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A Study on Performance Effects of Standard and Stabilized He-Ne Lasers in an Interferometric Measurement System

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Stabilized He-Ne lasers are commonly utilized in interferometric systems, and provide easy and accurate results. The main reason for their extensive use is their output beam's strength and stability. However, these are relatively high in cost. In interferometric measurement systems, standard He-Ne lasers can also be used. This type of lasers has a lower cost, but their output beam strength can fluctuate in time. And this in turn adversely affects the measurement performance. In this study, a standard He-Ne and a stabilized He-Ne lasers were used in the same measurement system. The measurement errors caused by the fluctuation of the output beam of the standard He-Ne laser are minimized by using a video processing technique. When the obtained results were compared with the ideal values, the relative error for the system with the stabilized He-Ne laser was recorded as 0.2%, while for the system with the standard He-Ne laser a relative error rate of 0.3% was achieved. When the results are analyzed, it is evident that in measurement systems with a standard He-Ne laser, the system performance can be boosted with a video processing technique, and that its results can achieve values closer to the performance of stabilized He-Ne lasers.

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1. Introduction

Interferometric systems play an important role in measuring the extent of displacement [1, 2]. With this system, nanometer and smaller displacements can be measured precisely [3, 4]. Furthermore, since the measurement is performed with a laser beam, a contact free measurement can be achieved [5]. In addition to all these advantages, it is important that the laser used has a fixed frequency and fixed beam amplitude, to ensure the required measurement accuracy. The research shows that the frequency and amplitude noises have an instability effect on interferometric measurements [6]. In interferometric systems, studies prove that ensuring stabilization increases the measurement accuracy and sensitivity [7, 8]. In stabilized He-Ne lasers, beam fluctuations as well as frequency deviations are much lower than in standard He-Ne lasers. However, a stabilized He-Ne laser is more costly than a typical He-Ne laser [9].

This study aims to compare the performances of a standard and a stabilized He-Ne laser in an interferometric measurement system, and to eliminate the disadvantages caused by the fluctuation of the beam amplitude in a standard He-Ne laser in addition to approximating the measurement performance of a standard He-Ne laser to that of a stabilized one. The signals obtained from the measurement results were processed and analyzed with the developed software. The varying beam amplitudes of the standard He-Ne laser were then fixed by thresholding. Furthermore, the adverse effects of frequency shifts that might occur during measurement were eliminated in the decision block of the software. Thus, measurement errors arising from the use of standard He-Ne lasers were reduced and the performance of the stabilized He-Ne laser was emulated.

2. Experimental setup

The displacement measurement system used in this study consists of three main parts, such as interferometric system, video camera and a computer. As the interferometric system, the Michelson interferometer was chosen due to its simple structure and its popularity in terms of the results it provides. A diagram for the operation principle of Michelson interferometer is shown in Fig. 1.

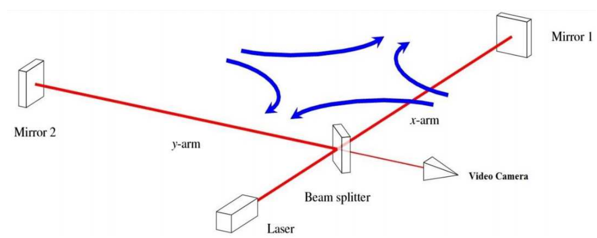

Fig. 1. Operation principle of Michelson interferometer.

The beam from the laser beam source in the Michelson interferometer is separated into x and y arms in the beam splitter. The beams are reflected back after striking the mirrors, and reconverge on the splitter. The optic path difference caused by the movement of any of the mirrors leads to a shift towards one direction in the interference pattern formed by the converging beams. The amount

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of displacement is then determined by identifying this change in the interference pattern. The beam amplitude of the resulting interference signal is given by equation

$$I = I_0 \cos^2 \frac{\Delta\varphi}{2}. \quad (1)$$

Here I_0 refers to the amplitude of the beam from the source, and $\Delta\varphi$ is the phase difference resulting from the optic path difference.

In this study, one of the mirrors was chosen as fixed and the other one as moving. The moving mirror was fixed to the copper test subject located in the furnace. This mirror was positioned to allow forward movement as a result of expansion by heating the copper test subject. The fixed mirror on the other hand serves as a reference in the system. The change of the optic path difference based on the displacement is shown in equation

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta L. \quad (2)$$

Here, λ is the laser wavelength and ΔL is the amount of displacement.

The phase shift induced by displacement at the interference signal was recorded with the video camera in 576×736 video format at 25 frames per second (fps). The interference video signal is received by the analysis program with a source video signal layer. The block diagram of the displacement analysis program is given in Fig. 2.

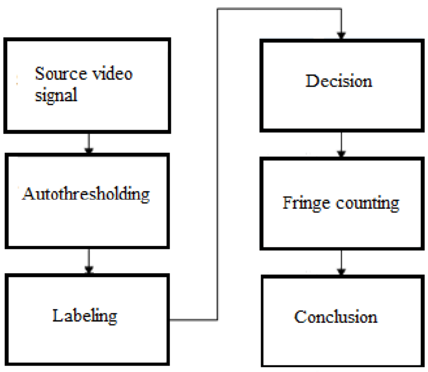

Fig. 2. Block diagram of the analysis program.

Through thresholding, the undesirable changes in the beam amplitude were eliminated. The thresholding was performed by using an autothreshold block in Matlab/Simulink platform. The basis of image thresholding relies on Otsu method. In Otsu method, the automatic threshold value is obtained from grey level histogram by a discriminant analysis [10]. The Otsu method provides especially successful results in grey level images containing bimodal distribution [11]. Since the grey level images of the interference fringes exhibit bimodal distribution properties, the automated thresholding can provide efficient results. Through thresholding, the grey level image frames are converted into binary images. As a result, the labeling block identifies the number of white interference fringes, represented by "1" binary data in the image, for that frame by checking the maximum neighboring relation and grouping these together. After identifying the number of interference fringes for each image frame in the labeling layer, in the decision block, the changes in the interference fringes are identified along the video file for the preceding and the processed image frames. The changes in the number of fringes indicate the displacement. With the aid of a counter located in the fringe counting layer, the total number of fringes is determined, and by using equation in the results layer, the amount of displacement can be identified

$$\Delta L_{\text{measured}} = \frac{\lambda}{2}N. \quad (3)$$

Here, $\Delta L_{\text{measured}}$ refers to the amount of expansion; N is the number of counted interference fringes, and λ is the laser wavelength.

To be able to compare the obtained measurement results, the total theoretical displacement of metal is determined by equation

$$\Delta L_{\text{calculated}} = \alpha L_0 \Delta t. \quad (4)$$

Here, $\Delta L_{\text{calculated}}$ denotes the amount of expansion, α is the coefficient of linear thermal expansion; L_0 is the initial length of the solid material, and Δt is the temperature range.

The relative error of the measurement results according to the theoretical values is calculated by equation

$$\beta = \frac{\Delta L_{\text{measured}} - \Delta L_{\text{calculated}}}{\Delta L_{\text{calculated}}}. \quad (5)$$

Here, β represents the relative error rate.

3. Results

A frame of interference video signal obtained from the displacement measurement setup is shown in Fig. 3.

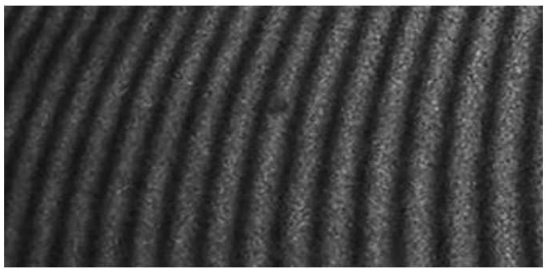

Fig. 3. A frame of interference video signal.

The changes in the beam amplitude in the interference video signal obtained using a standard laser are shown in Fig. 4 for a frame of video signal.

The amplitude changes in the interference fringes were eliminated for all video signals by thresholding and labeling, and the light and dark fringes were specified by preventing inter-coalescence before the decision block. The amplitude value of the light interference fringes were then identified as 1 and the amplitude value of dark interference fringes as 0. As a result of the thresholding

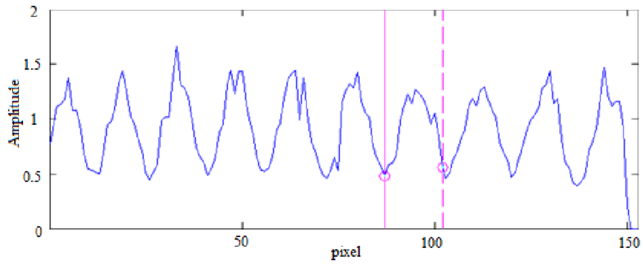

Fig. 4. The change of the beam amplitude of the interference video signal.

and labeling, the minimum interference amplitude was reduced to 0 from 0.5, and hence the inter-coalescence of light dark interference fringes caused by the fluctuation of the laser beam amplitude was prevented. A frame of video signal interference obtained through thresholding and labeling process is shown in Fig. 5.

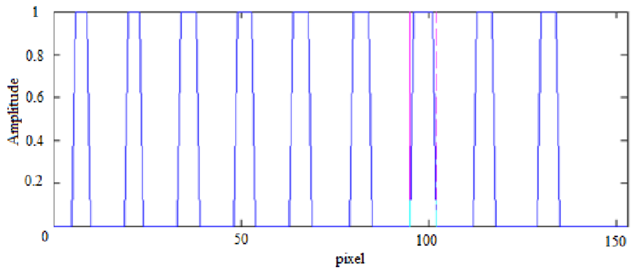

Fig. 5. The interference fringes after thresholding and labeling process.

The total displacement of the copper rod used as the test subject can be calculated using Eq. 3, by adjusting Eq. 2 with the number of fringes counted in the measurement system.

As a result of the conducted experiments, while the relative error values obtained for copper subjects was 3.3% without a displacement analysis software [9], the relative error for the unstable standard He-Ne laser was found to be 0.3% with the displacement analysis program. The relative error value was calculated as 0.2% when a stabilized laser was used.

4. Conclusions

Unlike stabilized He-Ne lasers, the beam amplitude changes in standard He-Ne lasers cause measurement errors in interferometric measurement systems. Irregularities in beam amplitude were successfully eliminated through thresholding and labeling by using the developed displacement analysis program. This in turn significantly reduced the errors in measurement results obtained from the measurement system with the standard He-Ne laser. Based on the results obtained from the measurements, while the relative error value for stabilized lasers was 0.2%, it was calculated to be 0.3% for standard He-Ne laser. This result indicates that in many applications standard lasers can be used instead of stabilized He-Ne lasers to reduce the overall costs.

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