ISSN 1068-3356, Bulletin of the Lebedev Physics Institute, 2014, Vol. 41, No. 12, pp. 348–350. © Allerton Press, Inc., 2014.
Original Russian Text © R.V. Romashko, M.N. Bezruk, S.A. Ermolaev, I.N. Zavestovskaya, 2014, published in Kratkie Soobshcheniya po Fizike, 2014, Vol. 41, No. 12, pp. 8–12.

Determination of the Adaptive Fiber-optic Interferometer Sensitivity

R. V. Romashko[a], M. N. Bezruk[a], S. A. Ermolaev[a], and I. N. Zavestovskaya[b,c]

[a] *Institute of Automation and Control Processes, Far-East Branch of the Russian Academy of Sciences, ul. Radio 5, Vladivostok, 690041 Russia; e-mail: romashko@iacp.dvo.ru*

[b] *Lebedev Physical Institute, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 119991 Russia*

[c] *National Research Nuclear University "MEPhI", Kashirskoe sh. 31, Moscow, 115409 Russia*

Received November 17, 2014

Abstract—The method for experimental determination of the sensitivity and detection threshold of the interferometer phase is proposed. Based on the method the indicated parameters for an adaptive fiber-optic interferometer are estimated using the dynamic hologram formed in the photorefractive CdTe crystal.

DOI: 10.3103/S1068335614120021

Keywords: adaptive interferometer, dynamic hologram, sensitivity, detection threshold.

The adaptive interferometer differs from the classical one by the fact that the beam-splitter cube combining the signal and reference light beams is replaced by a photorefractive crystal (PRC) [1]. The signal and reference light beams of the interferometer, crossing in the PRC, form a dynamic hologram in which the phase modulation is transformed to intensity modulation. The dynamic hologram continuously re-recorded in the crystal allows the interferometer to adapt to uncontrolled influences of external noise factors. The schematic diagram of the adaptive fiber-optic (FO) interferometer is shown in Fig. 1.

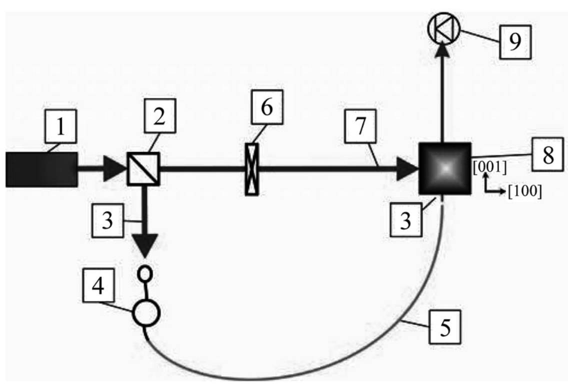

Fig. 1. Schematic diagram of the adaptive fiber-optic interferometer: (1) laser, (2) beam-splitter cube, (3) object beam, (4) calibration piezoelectric modulator, (5) fiber-optic sensitive element, (6) quarter-wave plate, (7) reference beam, (8) photorefractive crystal, and (9) photodetector.

Continuous radiation of the solid-state laser ($\lambda = 1064$ nm) is split into object and reference light beams by the beam splitter. The object beam is introduced into the multimode optical fiber 5 used as a sensitive element. Then the object beam 3 at the optical fiber output passes through photorefractive crystal 8 where it forms the dynamic hologram due to the interaction with reference beam 7. The intensity of the object beam passed through the PRC is measured by photodetector 9. The effect of the measured value on the optical fiber causes phase modulation of radiation in it. In turn, the phase modulation $\Delta\varphi$ is transformed in the adaptive interferometer to the intensity change ΔI described by the expression [2]

$$\Delta I = AJ_0(\Delta\varphi) \cdot J_1(\Delta\varphi), \tag{1}$$

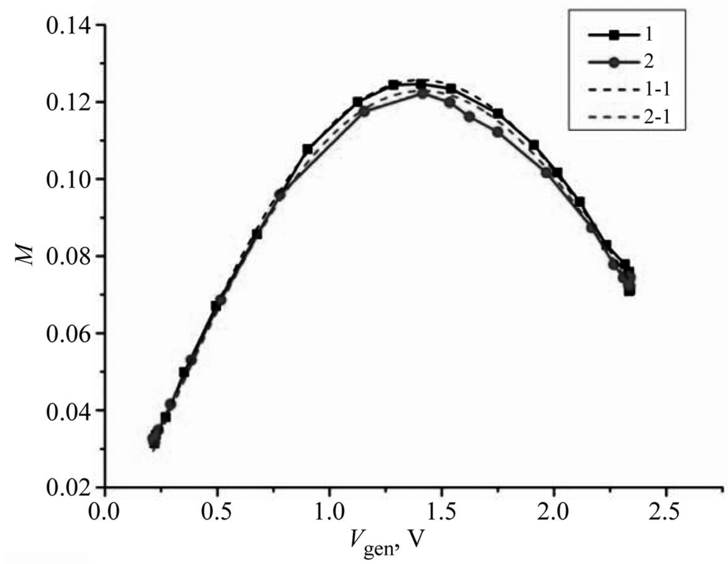

Fig. 2. Dependence of the interferometer output signal on the modulation signal amplitude, presented for two individual measurements (1 and 2): 1—1 and 2—1 are the approximation curves for measurements 1 and 2, respectively.

where J_q is the q-order Bessel function and A is the coefficient defining the interferometer sensitivity and taking into account the efficiency of the interaction of object and reference waves in the photorefractive crystal.

In this study, the phase was modulated using a piezoelectric modulator; an electrical voltage V applied to the modulator caused a change in the length of the optical fiber wound on and, hence, the phase change: $\Delta\varphi = BV$; where B is the proportionality factor between the action on the FO sensitive element and the modulation of the phase of radiation propagating in it.

The calibration factors A and B were determined experimentally as follows. An additional optical fiber wound on the calibrated piezoelectric modulator was connected to the optical fiber used as a sensitive element. A variable sinusoidal voltage was fed to the modulator, whose amplitude V_{gen} was gradually increased and then decreased. The modulation depth $M = \Delta I/I_0$ of the object wave intensity was taken as the interferometer output signal. Figure 2 shows the dependence of the interferometer output signal M on the modulation signal amplitude V_{gen}. Such measurements were cyclically repeated for two minutes. A series of such experiments (8 measurements 5 cycles each) with a total duration of 40 min was performed.

The dependences of the output signal shown in Fig. 2 were approximated using expression (1) and the calibration factors A and B were determined. Figure 3 shows the dynamics of the variation of factor A and B for the entire measurement period.

The stability of factors A and B controls the stability of the adaptive interferometer output signal. Based on the data of Fig. 3, root-mean-square deviations ΔA and ΔB of these factors were obtained. The short-term deviations of A and B (during 5 cycles) were 3% and 0.6%, respectively; for the entire experimental series, these values were 10% and 2%, which is a good result for such an observation time.

The sensitivity criterion of the adaptive interferometer is the relative detection threshold determined by the expression [3]

$$\delta_R = \frac{\varphi_A}{\varphi_C}, \tag{2}$$

where φ_A and φ_C are the minimum phase modulations which can be theoretically detected by the adaptive and classical homodyne interferometers, respectively. The quantity φ_C is known to be 1.5×10^{-9} rad(W/Hz)$^{1/2}$ [4]. Thus, the minimum phase modulation theoretically detectable by the adaptive

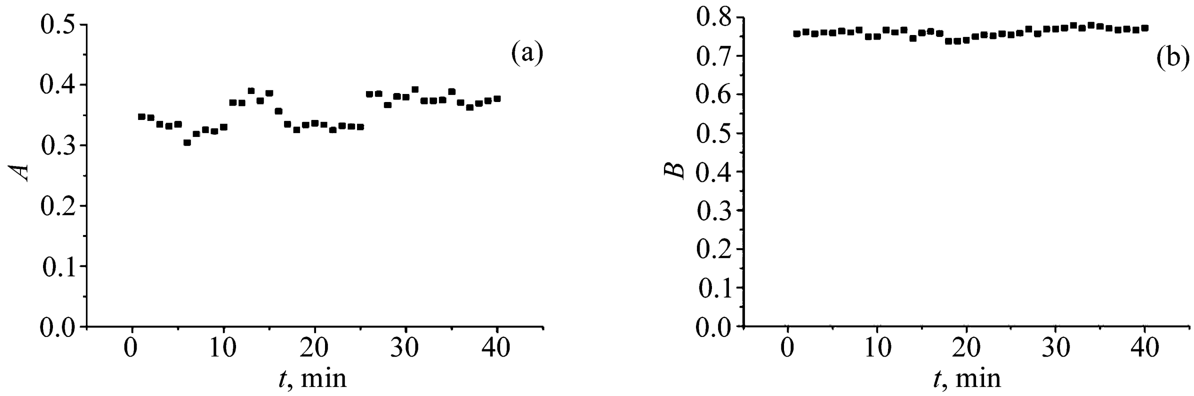

Fig. 3. Dynamics of the variation of calibration factors (a) A and (b) (B) for the experiment time.

interferometer can be determined as $\varphi_A = \delta_R \varphi_C$. In turn, the relative detection threshold δ_R can be determined experimentally [3],

$$\delta_R = \frac{\Phi}{\sqrt{TG}} \cdot M^{-1}, \tag{3}$$

where Φ is the phase modulation (the maximum change in the light wave phase), T is the factor accounting for the object wave loss, and G is the object wave gain due to its interaction with the reference wave in the PRC. The value of $\delta_R \cdot \sqrt{TG}$ experimentally obtained in this study was 2.0.

We note that the value of φ_A was obtained under conditions when all noises in the adaptive interferometer are eliminated, except for the photodetector shot noise of quantum nature. In practice, the measuring system contains various noises and exhibits parameter instabilities which increase the detection threshold. In this case, the minimum phase modulation which can be detected by the adaptive interferometer can be determined from the expression (3),

$$\Phi_A^{\min} = \delta_{\text{rel}} \cdot \sqrt{TG} \cdot \Delta M_{\text{noise}}, \tag{4}$$

where ΔM_{noise} is the noise level in the output signal of the adaptive interferometer, including noises of electronic circuits of measuring equipment, ΔM_E, and noises associated with output signal intensity fluctuations caused by changes in the crystal parameters (e.g., temperature) and by the dynamic hologram formed in the crystal, ΔM_{fl}. The latter factor manifests itself in stochastic fluctuations in calibration factors A and B, shown in Fig. 3, and can be determined as $\Delta M_{fl} = [\Delta A^2 + \Delta B^2]^{1/2}$. In turn, the total noise level can be determined as $\Delta M_{\text{noise}} = [\Delta M_E^2 + \Delta M_{fl}^2]^{1/2}$.

Using the obtained values of ΔA, ΔB, and $\delta_{\text{rel}} \cdot \sqrt{TG}$, and taking into account that the electronic noise level did not exceed 1%, using expression (4), we obtain the minimum detected phase modulation. In the adaptive interferometer, based on the dynamic hologram formed in the CdTe crystal, the phase modulation $\Phi_A^{\min}$ was 0.2 rad.

Thus, the technique for determining the sensitivity of the adaptive interferometer based on the dynamic hologram formed in the photorefractive crystal was proposed and experimentally tested. This approach made it possible to determine ways to lower the detection threshold and to increase the sensitivity of the adaptive interferometer.

ACKNOWLEDGMENTS

This study was supported by the Russian Scientific Foundation (project no. 14-12-01122).

REFERENCES

1. S. I. Stepanov, in *International Trends in Optics*, Ed. by J. W. Goodman (Academic Press; New York, London; 1991), Chap. 9.
2. A. A. Kolegov, S. M. Shandarov, and Yu. F. Kargin, Doklady TUSURa **22**(2), 66 (2010).
3. A. A. Kamshilin, R. V. Romashko, and Y. N. Kulchin, J. Appl. Phys. **105**, 031101 (2009).
4. J. W. Wagner and J. Spicer, J. Opt. Soc. Am. B **4**, 1316 (1987).