Tang, Dawei, Gao, Feng and Jiang, Xiangqian

Cylindrical Lenses Based Spectral Domain Low-Coherence Interferometry for On-line Surface Inspection

Original Citation

Tang, Dawei, Gao, Feng and Jiang, Xiangqian (2014) Cylindrical Lenses Based Spectral Domain Low-Coherence Interferometry for On-line Surface Inspection. In: Euspen 14th International Conference & Exhibition, 2nd - 6th June 2014, Dubrovnik, Croatia.

Cylindrical Lenses Based Spectral Domain Low-Coherence Interferometry for On-line Surface Inspection

Dawei Tang, F. Gao, X. Jiang
School of Computing and Engineering, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK

x.jiang@hud.ac.uk

Keywords: Channelled spectral signals, cylindrical lenses, surface inspection

Abstract

This paper presents a spectral domain low-coherence interferometry (SD-LCI) method that is effective for applications in on-line surface inspection because it can obtain a surface profile in a single shot. It has an advantage over existing spectral interferometry techniques because it uses cylindrical lenses as the objective lens in a Michelson interferometric configuration to enable the measurement of long profiles. The adjustable profile length in our experimental setup, determined by the NA of the illuminating system and the aperture of cylindrical lenses, is up to 10 mm. To simulate real-time surface inspection, large-scale 3D surface measurement was carried out by translating the tested sample during the measurement procedure. Two step height surfaces were measured and the captured interferograms were analysed using a fast Fourier transform algorithm. Both 2D profile results and 3D surface maps closely align with the calibrated specifications given by the manufacturer.

1 Introduction

The rapidly developing industries such as MEMS, micro fluidics, photovoltaic thin film, Si wafers and hard disks critically rely on micro/nano scale and ultra-precision structured surfaces. In most cases these surfaces are evaluated with an expensive trial-and-error approach, which makes manufactured items suffer from scrap rates of as high as 50%-70% [1]. It is therefore a great challenge to measure these products quickly and easily within the manufacturing environment. Spectral domain low-coherence interferometry (SD-LCI) overcomes the 2π phase ambiguity problem by using broadband illumination. It takes advantage of spectral interference fringes for a wide range of wavelengths without any mechanical scanning as well as shows its potential application in performing on-line measurement with just one shot.

In this paper, a new spectral domain low-coherence interferometric technique aimed at long profile on-line surface measurement is presented. Instead of the microscope objectives used in current spectral interferometers, cylindrical lenses are employed to enable the measurement of long profiles. Two step height surfaces were measured with the experimental setup and the good results show that cylindrical lenses based SD-LCI has the potential to be used for on-line surface inspection.

2 Measurement principle

The white-light interferogram of the tested surface is captured by the CCD camera with the phase information encoded as a function of wavenumber along the chromaticity axis. The spectral intensity $I\ (h,\sigma)$ recorded at the output of the interferometer can be expressed as:

$$I\ (h,\sigma)\ = I_r + I_o + 2\sqrt{I_r I_o}\, cos(\varphi(h,\sigma)) \tag{1}$$

Where σ denotes the wavenumber $(1/\lambda)$, $I_r,\ I_o$ are the intensities reflected from the reference and tested surface. The phase $\varphi(h,\sigma)$ varies linearly with wavenumber σ.

In this paper an accurate fast Fourier transform (FFT) algorithm was developed to analyse the channelled spectral signals [2]. The point elevation can be expressed as:

$$h = \Delta\varphi/4\pi(\frac{1}{\lambda_m} - \frac{1}{\lambda_n}) \tag{2}$$

Where $\lambda_{m,}\lambda_n$ are the wavelengths corresponding to the phase difference $\Delta\varphi$.

3 Experimental setup and results

The experimental setup of cylindrical lenses based SD-LCI is shown in Figure 1. The tested surface is observed through a cylindrical lenses ($f' = 75$ mm) based Michelson interferometric objective and the spectral interferograms are eventually received by CCD camera (ICL-B0620). An iris diaphragm and a compressor objective are used to meet different requirements of the system's spatial resolution. By selecting a proper grating spacing and adjusting the positon of CCD camera, a desired waveband can be captured by considering the spectral curve of light source. For wavelength calibration, a white light laser source (WhiteLase™ micro) in conjunction with the acoustic-optical tunable filter (AOTF) is used. In our setup the wavenuber σ spreads along chromaticity axis in a range of 1.57 μm^{-1} 1.82 μm^{-1}. Additionally, the tested sample is fixed on a precision displacement stage allowing the lateral scanning to simulate on-line measurement.

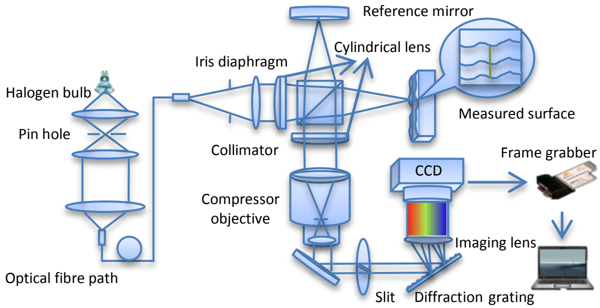
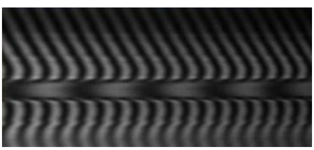
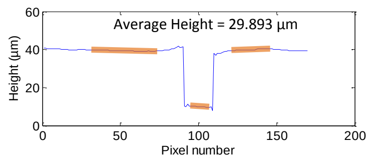


Figure 1: Setup of the cylindrical lenses based spectral domain low-coherence

Two step surfaces (with heights of 30 µm and 200 µm, respectively) made by Rubert & Co. Ltd. was measured with this SD-LCI setup. As shown in Figure 2 and Figure 3, the measured averarge heights are 29.893 µm and 199.229 µm, repectively. For the 200 µm step, there are some errors in the calculated 2D profile because the angle of sloped edge ($\theta > 45^{\circ}$) exceeds half of the apenture angle of the objective lens (3.81°). This is a limitation that exists in almost all interferometers and can be solved by rotating the interferometer to acquire the acceptable surface gradient. On the whole, both profile results closely align with the parameters calibrated by the manufacturer. By translating the tested sample at a speed of 0.5 mm/s, on-line measurement was simulated as well. Figure 4 shows 3D surface map of the 30 µm step. Taylor-Hobson CCI was used to measure the same step as compared with our setup. The calculated mean values of this step height are 29.964 µm and 29.859 µm corresponding to CCI and the proposed SD-LCI, respectively. Those two close results demonstrate that the proposed SD-LCI could be applied to production line like the R2R surface inspection, where only defects on the film surface are concerned in terms of the quality control.



(a)



(b)

Figure 2: Measurement Results (30 µm step): (a) interferogram, (b) 2D profile

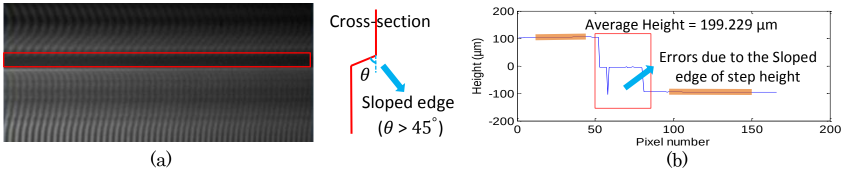


Figure 3: Measurement results (200 µm step): (a) interferogram, (b) 2D profile

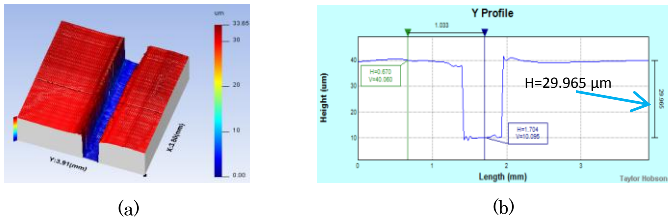


Figure 4: Surface results (30 µm step): (a) 3D surface map,(b) cross-sectional profile

4 Conclusions

A new Spectral Domain Low-Coherence Interferometric technique for long profile on-line surface inspection is proposed. Obtaining a surface profile in a single shot makes this setup minimise the effect of external perturbations and environmental noise when carrying out real-time measurement. The performance of the SD-LCI was evaluated by measuring two step surfaces and the obtained results closely align with the calibrated specifications given by the manufacturer as well as the measurement results by the other commercial instrument.

The authors gratefully acknowledge the UK's Engineering and Physical Sciences Research Council (EPSRC) funding of the First Grant (Grant Ref: EP/K007068/1) and the funding of EPSRC Centre for Innovative Manufacturing in Advanced Metrology (Grant Ref: EP/I033424/1).

References:

[1] Jiang, X., et al., Fast surface measurement using wavelength scanning interferometry with compensation of environmental noise. Applied Optics, 2010. 49(15): p. 2903-2909.

[2] Takeda, M., H. Ina, and S. Kobayashi, Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry. JosA, 1982. 72(1): p. 156-160.