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Measurement of phase shift of LC retarder using Michelson interferometer with linear photodiode array detector

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Abstract

A computer controlled high resolution phase shift measurement system, which can achieve a measurement uncertainty of less than 0.5°, has been developed. This system is based on a Michelson interferometer with a linear photodiode array detector. It was used to measure the curve of phase shift of a LC retarder versus driving voltage; results with high accuracy were obtained. This system can also be used in the micro-displacement measurement, and the measurement uncertainty is in the sub nanometer level.

1. Introduction

Michelson interferometer has broad applications. Normally, the Michelson interferometers use a screen target or a single pixel photo-electric as detectors, and the phase shift is determined by counting the number of emerging fringes. Nowadays, the linear photodiode array (LPDA) detector is widely used in spectrometers, high resolution LPDA can be obtained at low cost. Using LPDA as the detector in the Michelson interferometer to monitor the phase shifting of the interference fringe, measurement of phase shift with high accuracy may be achieved. Here we present a computer controlled high resolution phase shift measurement system based on a Michelson interferometer with LPDA as detector. This system makes use of common instruments in laboratory, such as oscilloscope, function generator, GPIB communication port, computer etc., they are made to work together like a virtual instrument through a self developed program. This measurement system was successfully applied in the measurement of the curve of phase shift versus driving voltage of a LC retarder, which is critical in the fabrication and characterization of various kinds of LC retarder, for example, the LC spiral phase plate we developed [1].

2. Working principle

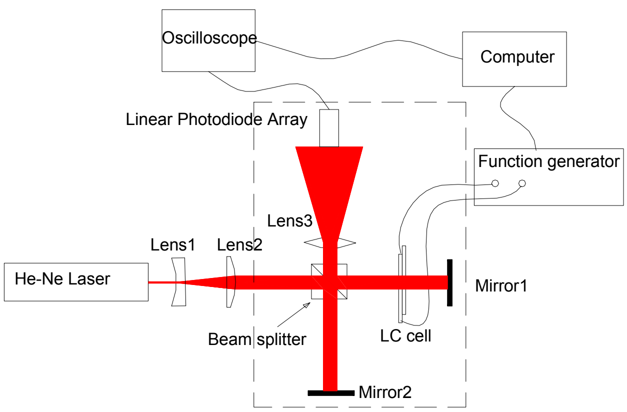


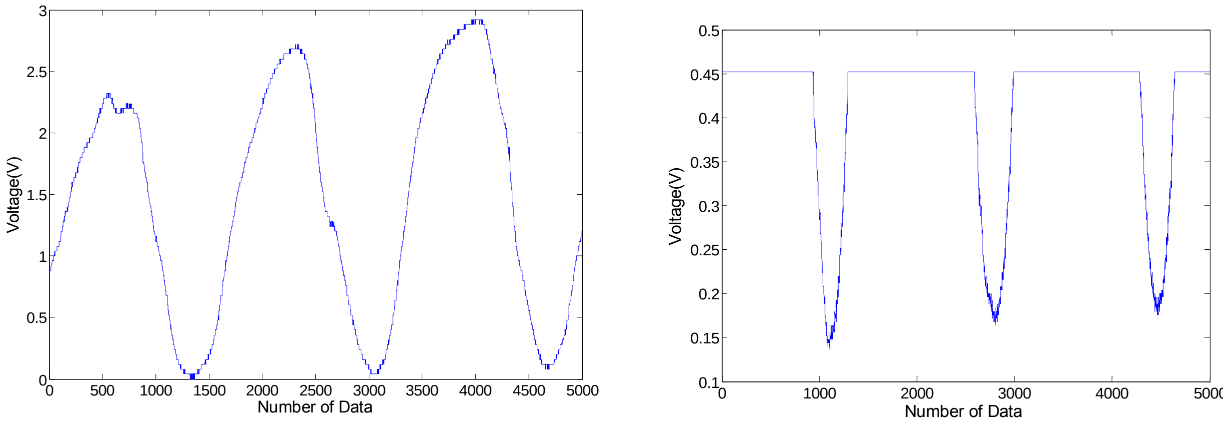
Figure 1: Setup of the measurement system. The dashed line enclosed area is covered with a cardboard box to reduce the atmosphere perturbation.

The system setup is schematically shown in Figure 1. The linearly polarized laser beam (632.8nm wavelength) emitted from a 4mW He-Ne laser is collimated to a beam of 6 mm in diameter by a beam expander. The unti-parallel rubbed LC cell is positioned in such a way that its rubbing direction is parallel to the polarization of the laser beam. The LC cell is driven by a function generator. The lens 3 is used to magnify the beam, so that only the central part of the beam is detected by LPDA; this corresponds to an area of 1mm in diameter on the LC cell. It helps to obtaining a uniform interference fringe to be detected by LPDA.

The software for the measurement system is composed of two parts, the first part, which is written in Visual Basic, is for the operation control of the measurement, including the oscilloscope parameter setting and waveform data acquisition. The second part, which is written in Matlab, is dedicated to data processing.

The typical waveform acquired from LPDA is shown in Figure 2(a). The waveform is actually consisted of many steps, which is due to the resolution limitation of the oscilloscope (the resolution of the oscilloscope is 10 bit). As trough positions are used as the reference points for determining the position of the waveform, these steps prevent the positions to be precisely determined. To overcome this problem, the vertical sensitivity of the oscilloscope is increased from 500mV/div to 50mV/div. Figure 2 (b) shows the waveform after increasing the vertical sensitivity. It has been experimentally proved that the trough position can be much more precisely determined in the later case.

Since the bottom of the trough tents to be affected by some noise, a simple yet effective method is adopted in the data processing. As shown in Figure 3, by finding the positions of a, a', b, b', c, c', d, d', e, e', the tough position can be precisely determined as $\left[(a'-a)+(b'-b)+(c'-c)+(d'-d)+(e'-e)\right]/5$.



(a) (b)

Figure 2: (a). Waveform acquired with oscilloscope vertical sensitivity of 500mV/div;
(b). Waveform acquired with oscilloscope vertical sensitivity of 50mV/div;

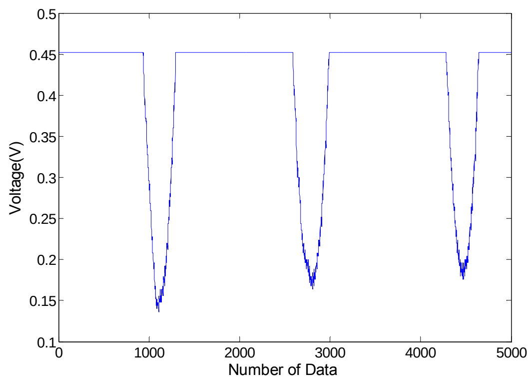


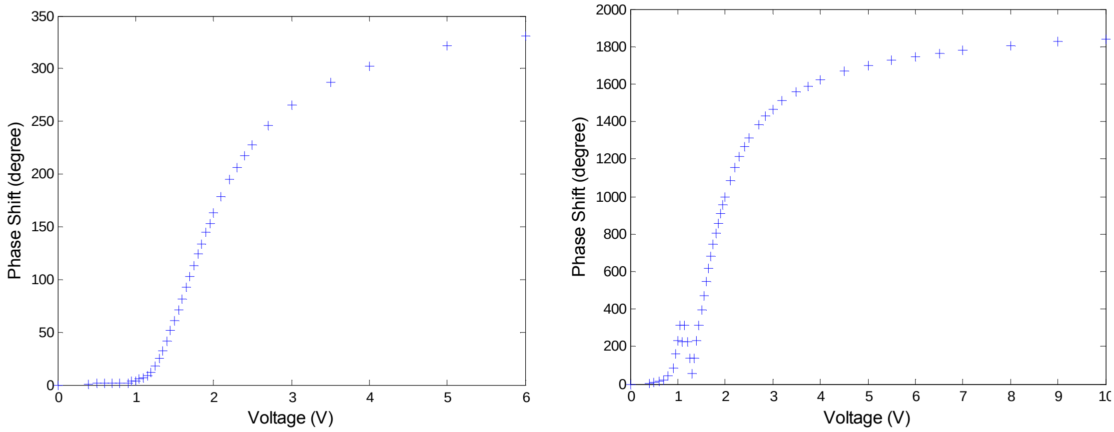
Figure 3: The trough position is determined by $\left[(a'-a)+(b'-b)+(c'-c)+(d'-d)+(e'-e)\right]/5$.

So long as the trough positions are determined, the pitch of the interference fringe can be determined by the offset between any two adjacent trough positions. The pitch of the fringe, which is needed in the calculation of the phase shift, is the mean value of pitches data calculated from all the trough positions. If the data acquired are accurate, the standard deviation of these values should be small.

The phase shift (in degree unit) between two waveforms can be obtained by $\frac{\Delta d}{p} \times 180^{\circ}$, where Δd represents the position shift between two waveforms; p is the pitch of the interference fringe.

3. Results

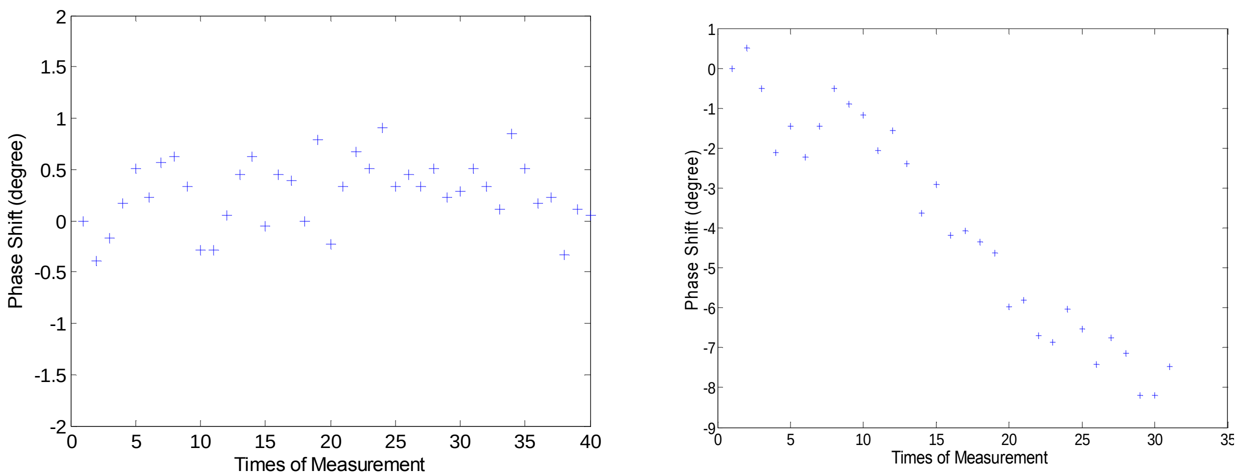
The curves of phase shift versus driving voltage for liquid crystal retarders with cell gaps of 6μm and 20μm, respectively, were measured by this system. The results are shown in Figure 4(a) and Figure 4(b), respectively. The time needed for the measurement depends on the data acquisition speed and the response time of LC cell. Since GPIB communication port is employed for the waveform acquisition, the time needed for each data acquisition is about 200ms.



(a) (b)

Figure 4: (a). Phase shift versus driving voltage measured for LC cell with 6μm cell gap.
(b). Phase shift versus driving voltage measured for LC cell with 20μm cell gap.

To estimate the uncertainty of the measurement system, the LC cell shown in Figure 1 is removed. 40 times of measurements are carried out during a period of 10 seconds. The results are shown in Figure 5(a); the uncertainty (standard deviation) is 0.35°. This uncertainty is mainly caused by vibration, and it can be further reduced by using the average value of multi-times of acquisition.



(a) (b)

Figure 5: Measurements with the LC cell shown in Figure 1 removed. (a) Results of 40 times of measurement during an interval of 10 seconds (b) Results of the measurements conducted every 30 seconds.

However, if the measurement lasts for minutes, the measurement uncertainty will be affected by the fringe drift problem, which is commonly encountered in using Michelson interferometer. The drift is mainly caused by the temperature fluctuation. The coefficient of linear thermal expansion of steel is $1.3 \times 10^{-5} / k$. Assuming the length of the arm of Michelson interferometer is 10 cm, if there is a temperature difference of 0.01º between two arms of the Michelson interferometer, the length difference between the two arms would be 0.013 µm, which corresponds to a phase shift of 14.8º for a 632.8 nm wavelength beam. It can be seen that the system is very sensitive to temperature changing. As this system is positioned in a normal air-conditioned room, the temperature is not strictly controlled; there is still a noticeable drift caused by the fluctuation of temperature. Figure 5(b) shows the measurement results during a period of 15 minutes. According to the results, the mean drift speed during the 15 minutes is 0.25° per half minute, and the standard deviation of the drift speed within half minute is 0.77°. After many runs of experiment, it was found that the drift speed was not quite regular, but in most of the time, it was below 2.5° per minute.

4. Conclusions

A computer controlled high resolution Michelson interferometer measurement system, which can achieve a measurement uncertainty of less than 0.5º, has been developed. It was applied in the measurement of optical phase shift versus driving voltage of LC retarder, and results with high accuracy were obtained. Comparing with other methods in the measurement of phase shift [2~4], this measurement system has advantages of high accuracy, cost effective, no moving parts, applicable to homogeneous material and unaffected by the absorption anisotropy of birefringence material. If system is put into a thermal isolated vacuum chamber, the measurement accuracy could be further improved. It may find applications in the situation when extreme high accuracy is desired, for example, in the measurement of the displacement of piezo actuator.

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