Modified Fizeau interferometer with the fringes polynomial smoothing algorithm

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***Abstract*—The modified Fizeau interferometer that allows to diagnose plane and spherical optical elements with the diameter ranging from 10 to 100 mm is discussed. The method of interference patterns reconstruction based on reference lines is modified, the algorithm of 4th order polynomial smoothing is implemented. The modified method increases the reliability and accuracy of interferometric pattern reconstruction and suppress the influence of incoming noise. Accuracy of the measurements is about λ/10 (λ=0.63 um).**

Keywords— Fizeau interferometer, optical surface testing, polynomial smoothing algorithm.

1. Introduction

Interferometric techniques for optical surface quality control are well-known and well-established methods due to the high accuracy of the interferometer devices. In this paper we present the modified Fizeau interferometer that was assembled and tested in our laboratory as well as discuss the new algorithm of 4^{th} order polynomial smoothing of reconstructed interference patterns.

Overall, the main goal of this work was to increase the efficiency of the interference pattern reconstruction algorithm of the Fizeau interferometer to measure the flatness of optical elements in case of noisy image conditions. The origin of the noise is not really matter for the algorithm – whether it is due to the presence of inhomogeneities along the optical path between the input aperture of the interferometer and the detail under test or it is due to digital noise of the video camera used.

2. Optical scheme of the interferometer

The interferometer described in this paper is based on Fizeau scheme [1]–[3]. The scheme of the interferometer assembled in our laboratory is presented on Fig. 1.

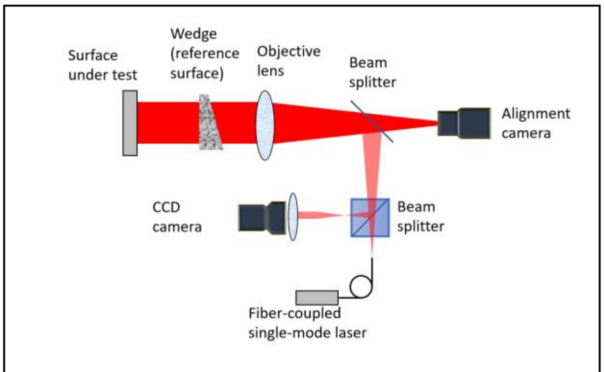

Fig. 1. Principal scheme of the Fizeau interferometer

3. Phase surface reconstruction algorithm

One of the main problems of analysis of interference pattern images is how to correctly determine extremuma. For this purpose we used the previously developed method that allowed to exclude false extremuma and to determine the position of the extremuma with high precision [3].

4. Fourth order polynomial smoothing algorithm

Due to the presence of noise component on the interference pattern image it was necessary to reduce it. We used the algorithm of moving average to smooth the noise effects. If the noise impact is rather high, the interference pattern will be reconstructed with the error because of the error in determination of extremuma. But we found out that sometimes the strength of the moving average algorithm is not enough. There are still some reconstructed fringes with a false bends after applying the algorithm of moving average. This bends introduces the additional error to the calculated set of Zernike coefficients [4], [5] and to the resultant phase surface [6].

In order to decrease this error, we applied the 4th order polynomial smoothing algorithm. This algorithm takes the X and Y coordinates of each point of the determined interference patterns and approximates it using the polynomials of 4th order. By solving the least squares problem, the approximation coefficients C_i are obtained. The resultant Y_{new} coordinates of each point of the determined interference patterns are recalculated (based on the old Y_{old} values) using the formula:

$$Y_{new} = C_0 + C_1 \cdot Y_{old} + C_2 \cdot (Y_{old})^2 + C_3 \cdot (Y_{old})^3 + C_4 \cdot (Y_{old})^4$$

The application of this algorithm allows to eliminate false bends of the color lines in the interference patterns.

There are a few other algorithms that supposed to increase the efficiency of the fringe identification and reconstruction. In [7] the nonlinear regression analysis is described. But as is known, all nonlinear regression algorithms are iterative. As such they require significant amounts of computer time. Also, unlike linear regression analysis, they require initial guesses of the values of all coefficients. In [8] authors applied continuous wavelet transform and Hilbert transform algorithms to obtain phase map from the interference fringes pattern. However, Hilbert transform algorithm gives a noisy result, since its frequency spectrum has harmonic noise. In [9] the authors proposed a method for producing stabilized interference patterns using CCD camera as the detector element. This method allowed to decrease the photoresist grating fill factor from ~60% to less than 50%.

a)

b)

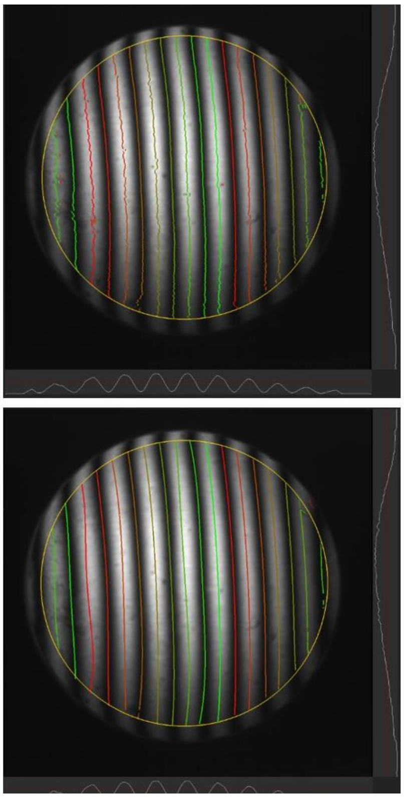

Fig. 2. a) interference fringe pattern and reconstructed fringes (color lines) after applying classical mooving average algorithm; b) reconstructed fringes after applying the 4th order polynomial smoothing algorithm

The advantages of the proposed fourth order polynomial smoothing algorithm are independence of noise and fast calculation speed which allows to reconstruct and smooth the interference fringes in real-time (figure 2).

Table 1 contains the resultant PV, RMS and Zernike coefficients obtained after interference fringes pattern reconstruction before (row #1) and after (row #2) applying 4th order polynomial smoothing algorithm.

TABLE 1. ZERNIKE COEFFICIENTS (IN WAVELENGTH) FOR THE RECONSTRUCTED FRINGES

	PV	*RMS*	*Z3*	*Z4*	*Z5*	*Z6*	*Z7*	*Z8*
1.	0.3	0.046	0.069	0.032	-0.014	0.005	-0.01	0.01
2.	0.13	0.038	0.061	0.025	-0.004	-0.002	-0.001	0.003

The proposed algorithm of polynomial smoothing can possibly be effective in solving the problems of phase surface reconstruction in Shack-Hartmann wavefront sensors [10], [11] with the B-spline approximation technique [12]. Moreover, such a technique can be applied in case of approximation of average wavefronts [13] of the radiation passed through the scattering medium [14], because the wavefront in that case is almost flat in the central part of the beam and dramatically increases to the edge of the beam [14]. It can cause an error in surface approximation which can be decreased by means of the proposed algorithm.

5. CONCLUSION

The method of interference patterns reconstruction based on reference lines is modified, the algorithm of 4th order polynomial smoothing is implemented and successfully tested. The modified method increases the reliability and accuracy of interferometric pattern reconstruction and suppress the influence of incoming noise. The proposed algorithm can also be applied to the phase reconstruction in Shack-Hartmann sensor.

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