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Accurate interference pattern analysis module of automatic measurement system

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Profile measurement of surfaces is of vital importance in today's industries, such as lens, wafer fabrication, microstructure. The phase-shifting interferometry (PSI) is very useful in optical measurement. The PSI has many advantages including noncontact measurement, high accuracy and high-speed of measurement. However, most of the PSI measurements are only suitable for certain measurement function and must match the specific algorithms. Therefore we can not integrate the system effectively. In this paper, we choose an interference fringe analysis program, named Intelliwave that can support an automation measurement system. The system can also be integrated with interferometers for different application mechanics, including Michelson, moiré, ESPI, Twyman–Green, Fizeau and shearing interferometers.

Keywords: automatic measurement system, interferometry, integrate with interferometers, error -compensating algorithms.

1. Introduction

Since Young's observation of the interference pattern, people began investing in the aspect research. Optical interferometry utilizes interference phenomenon to perform noncontact measurement of delicate surfaces, and so far we know the interferometer to be the most precise system. As lasers improve, the interferometry is used in different applications, like those concerning displacements, vibrations, lengths, optical systems, temperature and pressure environment, object profile, even to index of materials. Because a tendency today is to reduce the structure of many goods, it is more and more difficult to do contact tests on the surface of their components, which requires further research and updating of noncontact measurement technology.

Use is made of the light wave of an interferometer to test samples. So, one can perform noncontact measurement, thus reducing the destruction and interference of the test component surface. Besides, the system has the advantages consisting in high resolution and high-speed of measurement. At present, for the accuracy of measurement, interferometers are usually used to measure delicate structures, since accuracy in this case falls within the range of nanometers, and vertical resolution can limit to ranges of an order of 10 μm. Recently, several new researches have extended the application range and accuracy, enabling 3-D surface profile measurement of exquisite production [1], [2].

Nowadays, interference measurement systems have been used in many industries in different applications [3]. In general, the measurement systems should be changed for the different applications, and we must find the suitable analysis software to match the measurement systems. Therefore, these systems become very inconvenient, as they lack elasticity.

In this paper, we present a new measurement and analysis configuration to overcome the shortcomings of common interferometer. We rely on Intelliwave that is a new interference analysis software, and try to associate with different measurement systems. Using the new measurement systems to carry out the automation and standard measurements system we can raise the efficiency of work.

2. Design concept

There are numerous fine manufactures that require precise measurement, but there is lack of a uniform system. Figure 1 illustrates how we will change the measurement system if we want to do different testing. Besides, we must use appropiate software for performance interference analysis to match these systems. For example, we check the surface profiling by Michelson interferometer, and we obtain index of materials by Mach–Zender interferometer. In other words, we need different systems in different testing applications, and use different interference analysis software. Therefore, the aim of this paper is to present a new analysis software that can be set up easily and can be connected to various standard optical equipment.

We propose a new analysis process. We substitute Intelliwave for a common program, as shown in Fig. 2. The new interference software can effectively integrate

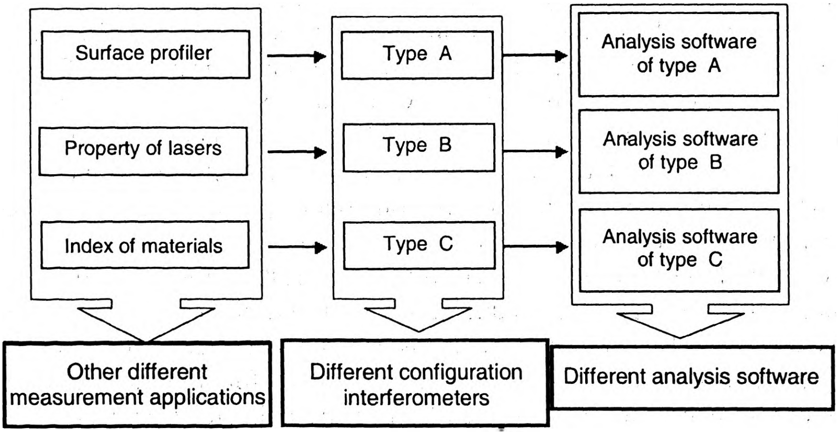


Fig. 1. Schematic diagram of the traditional analysis systems.

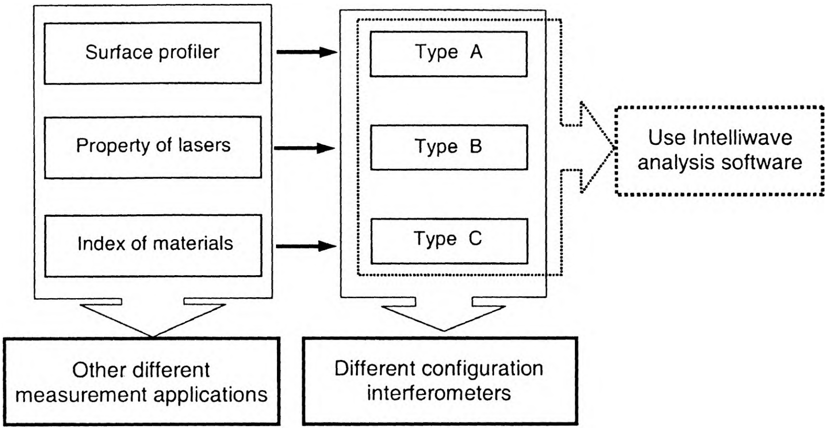


Fig. 2. Display of improved structure with Intelliwave.

with interferometers for different application mechanics. The software can deal with interferogram data, show 3-D surface contours, and calculate surface data and quantity of aberration in a short time. The system should correct a fault of the part of analysis that is too complex, and make the flow sheet simpler.

3. Experimental setup

When two light waves are superposed, their intensity at a given point is reinforced or cancel each other. Therefore, it is very important to know how to retrieve a wave-front phase encoded in the interference pattern for this technique. Generally, we use two common manners to obtain light wave phase. One is changing in discrete steps (stepping); the other is changing linearly with time (ramping). Most of the commercially available optical instruments depend on moving actuator to introduce the desired phase shift. The most common way is to mount the reference mirror on a piezoelectric transducer (PZT) and change the voltage to the PZT.

Figure 3 illustrates the experimental setup of phase-shifting Fizeau [4] microscopy interferometers that are now widely used to test optical surface. The light source is a He-Ne laser with an operating wavelength of $\lambda = 632.8$ nm. The laser beam passes through the spatial filter and a collimating lens to expand the testing beam diameter. Through a simple optical path design, the interference fringe of test surface is imaged onto a CCD array. Moving the reference flat in 3-D direction using three PZT scans the test surface. With the optical path difference (OPD) of the interferometer varying, and we can grab the sequence of interference intensity frames by CCD camera and store in a computer.

The driving voltage applied to the scanning PZT determines the sampling position and that will cause enormous effect to analysis results [5]–[8]. So, it is very important to precisely control the phase-shift in the interferometer. We present a self-calibration technique to calibrate the PZT in this system. By observing phase-shifting instan-

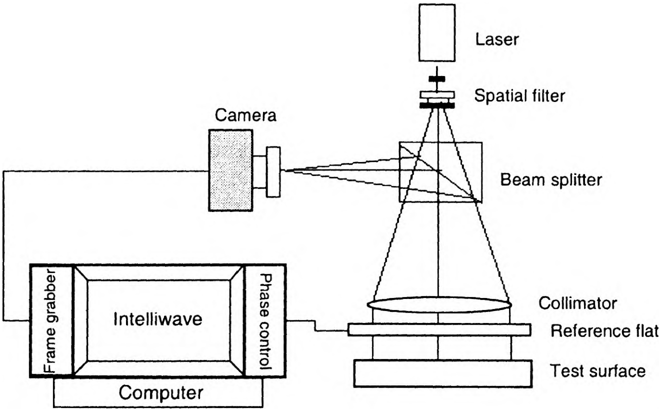


Fig. 3. Experimental setup for phase-shifting Fizeau microscopy interferometers.

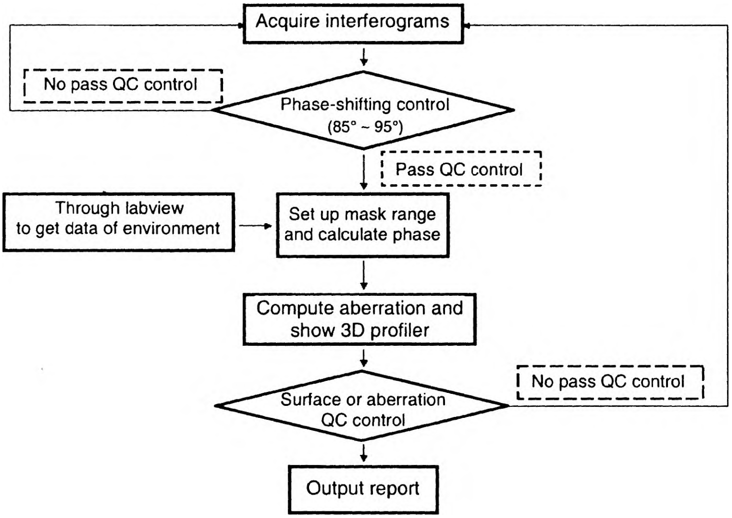


Fig. 4. Flow-sheet of the automation process of the measurement system.

taneously, we can design an automatic measurement process, as shown in Fig. 4. We can perform the quality control of phase shifting and measurement system. The new analysis will determine the phase shifting by a sequence of frames. If the phase shifting is erroneous, the system will send a feedback signal to grab frames again. The conventional calibration method requires an accurate calibration reference, which is difficult to obtain. Because of automatic calibration, the accuracy of the measurement module could be raised and increase the work efficiency. Thus, this cannot be easily performed with the conventional comparison method, and self-calibration techniques are needed.

In addition, we are able to devise an item of analysis for various cases, and set up other data of quality control in measurement systems. The flow-sheet of analysis can also be used in other interferometers, such as Michelson, moiré, ESPI and Twyman–Green. It is most advantageous to increase flexibility of measurement systems by the analysis software.

4. Experimental results and discussion

We usually use PZT to change the phase shifting. Therefore, knowing how to calibrate the PZT for proper phase shift between particular frames is a very important issue. PZT has some undesirable properties, including hysteresis, nonlinear motion and environmental variation of sensitivity, which will cause the phase error in measurement systems. This is the main source of error in measurement systems.

We must avoid errors due to the undesirable properties of PZT which may greatly affect the operation of the phase-shifting interferometer. In an attempt to reduce phase

Table. Error-compensating algorithms of different frames.

	$\tan\varphi$	
Frame no.	Class A	Class B
Three-frames		$\frac{I_1 - 2I_2 + I_3}{I_1 - I_3}$
Four-frames	$\frac{I_4 - I_2}{I_1 - I_3}$	$\frac{I_1 - 3I_2 + I_3 + I_4}{I_1 - 3I_3 + I_2 + I_4}$
Five-frames	$\frac{2I_4 - 2I_2}{I_1 - 2I_3 + I_5}$	$\frac{I_1 - 4I_2 + 4I_4 - I_5}{I_1 - 2I_2 - 6I_3 + 4I_4 + I_5}$
Six-frames	$\frac{4I_4 - 3I_2 - I_6}{I_1 - 4I_3 + 3I_5}$	$\frac{I_1 - 5I_2 - 2I_3 + 10I_4 - 3I_5 - I_6}{I_1 + 3I_2 - 10I_3 + 2I_4 + 5I_5 - I_6}$

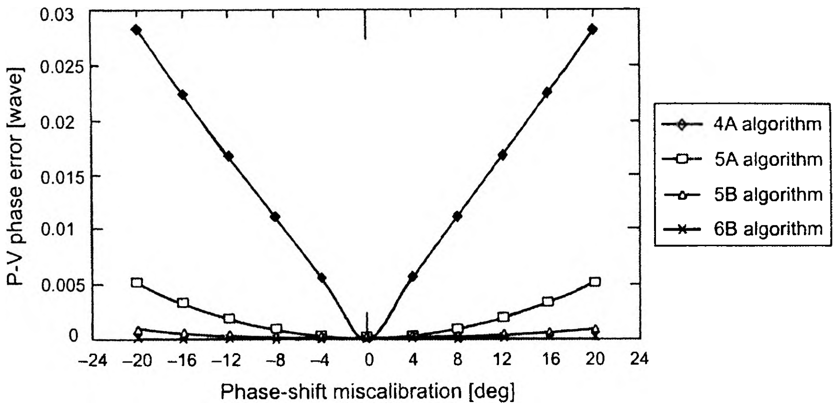
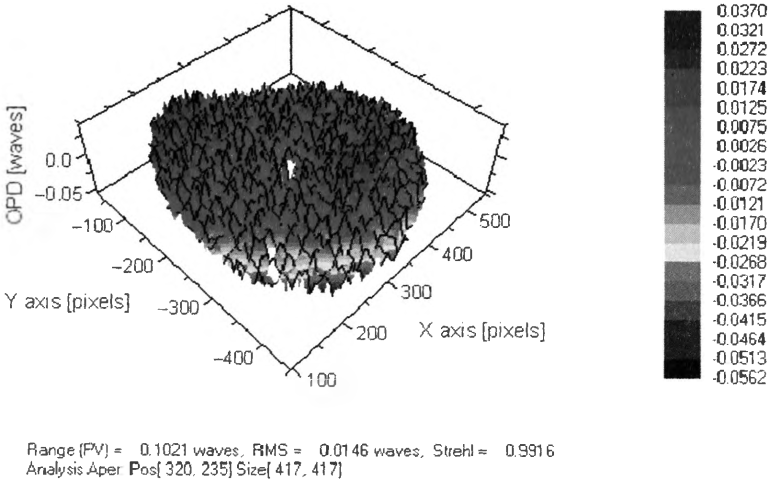


Fig. 5. Graph of different phase-shift errors *vs.* the P-V phase error.

error, researchers developed families of error-compensating algorithms [9]–[11], and the accuracy of the profile measurement can be improved through error compensation. According to the average technique, we can derive the $M + 1$ frame algorithm. Besides, we can also obtain the $M + 2$ frame algorithm by using the same theorem. All of the error-compensating algorithms are derived up to the six-frames. The error -compensating algorithms are shown in the Table. At present, the most common of these was the five-frame algorithm.



Range (PV) = 0.1021 waves, RMS = 0.0146 waves, Strehl = 0.9916
Analysis Aper Pos[320, 235] Size[417, 417]

Fig. 6. Two-dimensional view of a standard flat obtained by Intelliwave system.

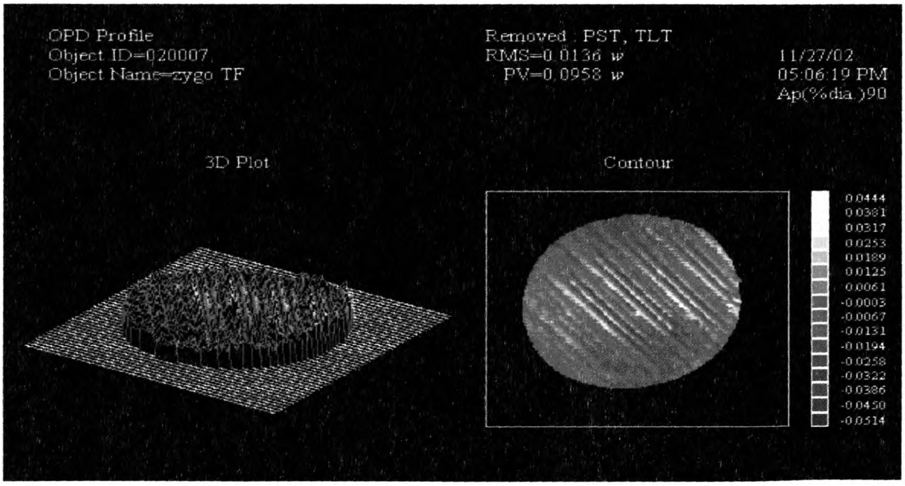


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Fig. 7. Measurements of the surface OPD profile by using a diffrerent program.

Class A is based on three-stepping algorithm

$$\tan\varphi = \frac{-I_1 + 2I_2 - I_3}{I_1 - I_3} \qquad (1)$$

and class B is extended to four-stepping

$$\tan\varphi = \frac{I_2 - I_4}{I_3 - I_4}. \qquad (2)$$

We compare the phase error for four, five and six frames from both classes. We use the Intelliwave to generate the interferograms without noise, and we compare the P-V error under condition of different phase-shift errors. We calculate the results for the different phase-shift miscalibration effects on each of the algorithms; Fig. 5 shows the different phase-shift error versus the P-V phase error. From the results, we can observe 6B algorithm to have a better degree of accuracy than other algorithms; the 3B algorithm has the worst degree of accuracy. In other words, the more frames we grab, the higher degree of accuracy we get. When we grab more interferograms to analyse surface data, we encounter the problem of how to control the phase shift accurately. So we use 5B algorithm to analyse the data of frames.

We carried out the measurement using the phase-shifting Fizeau microscopy interferometers. The system captures five consecutive phase-shift frames via a commercial camera, and executes the flow-sheet of the automation process. We measure a standard flat by the system. Figure 6 shows a 2-D view of a standard flat obtained by Intelliwave system, and Fig.7 shows the surface OPD profile by using a different program. Making use of Intelliwave software, the result of surface P-V is 0.1021 waves, and the other result of measurement obtained by a different program is 0.0953 wave. So, it can be said that Intelliwave performs with high degree of accuracy in profile measurement.

5. Conclusions

We have found that the technique of Intelliwave produces fast, accurate, and repeatable 3-D profiling of surfaces. The principle of the self-calibration method can be fulfilled by Intelliwave, which can calibrate commercially phase-shifting Fizeau microscopy interferometers. We are able to devise an item of analysis for different cases in many interferometers. In addition, the analysis software can be adapted to different interferometers. We can also raise the precision of systems by error-compensating algorithms; the average phase of error being very small (for phase error smaller than 20°, the error of surface P-V< $\lambda/1000$). Another advantage consists in increasing the flexibility of setups by Intelliwave.

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