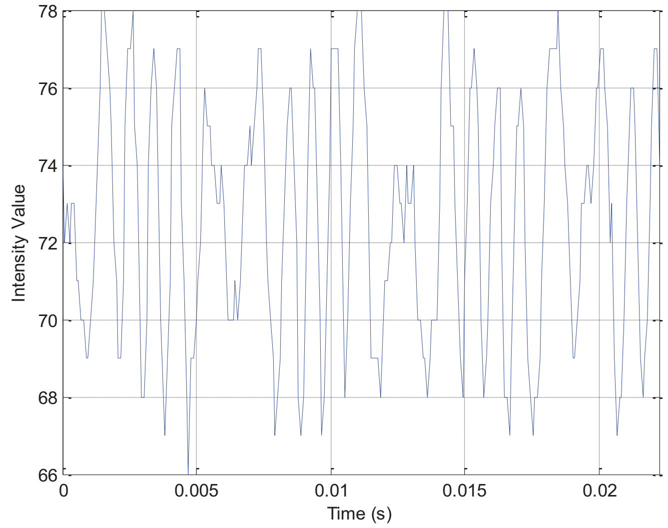


Figure (5): is representing relationship between 1st-order intensity with capturing time.

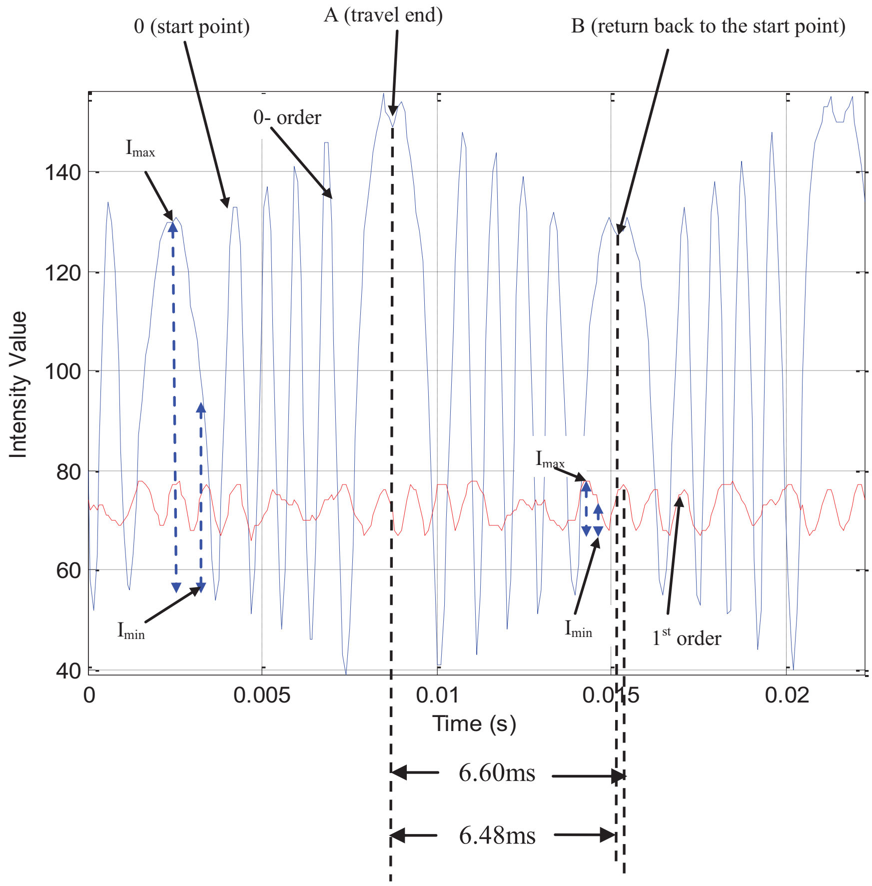


Figure (6): is representing the comparison for visibility between 0-order and 1st order respect to with capturing time.