Results in Physics 11 (2018) 182–187

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.elsevier.com/locate/rinp

Development of Digital Holographic Microscopy by reflection for analysis of surface

Meylí Valin Fernández[a,*], Edison Gonçalves[b], José Luis Valin Rivera[a], J. Ricardo[c], Maria Elena Fernández Abreu[d], Mário Augusto Pires Vaz[e]

[a] Pontificia Universidad Católica de Valparaíso, Escuela de Ingeniería Mecánica, Valparaíso, Chile
[b] Departamento de Mecatrônica e Sistemas Mecânicos, Escola Politécnica da Universidade de São Paulo USP, São Paulo, SP, Brazil
[c] Departamento de Física, Facultad de Ciencias Naturales y Exactas, Universidad de Oriente, Santiago de Cuba, Cuba
[d] Departamento de Contrucción de Maquinárias, Facultad de Ingeniería Mecánica, Universidad Tecnológica de La Habana "José Antonio Echeverría" (CUJAE), La Habana, Cuba
[e] Departamento de Engenharia Mecânica da Universidade do Porto, Portugal

ARTICLE INFO

Keywords:
Digital holography
Digital Holographic Microscopy
Surface profile

ABSTRACT

A methodology based on the DHM of reflection using a Michelson micro interferometer scheme is used here for dimensional controlling objects and for determining the surface profile of steel samples. To reconstruct phase contrast distribution images, numerical techniques are used that enable Digital Holographic Microscopy to suppress zero order, pixel resolution control, optical phase unwrapping, intensity and phase mapping, filter and compensation of optical system aberrations that influence the quality of the image. The numerical reconstruction of the images is conducted using the double propagation algorithm. The program used allows quantitative measurements of the dimensions of objects and the surface profile of the samples, as well as the 3D representation of the reconstructed phase image. The results from DHM are validated by comparison with those from a non-contact 3D profilometer model CCI-MP.

Introduction

Initial considerations

Some of the characteristic of the Digital Holography are the direct access to the information of the phase from the reconstructed amplitude optical field, the numerical correction of the optical aberrations and the refocusing capacity from a single hologram. These characteristics are optimal for solving various measurement problems in science and technology, such as the inspection and characterization of mechanical systems [1,2]. Applications of Digital Holographic Microscopy (DHM) for measurements and optical characterization are discussed by [3], as well as their basic principles. It is used for studying and analyzing several areas of knowledge [4,5]. Digital Holographic Microscopy (DHM) is one of the best non-invasive methods for its ability to give information about the entirety of an object by investigating its image [6,7] in a single measurement.

The resolution for transmission thickness measurements depends on the refractive index of the sample, with a resolution of approximately 30 nm in height and approximately half a micron in lateral resolution using a high numerical aperture [8]. Using reflection, this problem does not affect the measurements to determine some parameters such as surface contour [9,10].

Digital Holographic Microscopy (DHM) has been considered one of the best non-invasive assays and metrological tools [7]. An application of the (DHM) takes place in biology for the transmission of phase contrast of living cells in culture [8].

Contemporary publications on digital holographic metrology and microscopy have emerged. Goodman and Lauren were the first to use a computer to reconstruct a hologram. The diffraction of the zero order and its two conjugated images overlap in the configuration [9,10].

This paper presents a methodology to determine the profile surface of relatively large steel samples through digital holographic microscopy using an experimental configuration by reflection, based on a Michelson interferometer. This problem was partially treated by our Digital Holography group, using samples Magnification Objects (OM) with high magnification, in the order of 40–60 x [11], focused on the measurement of the error of the phase, analysis of specific cases and

* Corresponding author.
E-mail addresses: meyli80@gmail.com, meyli80@usp.br (M.V. Fernández), edison@usp.br (E. Gonçalves), jose.valin@pucv.cl (J.L.V. Rivera), mary@mecanica.cujae.edu.cu (M.E.F. Abreu), gmavaz@fe.up.pt (M.A.P. Vaz).

https://doi.org/10.1016/j.rinp.2018.08.050
Received 27 June 2018; Received in revised form 25 August 2018; Accepted 27 August 2018
Available online 01 September 2018

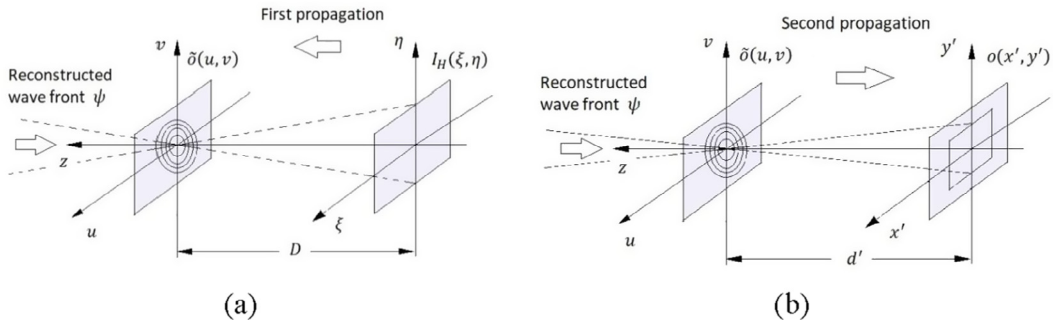

Fig. 1. (a) Reconstruction of the distribution wave $\bar{o}(u, v)$ in plane (u−v) with a distance $z = D$ (first spread); (b) Reconstruction of optical wavefront $o(x', y'; d')$ in the image plane from plane $(u-v)$ (second propagation).

dimensional control [12,13]. The aim of this work is to study large objects and to determine the profile of their surface.

Double propagation method

The double propagation algorithm was used for reconstructing the phase image [14]. When applying this algorithm, the field is reconstructed in the back focal plane of the objective or Fourier plane located at a distance z = D from the plane of the hologram, in which a pass-band filtering is performed and this filtered field propagates to image plane (x′−y′), managing to rebuild $\psi(x'-y')$, as in Fig. 2, [14]. The reconstruction of the complex wave of distribution $o(x', y') = \psi(x', y'; z= d')$ consists of two stages involving two fronts of propagation waves. In the first stage, Fig. 1 (a), the distribution of the wave front in the reconstruction plane is reconstructed with a distance z = D (first propagation).

The first propagation is carried out by means of the Fresnel approximation method, through the Simple Fourier Transform SFTF.

$$\psi_{SFTF}(u, v; z) = Aexp\left[\frac{i\pi}{\lambda z}(u^2 + v^2)\right]\Im\left\{I_H(\xi, \eta)exp\left[\frac{i\pi}{\lambda z}(\xi^2 + \eta^2)\right]\right\} \quad (1)$$

where z is the reconstruction distance, $\Im$ an operator denoting the Fourier Transform, $A = \exp(i2\pi z/\lambda)/(i\pi\lambda)$ and considering the wave of the reference plane with a unit force perpendicular to the plane of recording. The filtered complex wave field can be expressed by Eq. (2) substituting hologram $I_H(\xi, \eta)$ with hologram $I_H I_H^f(\xi, \eta) = RO$ containing only the spatial components of the real image [15].

$$\Psi^f_{SFTF}(u, v; z = D) = exp\left[\frac{i\pi}{\lambda z}(u^2 + v^2)\right]\Im\left\{I^f_H(\xi, \eta)exp\left[\frac{i\pi}{\lambda z}(\xi^2 + \eta^2)\right]\right\} \quad (2)$$

Complex field Ψ^f_{SFTF} is equivalent to the distribution with complex field $\bar{o}(u, v)$ in the back focal plane of the objective lens (3).

$$\Psi^f_{SFTF}(u, v; z = D) \cong \bar{o}(u, v) = S_{\varnothing}(u, v)\Im[o(x_0, y_0, \lambda f)] \quad (3)$$

where $\Im[o(x_0, y_0, \lambda f)]$ is the Fourier Transform of the distribution of the object wave in plane with $o(x_0, y_0)$, the amplitude of the object transmittance.

All the information about the wave field of the image in the plane of the hologram is contained in the complex wave front $o(u, v)$ in the back focal plane. For that reason, optical wave field $o(x', y'; d')$ can be reconstructed from plane , instead of the traditionally flat hologram (ξ, η). The corresponding phase for each pixel of the image is calculated from (4).

$$\psi(m, n; d') = FFT^{-1}\left\{\psi^f_{SFTF}(l, j; =D) \times \exp\left[2\pi i d'\sqrt{\left(\frac{1}{\lambda}\right)^2 + \left(\frac{l}{N\Delta\xi}\right)^2 + \left(\frac{j}{M\Delta\eta}\right)^2}\right]\right\} \quad (4)$$

Materials and methods

Experimental setup

The experimental scheme used to capture the holograms shown in Fig. 2 consists of an Excelsior laser 532 nm of 150 mW, neutral attenuator (A), spatial filter Melles Griot (FE), diaphragm (D), corrective lens of parallelism (L), capacitor (C), beam splitter (BS), an objective lens (OL) 3× with infinite correction, object (O) which is the metal sample, lens (L) to correct the focus and the CCD for the object channel. The reference beam is formed by the reflecting mirror (M), the polarizer (P) and again the BS. Both beams arrive at the CCD and the interference pattern (Hologram) is formed. The intensities of the beams are controlled by the polarizer (P) and by the attenuator (A).

Ten samples of 1010 steel according to the AISI-SAE standard were used for analyzing the surface roughness, in the form of a cylinder with a diameter of 20 mm embedded in resin. These samples went through a process of abrasive grinding with sandpapers of different grain size or cloth according to Table 1.

The polishing was performed with special cloths and small amounts of abrasive diamond paste with grain sizes of 6, 3, 1 μm, respectively. During this process, the sample is refrigerated with the use of alcohol. For each of the 1010 steel samples, three (3) regions were randomly chosen to perform the surface roughness measurements. In each of these regions three, (3) holograms were captured and stored for later reconstructing the phase image.

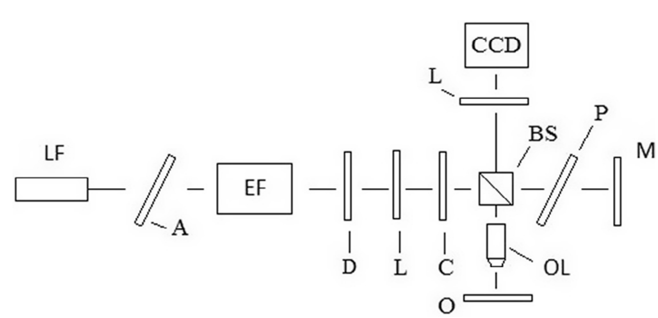

Fig. 2. Experimental Setup.