Faculty of Engineering

PHASE MEASUREMENT METHOD USING INTERFEROMETRY TECHNIQUE

Lee Kean Yew

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Alamat tetap:	
27, JLN MARUDI 8, TMN BERINGIN,	IR. DR. MOHD SHAHRIL B. OSMAN
JINJANG UTARA, 52000 K.L.	Nama Penyelia
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Author : Lee Kean Yew

Matric No. : 12206

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b/p

Ir. Dr. Mohd Shahril b. Osman

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Date

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LEE KEAN YEW

This project is submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering with Honours
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To my beloved family, friends and all who has supported me.

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ABSTRAK

Terdapat banyak kaedah untuk mengesan dan mengukur permukaan sesuatu bahan. Salah satu kaedah adalah kaedah interferometri. Teknik ini diapplikasikan secara meluas kerana teknik ini merupakan satu kaedah tanpa-musnah dan tanpa-gangguan dimana tiada sebarang perubahan dan sentuhan dilakukan ke atas permukaan bahan tersebut. Kerja ini membentangkan pembinaan dan percubaan interferometer Michelson. Kaedah ini mengaplikasikan teknik optik dengan menggunakan laser He-Ne untuk menyinar sampel. Kaedah ini membolehkan beberapa parameter seperti deformasi, ketegangan, indeks pembiasan, dan profile permukaan diketahui. Interferometer Michelson dipilih kerana interferometer ini paling senang dibina dan sering digunakan. Laser digunakan untuk interferometer ini ialah He-Ne laser pada 632.8nm jarak gelombang. Superposisi wujud apabila laser daripada cermin dan spesimen terpantul dan bergabung. Superposisi laser tersebut, dikenali sebagai "fringes", ditangkap oleh Charged Coupled Device (CCD). Imej ini dikenali sebagai interferogram. Interferogram ini dimasukkan ke dalam perisian Franwin dan Matlab® dimana imej ini dianalisis. Kaedah yang digunakan adalah kaedah Fast Fourier Transform dan kaedah "three-frame". Keputusan daripada kedua-dua kaedah diilustrasikan dalam bentuk graf. Keputusan daripada kedua-dua kaedah tersebut dibandingkan. Daripada eksperiment ini, adalah diketahui bahawa kedua-dua teknik tersebut memberikan keputusan yang agak sama. Ini dibuktikan oleh kesamaan kecerunan dalam kedua-dua graf kaedah-kaedah tersebut.

ABSTRACT

There are many types of methods to detect and measure the surface of a material. One of these is an interferometry method. This technique is widely applied due to the fact that it is a non-destructive and non-intrusive method whereby it makes no changes and contacting work to the surface of the material. This work describes the construction and testing of the Michelson interferometer. The method employs an optical technique using He-Ne laser to illuminate the sample. This method enables various parameters such as deformation, strain, refractive index, and surface profile to be obtained. Michelson interferometer is chosen because it is the easiest and the most common type of interferometer. The laser used for the interferometer is the He-Ne laser at 632.8nm wavelength. Superposition occurred when the laser from the mirror and the specimen are reflected and recombined. The superposition of the lasers, known as fringes, is captured by a Charged Coupled Device (CCD). This image is known as interferogram. The interferogram is loaded into the Franwin and Matlab® softwares where the image is analyzed. The method employed is the Fast Fourier Transform method and the three-frame method. Both the results obtained are illustrated in graphs. The results from the two methods are then compared to. From the experiment conducted, it is known that both the method yield almost similar results. This is proved by the similarity of slope of the graphs from the two methods.

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NOMENCLATURE

AVT	-	Allied Vision Technologies
CCD	-	Charged Coupled Device
FFT	-	Fast Fourier Transform
He-Ne	-	Helium-Neon
TIFF	-	Tagged Image File Format
XPS	-	X-ray Photoelectron Spectroscopy
PZT	-	Piezoelectric Tranducer
f	-	Spatial frequency in the x-direction
f_o	-	Carrier frequency in the x-direction
$I_{n\theta}$	-	Intensity of the interference beam at a pixel in the interferogram
n	-	Integer
S	-	Distant between peaks of the fringe
X_i	-	Coordinate-X of i-th point
$\overline{X}$	-	Min value of coordinate-X
Y_i	-	Coordinate-Y of i-th point
$\overline{Y}$	-	Min value of coordinate-Y
σ	-	Standard deviation
α	-	Number of phase steps

λ	-	Light source wavelength
Δ	-	Deviation of the straightness of the fringe image
θ	-	Phase step
$a(x,y)$	-	Speckle or background noise
$b(x,y)$	-	Modulation noise
$\mathrm{cov}(x,y)$	-	Covariance
$\phi(x,y)$	-	Phase information of interest
$\Im[c(x,y)]$	-	Imaginary components of $c(x,y)$
$\Re[c(x,y)]$	-	Real components of $c(x,y)$
$I_n(x,y)$	-	The n-th interferogram
ϕ	-	Phase shift angle (in radian)

CHAPTER 1

INTRODUCTION

1.1 Introduction

The measurement of profiles or surface defects of materials is currently employed in many applications. This is implemented especially in the hard disk industries, the optical lens industries and many more.

In the hard disk and optical lens industries, smoothness of the materials is very important. This is because defects greatly affect the performance of the materials and products. Defects also reduce hard disk capacity and data storage ability.

Currently, there are many tools in which profile or surface defects can be detected. This includes 3D scanning, designing through 3D software, X-ray Photoelectron Spectroscopy (XPS) and interferometry technique.

This project is intended to set up a hard disk platters profiles or surface defects measurement interferometer that utilized a laser beam. The interferometer will be able to detect and compute the depth of the small defects on the hard disk platters.

Interferometer is a device that employs the principle of light interference to create images of a material. These images known as fringe patterns will be used to calculate the desired surface information.

In this project, the design and construction of the interferometer is based on the principle of Michelson interferometer. Michelson interferometer is selected because it has the simplest design and is the easiest to construct.

A highly sensitive high-quality CCD camera is employed to capture the generated fringe patterns. The fringe patterns captured is known as interferogram. The interferogram is further analyzed by using the three-frame method or phase shifted by using Fast Fourier Transform method. Franwin software is used in the computation of both the three-frame method and the Fast Fourier Transform method. The results are further analyzed in Matlab® software which will display the results in the form of graphs. This can greatly reduce the computational time compare to calculating manually.

To determine the surface defects, a hard disk platter is used as the test piece. It is used to verify the accuracy, repeatability and variation of the interferometry system. A collection of data gathered is used to evaluate the surface measurement system.

It is hope that a small and portable surface measurement system can be design and fabricated. This would enable the equipment to be installed in the manufacturing floor or even in the laboratory for testing purposes.

1.2 Objectives of the Project

This project focused on a few primary objectives. One of the objectives is to construct an interferometer. The interferometer constructed in this experiment is based on the Michelson interferometer. This interferometer can be used to determine the surface profile of the hard disk platters.

The second objective is to implement the Fast Fourier Transform method in the computation and analysis of the interferogram obtained. This can be achieved with the use of Franwin software.

The third objective is to implement the three-frame method in the computation and analysis of another set of interferograms obtained using the same method. This is also completed with the use of Franwin software.

Last but not least is to compare both the Fast Fourier Transform (FFT) method and the three-frame method. These results of the two methods are compared to check the difference of both methods and to validate their accuracy.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The technique used in interferometry and its fringe pattern analysis has been traced back to as early as 1800s. During that period, this technique can only be performed manually by hand. This technique proved to be erroneous and unreliable as the outcomes greatly depend on the interpreter's expertise and knowledge. Usually, measuring and counting the recorded interferogram or fringe pattern in a photograph is used in the technique [1][2].

Interferogram is the recorded interference signal that occurred between two light beams. Usually, interferogram is modeled as the interference between two sinusoidal wave with one of the signal been phased shifted. Information that can be obtained from the interferogram are the phase, the spectral content of the source and its spatial distribution [2][3].

This technique evolved in the seventies with the introduction of powerful and low cost computer and the development of the Charge Coupled Device (CCD). The evolution leads to the automation of the fringe pattern analysis. Thus, interferometry technique becomes a reliable and accurate method in metrology [1]. It is known that interferometry techniques were used in application such as head-disk spacing measurement [4], contouring aspheric surfaces [5], surface roughness measurement [6], surface topography measurement [7], large deformation measurement [8], microscopic displacement measurement [9][10][11][12][13], surface profiling [14][15][16][17][18], straightness measurement [19], length measurement [20], vibration [21] and etc.

In this chapter, the review of the classical fringe pattern analysis techniques is described in section 2.2. This is followed by the elaboration of current fringe pattern analysis methods. The current methods of fringe pattern analysis include the phase stepping and Fourier Transform.

Phase stepping will be reviewed in detail in section 2.3. The theory of phase shifting and the techniques used are included in section 2.4 and 2.5 respectively. Fourier Transform is described in section 2.6.

The last section in this chapter is the section on the subject of interferometer. This is described in section 2.7. Type of interferometers and some brief descriptions are revealed to provide some information and idea about interferometers.

2.2 Classical Fringe Analysis Technique

The classical fringe analysis technique presented in this section is to provide a brief introduction to fringe analysis before further elaboration on this subject in the following section. This is aims to provide a better understanding and appreciation of the recent fringe analysis technique developed, such as the phase shifting technique and the Fourier transform technique [43].

In the classical method, interferogram is used to analyze the amount of deviation from the theoretical fringe location. The fringe is measured in the amount of deviation from the supposed straightness. Based on this deviation, the surface height error can be calculated. The surface height error is given by [22][43]:

$$\textit{Surface height error} = \left(\frac{\lambda}{2}\right)\left[\frac{\Delta(x,y)}{S}\right] \tag{1}$$

where λ is the wavelength of the light source and Δ is the deviation of the straightness of the fringe image at the coordinate of (x,y). S is the distant between peaks of the fringe. This is shown in Figure 2.1.

This method is tedious and erroneous as it involves the peak to the valley measurement. Thus, the interpretation can be wrong if compare to the actual condition of the surface [22].

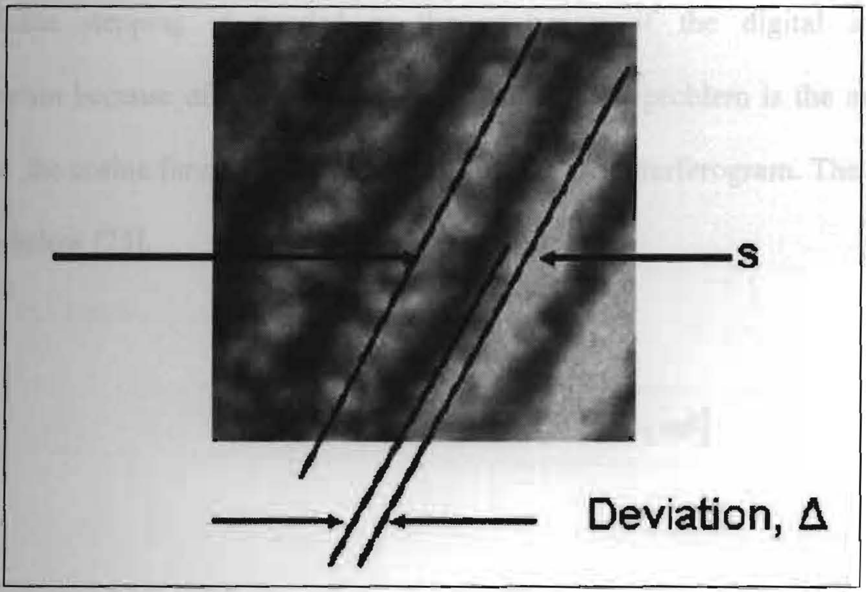

Figure 2.1: Measurement in classical fringe analysis [22]

2.3 Phase Shifting or Phase Stepping

The phase stepping method was originally founded by Brunning et. al. in year 1974 [1]. He used a CCD array to analyze a waveform by capturing the phase map of an optical component. This method thus becomes the most widely used technique to detect the modulating phase of interferogram [23][24].

This technique becomes vastly used because of the development in several fields that directly affected it; namely the usage of piezoelectric transducer (PZT), the advancement in CCD image capturing technology and the enhancement in the performance of personal computer.

The concept of this technique is to capture the phase step in the form of digital images in series. These images must be captured either over a fixed amount of time or with a known amount of spatial shift via CCD. The images are then stored in the personal computer to be analyzed.

Phase stepping is needed in the analyzing of the digital image or interferogram because of the inherent problem in it. The problem is the ambiguity caused by the cosine function that forms the basis of the interferogram. The function is shown below [25].

$$I_{n\theta} = a(x,y) + b(x,y)\cos[\phi(x,y) + n\theta] \tag{2}$$

where $I_{n\theta}$ is the intensity of the interference beam at a pixel in the interferogram, $a(x,y)$ is the speckle noise, $b(x,y)$ is the modulation noise, θ is the phase step, $\phi(x,y)$ refers to the phase information of interest and n is the integer.

It is known that $\cos(x)$ is mathematically equivalent to $\cos(-x)$. Thus, the fringe cannot be differentiated from a $\cos(x)$ or a $\cos(-x)$ in the dark or bright fringe. This means that it is impossible to mathematically tell whether a fringe is a peak or a valley without having the knowledge in advance. So, it is impossible to obtain a unique phrase distribution from a single fringe method [3].

There are many solutions to this ambiguity problem. One of them is to integrate the phase stepping method in interferometry. Phase stepping method has gone through many extensive researches. These researches eventually lead to the creation of many different methods of phase stepping. These methods have their own advantages and disadvantages. Some of the studies carried out are such as the three-frame method [26], the four-frame method [26][27], and the five-frame method [27][28].