Optik 140 (2017) 304–307

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Calibration of photoelastic modulator using direct current component

Liyuan Gu [a,b], Jian Wang [a,b], Linglin Zhu [a], Jing Zhu [a], Aijun Zeng [a,b,*], Huijie Huang [a,b]

[a] Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
[b] University of Chinese Academy of Sciences, Beijing 10049, china

ARTICLE INFO

Article history:
Received 26 January 2017
Accepted 16 April 2017

Keywords:
Peak retardation
Photoelastic modulator
Wollaston prism

ABSTRACT

A method of calibrating the photoelastic modulator (PEM) using direct current component is proposed. The laser beam passes through a polarizer, the PEM to be calibrated and is then split into two sub-beams by a Wollaston prism. The two sub-beams are then detected by two detectors. The small peak retardation is independent of the fluctuation of the initial intensity. The calibration setup is compact. In experiments, a PEM was calibrated and the calibration error was less than 0.008 rad when the peak retardation changed in the range of 0.1λ–0.5λ.

1. Introduction

Photoelastic modulator (PEM), using isotropic optical material and operating at the resonant frequency, is a phase modulator based on the photoelastic effect. It has many unique optical properties, such as high modulation purity and efficiency, good retardation stability, broad spectral range, large acceptance angle and useful aperture, relatively high modulation frequency, high power handling capability and low power consumption [1–3]. The PEM is widely applied in cases like the measurement of linear birefringence, the phase shifting interferometry, the reflection adsorption spectroscopy and the polarimetric remote sensing [4–9].

First of all, the PEM needs to be calibrated. Several methods to calibrate the PEM have been presented. They are the oscilloscope waveform method, the Bessel function zero method and the first Bessel function maximum method [10–12]. The oscilloscope waveform method uses half-wave peak retardation (3.142 rad) to form a flat topper waveform. In Bessel function zero method, the PEM is calibrated with zero values of the zeroth Bessel function, the first Bessel function and the second Bessel function when the peak retardation is set at 2.405 rad, 3.872 rad and 5.136 rad, respectively. For the first Bessel function maximum method, the first Bessel function gets maximum value to coarsely determine the peak retardation at 1.841 rad and then the zeroth and second Bessel functions are obtained to finely calibrate the PEM around 1.841 rad. In the methods mentioned above, the PEM is calibrated with the peak retardations larger than 1.841 rad. Thus these methods are not suitable to calibrate the PEM with small peak retardation. In the atomic collision setup with a weak signal and the ellipsometry using data acquisition system, the PEM can be calibrated under any peak retardation with the single photon-counting method [13] and the multiple-harmonic intensity ratio method [14], respectively. But these two methods require complex setup and operating process.

* Corresponding author at: Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China.
E-mail addresses: aijunzeng@siom.ac.cn, aijunzeng@163.com (A. Zeng).

http://dx.doi.org/10.1016/j.ijleo.2017.04.067
0030-4026/

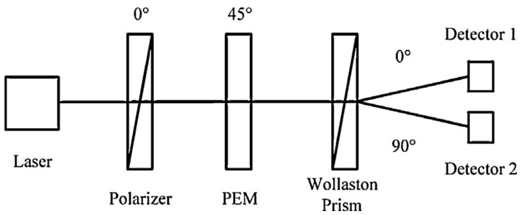

Fig. 1. Schematic diagram of calibrating PEM using direct current component.

In this paper, a method to calibrate the PEM using direct current component with compact calibration setup and operating process is proposed. Two direct current terms are obtained to calculate the value of the zeroth Bessel function directly. Then the peak retardation of the PEM is resolved at a small value with monotone decreasing property of the zeroth Bessel function.

2. Principle

The schematic diagram of calibrating the PEM using direct current component is illustrated in Fig. 1. The laser beam passes through a polarizer and the PEM to be calibrated. It is then split into two sub-beams by a Wollaston prism. The modulation axis of the PEM is oriented at 45°, relevant to the transmission axis of the polarizer. The two polarization axes of the Wollaston prism are parallel and perpendicular to transmission axis of the polarizer, respectively. The two measured sub-beams are then detected by detector 1 and detector 2. The two detectors share the same frequency response and circuit parameters. Signals from detector 1 and detector 2 are then filtered to obtain their direct current terms. By processing the two direct current terms, the value of the zeroth Bessel function can be calculated. With the measured value of the zeroth Bessel function, the peak retardation can be resolved and the PEM can be calibrated.

The beam emitted from the polarizer becomes linearly polarized light. Its Jones vector can be written as

$$E_0 = \sqrt{I_0}\begin{bmatrix}1\\0\end{bmatrix}, \tag{1}$$

Where I_0 is the initial intensity of the laser beam after the polarizer. The Jones matrix of the PEM is presented by

$$G_M = \begin{bmatrix}\cos\frac{\delta}{2} & i\sin\frac{\delta}{2}\\ i\sin\frac{\delta}{2} & \cos\frac{\delta}{2}\end{bmatrix}, \tag{2}$$

The phase retardation δ of the PEM is given by

$$\delta = \delta_0 \sin(\omega t), \tag{3}$$

Where δ_0 is the peak retardation, ω the modulation frequency. The Wollaston prism analyzes the measured beam with two transmission axes. The two Jones matrices of the Wollaston prism can be respectively shown as

$$G_{W1} = \begin{bmatrix}1 & 0\\0 & 0\end{bmatrix}, \tag{4}$$

$$G_{W2} = \begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}. \tag{5}$$

The two measured sub-beams emitted from the Wollaston prism can be expressed respectively as

$$E_1 = G_{W1}G_M E_0 = \sqrt{I_0}\begin{bmatrix}\cos\frac{\delta}{2}\\0\end{bmatrix}, \tag{6}$$

$$E_2 = G_{W2}G_M E_0 = \sqrt{I_0}\begin{bmatrix}0\\ i\sin\frac{\delta}{2}\end{bmatrix}. \tag{7}$$

After multiplying the Jones vector and its conjugate transposed matrix, the intensities of the two measured sub-beams are calculated as following

$$I_1 = E_1 \cdot E_1^* = I_0(1+\cos\delta)/2, \tag{8}$$

$$I_2 = E_2 \cdot E_2^* = I_0(1-\cos\delta)/2, \tag{9}$$