Conference Paper

Use of 3×3 Coupler in the Fiber Optic Strainmeter Based on Mach-Zehnder Interferometer

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Abstract

In this paper a strainmeter based on the fiber optic Mach-Zehnder interferometer with 3x3 coupler for a phase shift demodulation is presented. Laboratory experiments on registration of harmonic deformation with the use of strainmeter were carried out. The experiment demonstrates efficiency of the strainmeter.

Keywords: strainmeter, interferometer, coupler

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1. Introduction

In fiber optic strainmeter the optical scheme of the Mach-Zehnder interferometer [1] providing a possibility of registration of deformations to 10^{-12} m is convenient for application. However, the high sensitivity of the interferometer leads to the drift of working point caused by changes of conditions of the environment, for example, of temperature and pressure. This problem can be solved by use of passive homodyne demodulation technique with a 3x3 coupler. A demodulation scheme utilizing a 3x3 coupler has the advantage of passive detection and low cost as it requires no phase or frequency modulation in the reference arm or of the laser source, and so there are no active components in the optical domain.

In the early 1980s the use of 3x3 couplers in the demodulation of interferometric fiber optic sensors was first proposed [2] and demonstrated [3]. This demodulation allows the generation of three outputs separated in phase by 120 degrees. In early methods two of the three outputs are used to obtain the required 90 degrees phase difference from their sum and difference and these form the inputs to a differentiating cross-multiplying demodulator [3], the method needs a dc offset in the circuit to eliminate the dc component resulting from summing up the two inputs, therefore when the light power in the interferometer changes, the circuit will become unbalanced. Further all three outputs are utilized symmetrically in an analog processing algorithm to obtain the demodulated time-changing phase difference [4].

In this paper a strainmeter based on the fiber optic Mach-Zehnder interferometer with 3×3 coupler for a phase shift demodulation is presented. Use of the splitter 3x3 has allowed to exclude the opto-electronic feedback used for active stabilization of interferometer working point.

2. Materials and Methods

The three outputs of the 3×3 coupler are nominally 120° out of phase with either of its neighbors

and can be expressed as:

$$x_1 = C + B\cos(\Delta\phi(t));\tag{1a}$$

$$x_2 = C + B\cos(\Delta\phi(t) - 120^\circ);\tag{1b}$$

$$x_3 = C + B\cos(\Delta\phi(t) + 120^\circ)\tag{1c}$$

where subscripts 1, 2 and 3 denote the three outputs of the 3×3 coupler, respectively; $\Delta\varphi(t)$ is the phase shift between the sensing and reference fibers of the Mach-Zehnder interferometer; C is the central value around which the output will vary with amplitude B.

To calculate phase shift $\Delta\varphi(t)$ the algorithm of interferometer signals processing offered in [4] was used.

The DC offset C of the output can be obtained by adding the three inputs as follows:

$$x_1 + x_2 + x_3 = 3C + B(\cos(\Delta\phi(t)) + \cos(\Delta\phi(t) + 120^\circ) + \cos(\Delta\phi(t) - 120^\circ)) = 3C\tag{2a}$$

$$C = \frac{1}{3}\left(x_1 + x_2 + x_3\right)\tag{2b}$$

Three new parameters, y_1, y_2 and y_3 are introduced as follows:

$$y_1 = x_1 - C = B\cos(\Delta\phi(t));\tag{3a}$$

$$y_2 = x_2 - C = B\cos(\Delta\phi(t) - 120^\circ);\tag{3b}$$

$$y_3 = x_3 - C = B\cos(\Delta\phi(t) + 120^\circ)\tag{3c}$$

The next step in the processing is to take the difference between each of the three possible pairings of the derivatives and multiply this by the third signal:

$$d = y_1\left(\dot{y}_2 - \dot{y}_3\right) = \sqrt{3}B^2\Delta\dot{\phi}(t)\cos^2(\Delta\phi(t))\,; \tag{4a}$$

$$e = y_1\left(\dot{y}_3 - \dot{y}_1\right) = \sqrt{3}B^2\Delta\dot{\phi}(t)\cos^2(\Delta\phi(t) - 120^\circ)\,; \tag{4b}$$

$$f = y_1\left(\dot{y}_1 - \dot{y}_2\right) = \sqrt{3}B^2\Delta\dot{\phi}(t)\cos^2(\Delta\phi(t) + 120^\circ) \tag{4c}$$

Summation of Equations (4a), (4b) and (4c), yields:

$$N = d + e + f = \frac{3\sqrt{3}}{2}B^2\Delta\dot{\phi}(t) \tag{5}$$

Taking the squares of Equations (3a), (3b) and (3c), then adding them, leads to:

$$D = y_1^2 + y_2^2 + y_3^2 = B^2\left(\cos^2(\Delta\phi(t)) + \cos^2(\Delta\phi(t) - 120^\circ) + \cos^2(\Delta\phi(t) + 120^\circ)\right) \tag{6}$$

Dividing Equation (6) into Equation (5), yields:

$$Z = \frac{N}{D} = \sqrt{3}\Delta\dot{\phi}(t) \tag{7}$$

We can integrate Equation (7) to obtain the phase shift Δφ(t) as follows:

$$\Delta\phi(t) = \frac{1}{\sqrt{3}}\int Z\,dt \tag{8}$$

The described algorithm was used for processing of output signals of the fiber optic Mach-Zehnder interferometer in a strainmeter which scheme is shown in fig. 1.

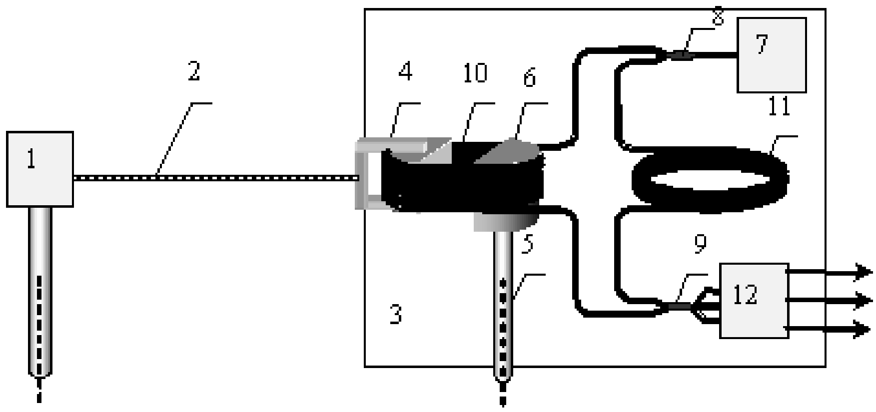

Figure 1: Functional scheme of strainmeter based on the fiber optic Mach-Zehnder interferometer with 3×3 coupler: 1 – column for rope fastening, 2 –rope, 3 – sealed casing, 4 – movable half-cylinder, 5 – post, 6 – rigidly fixed half-cylinder, 7 – semiconductor laser, 8 – Y-splitter, 9 - 3×3 coupler, 10 – single-mode optical fiber of sensing arm, 11 – single-mode optical fiber of reference arm, 12– photodetectors.

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CW optical radiation from laser (7) is coupled by means of fiber-optic Y-splitter (8) into two single-mode optical fibers which work as sensing (10) and reference (11) arms of the interferometer. Sensing optical fiber wound between mobile (4) and fixed (6) half of the cylinder. A mobile half of the cylinder fastens by the end of an extensive rope (2) which second end is fixed on a column (1). Afterword the signal and reference waves are combined at the 3×3 coupler (9). Optical signals are detected by photodiodes (12). An optoelectronic part of the strainmeter is placed in the sealed casing (3).

Experimental setup for testing performance of the fiber-optic strainmeter is shown in fig. 2. Vibrator (3) sustains harmonic oscillations of the end of a strainmeter rope (2). The corresponding signal is registered by means of Michelson's interferometer consisting of He-Ne laser (4), beamsplitter (5), photodetector (6), mirrors (7) and (8). The Mirror (7) is fixed on a mobile part of a vibrator. The dotted line has shown a laser beam.

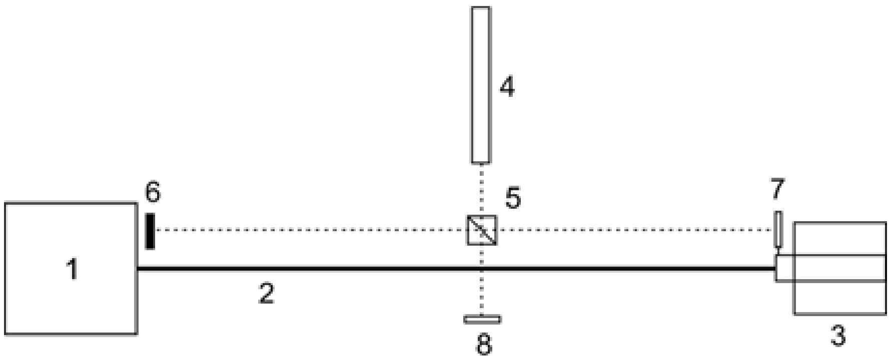

Figure 2: Experimental setup for testing performance of the fiber-optic strainmeter: 1 – sealed casing of the strainmeter; 2 – rope; 3 – vibrator; 4 – He-Ne лазер; 5 – beamsplitter; 6 – photodetector; 7 – movable mirror; 8 – fixed mirror.

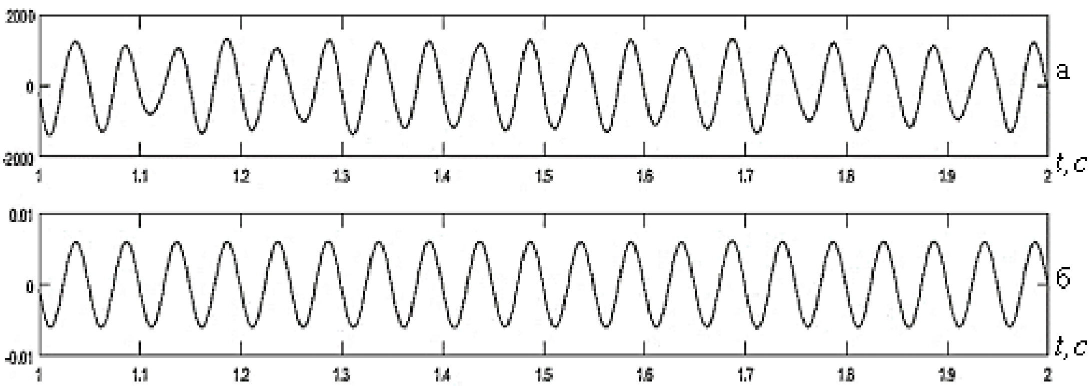

Figure 3: Results of testing of the fiber optic strainmeter with the 3x3 coupler: a – the signal corresponding to the shift of the end of a strainmeter rope, b – the result of reconstruction of this signal received after processing of strainmeter output signals.

3. Results

Results of testing of the fiber optic strainmeter with the 3×3 coupler are presented in fig. 2. The signal corresponding to the shift of the end of the strainmeter rope is presented in fig. 2a. The result of reconstruction of this signal received after processing of strainmeter output signals is presented in fig. 2b. As seen, good compliance of the initial and restored signals is observed.

4. Conclusions

In this paper a strainmeter based on the fiber optic Mach-Zehnder interferometer with 3x3 coupler for a phase shift demodulation is presented. Laboratory experiments on registration of harmonic deformation with the use of strainmeter were carried out. The possibility of use of the splitter 3×3 in fiber optic strainmeter for registration of longitudinal deformations of studied objects is shown.

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