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PHASE DIFFERENCE MEASUREMENT BASED ON OPTOELECTRONIC METHOD

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A new method of measuring of the phase difference of electromagnetic signals by a photopolarimetric method is offered in this work. The advantage of an offered method before the known ones of phase measuring is shown. The potential error of method is about 10^{-3} degrees.

Keywords: optoelectronical method; measuring of phase; electromagnetic signals; polarization; magneto-optical optron; phase registration.

Introduction. For measuring of phase difference φ of two electric signals u_1 and u_2 the method of full-wave current rectification by phase detector is used [1], the output voltage of which is equal to

$$u_{\text{out}} = u_{01} \cdot u_{02} \cos \varphi, \tag{1}$$

where u_{01} and u_{02} are the amplitudes of electric signals; φ is the phase difference between them.

Consequently the exactness of the phase registration is determined by the exactness of measuring u_{out}, u_{01} and u_{02}, the measuring error of which doesn't exceed one percent. Let's determine an absolute phase error from the formula (1)

$$\Delta\varphi = \frac{1}{\operatorname{tg}\varphi}\left(\frac{|\Delta u_{\text{out}}|}{u_{\text{out}}} + \frac{|\Delta u_{01}|}{u_{01}} + \frac{|\Delta u_{02}|}{u_{02}}\right). \tag{2}$$

The error of phase measuring is equal to zero by $\varphi = \frac{\pi}{2}$ and doesn't depend on amplitude fluctuations. This is a characteristic property of the method. If only φ deflects from the value $\frac{\pi}{2}$, the phase meter is no longer in asymmetrical operating mode and the amplitude fluctuations cause error increase. For instance, by values $\varphi = \frac{\pi}{4}$ and relative error of amplitude measuring ~ 10^{-2}, the absolute value of error lies within the limits 1° – 5°. The defect of the method is the dependence $\Delta\varphi$ on φ, which can be partly eliminated by the etalon phase-changing facility.

Phase difference conversion technique in a time slot τ [2; 3] became widespread with a further development of digital and microprocessor technology. The error of phase difference is equal to

$$\Delta\varphi = 360° f \Delta\tau, \tag{3}$$

where f is the frequency of researching signal, $\Delta\tau$ is the accuracy of measuring of a time slot. For example, if $f = 10^5$ and $\Delta\tau = 10^{-8} \dots 10^{-9}$sec, then $\Delta\varphi = 0{,}1° \dots 0{,}03°$ [4 – 7]. The accuracy is considerably higher. The defect of the method is the dependence of error on frequency of the measuring signal.

A new photopolarimetric measuring method of φ with higher accuracy is given here. This became possible due to signal amplitude conversion into angle of polarization twisting of light (angle of optical polarization twisting) (fig. 1). Current I is generated by a signal, the phase of which must be measured by a photopolarimetric method, by measuring of angle of optical polarization twisting θ. The angle θ can be measured to $\Delta\theta = 10^{-3} \dots 10^{-4}$ degree [8 – 10].

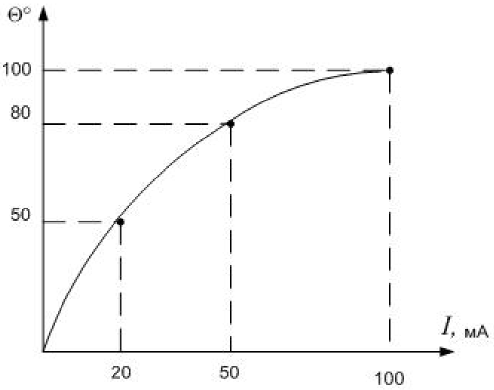


Fig. 1. Typical dependence of angle of optical polarization twisting on current in magnetizing coil

In fact, let reference and measuring signals be equal

$$u_1 = u_{01} \sin \omega t, \tag{4}$$

$$u_2 = u_{02} \sin\left(\omega t - \varphi\right). \tag{5}$$

Then angles of optical polarization twisting are respectively equal

$$\Theta_1 = \Theta_{01} \sin \omega t, \tag{6}$$

$$\Theta_2 = \Theta_{02} \left(\sin \omega t - \varphi\right). \tag{7}$$

It is possible to fix points of time with the accuracy of measurement error $\Delta\Theta$, when Θ_1 and Θ_2 are equal to zero.

$$\Delta\Theta_1 = \Theta_{01} \sin \omega t_1, \tag{8}$$

$$\Delta\Theta_2 = \Theta_{02} \left(\sin \omega t_2 - \varphi\right), \tag{9}$$

where t_1, t_2 are the points of time of signal passage through zero.

According to (8), (9) we get value of error in registration of phase

$$\Delta\varphi = \omega\left(t_2 - t_1\right) - \varphi = \frac{\left|\Delta\Theta_1\right|}{\Theta_{01}} + \frac{\left|\Delta\Theta_2\right|}{\Theta_{02}} \approx \frac{2\left|\Delta\Theta\right|}{\Theta_0}\,. \tag{10}$$

(Let’s consider the amplitudes of signals that are equal in quantity. $\Theta_{01} = \Theta_{02}$, though this condition is not obligatory).

Usually quantity $\Theta_0 \approx 10^0$ [10; 11], having inserted it in (9), we get a real value of error of measuring phase $\Delta\varphi \approx 2\ (10^{-3} \ldots 10^{-4}$ degree), that is two orders higher than accuracy of measurements of known methods.

Main part. Let’s discuss the possibilities of the use of magneto-optical optron in the mode of phase measurement of electric signal, and more precisely the point of time registration, when signal amplitude is equal to zero. Magneto-optical optron is represented in fig. 2. The principle of operation is described in detail in the works [8; 12].

We will denote signal the phase of which must be measured as u_ω and infill signal will be denoted as u_Ω (it is significant, that their frequencies are different and $\Omega >> \omega$)

$$u_\omega = u_{0\omega} \sin\left(\omega t - \varphi\right), \tag{11}$$

$$u_\Omega = u_{0\Omega} \sin \Omega t. \tag{12}$$

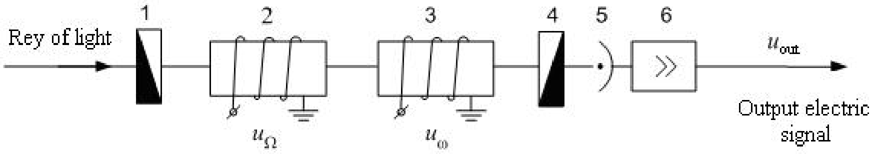


Fig. 2. Magneto-optical optron: *1*, *4* – are the polarizer and the analyzer; *2*, *3* – are the magneto-optical crystals (dice) with magnetic biasing coils; *5* – is the photodetector; *6* – is the narrow-band amplifier

The optical ray, falling on photodetector 5 in time will be modeled in intensity below (Maljus law) [10].

$$I = I_0\cos^2\Theta = I_0\cos^2\left[\Theta_0 + \Theta_{0\omega}\sin(\omega t - \varphi) + \Theta_{0\Omega}\sin\Omega t\right]. \tag{13}$$

The initial angle between the polarizer and the analyzer $\Theta_0 = \dfrac{\pi}{2}$, and $\Theta_{0\omega}, \Theta_{0\Omega}$ are the amplitudes of swinging angle of polarization twisting by changing and infill signals. Let’s factorize (13) according to Bessel functions [12].

$$\begin{aligned} I = \frac{I_0}{2}\Bigg\{1 - &\left[J_0(2\Theta_{0\omega}) + 2\sum_{p=1}^{\infty} J_{2p}(2\Theta_{0\omega})\cos 2p(\omega t - \varphi)\right]\times \\ &\times\left[J_0(2\Theta_{0\Omega}) + 2\sum_{p'=1}^{\infty} J_{2p'}(2\Theta_{0\Omega})\cos 2p'\Omega t\right] + \\ &+ 4\sum_{p=1}^{\infty} J_{2p-1}(2\Theta_{0\omega})\sin(2p-1)(\omega t - \varphi)\sum_{p'=1}^{\infty} J_{2p'-1}(2\Theta_{0\Omega})\sin(2p'-1)\Omega t\Bigg\}. \end{aligned} \tag{14}$$

An optical signal (14) is converted by photodetector 5 into electrical one. Let’s put conditions $\Omega >> \omega$, and narrow-band intensifier has such passband to amplify only spectral rectangular components $\Omega \pm \omega$, Ω. We will get voltage on the amplifier output.

$$u_{\text{out}} = u_0' J_1(2\Theta_{0\omega}) J_1(2\Theta_{0\Omega})\sin(\omega t - \varphi)\sin\Omega t = u_0\sin\Omega t, \tag{15}$$

where $u_0 = u_0' J_1(2\Theta_{0\omega}) J_1(2\Theta_{0\Omega})\sin(\omega t - \varphi)$, u_0 is the output signal amplitude slowly changing in time relative to $\sin\Omega t$ function.

The point of time, when $u_0 = 0$, we denote as t_2, then

$$\omega t_2 - \varphi = n\pi, \tag{16}$$

where $n = 1, 2, 3\ldots$.

Let’s count time t_2 relative to the moment of equality to zero of the reference signal on intensifier output 6 $\omega t_1 = 0$ or $n\pi$. It is necessary to pass reference signal $u_{\Omega} = u_{0\Omega}\sin\Omega t$ and measuring signal $u_{\omega} = u_{0\omega}\sin(\omega t - \varphi)$ through two identical optron channels (1 and 1') (fig. 3).

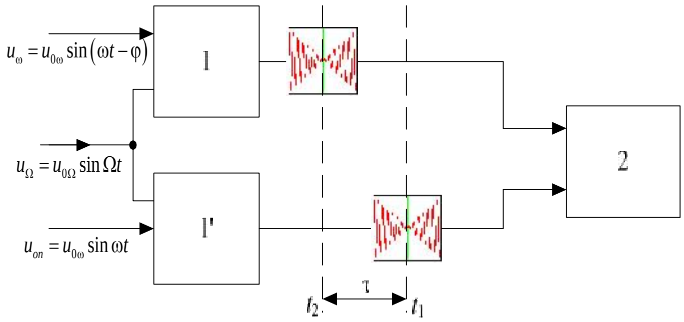
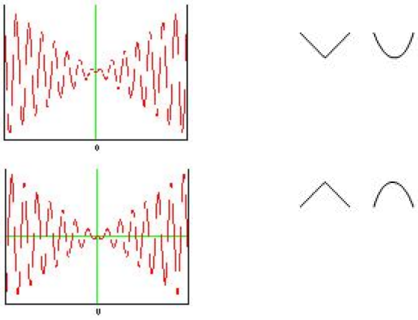


Fig. 3. Photopolarimetric phase meter: 1, 1' – are optrons for signal u_{on} and reference signal u_{ω}; 2 – is the digital microprocessor of the interval measurement τ

The signal phase is changing on the opposite one (on π) in points t_1, t_2, that's why the signal doesn't change polarity (fig. 4, *a*). Depending on phase quantity the signal can have critical tops (depressions) and mildly sloping tops (depressions) in the points of time t_1, t_2 (fig. 4, *b*). Under condition $\Omega >> \omega$ we can not see them. They will be covered in noise.



a *b*

Fig. 4. The signal phase is changing

The ratio of signal and noise is determined by analogy with work [11] taking into account expression (14), for perfect analyzer and polarizer taking into account flash noise of the photodetector (generation-recombination noise for semi-conductor photodetector and shot noise for photomultiplier). We will disregard depolarization of light in magneto-optical crystals (dice). We are not going to regard dark noise, because flash noise is much less. The ratio of signal and noise is equal to

$$S/N = \frac{u_{\text{out}}^2}{u_{\text{light}}^2} = A\left(\Theta_{0\omega}\Delta\varphi\right)^2.$$

The quantity $A \sim 10^6$, $\Theta_{0\omega} \sim 10°$ [10; 11], then at the signal-to-noise ratio of $S/N = 1$, $\Delta\varphi \sim 10^{-4}$ degree.

Conclusions. In conclusion, we should emphasize that photopolarimetric method of phase registration of electric signals allows us to increase accuracy of measuring. The offered method of measuring of phase will probably find application first of all for infra- and low-frequency signals.

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Оптоелектронний метод вимірювання різниці фаз

Представлено новий фотополяриметричний метод вимірювання різниці фаз електромагнітних сигналів. Показано перевагу запропонованого методу серед відомих фазових способів вимірювання різниці фаз. Потенційна точність методу становить близько 10^{-3} градусів.

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Оптоэлектронный метод измерения разности фаз

Представлен новый фотополяриметрический метод измерения разности фаз электромагнитных сигналов. Показано преимущество предлагаемого метода среди известных известных способов измерения разности фаз. Потенциальная точность метода составляет около 10^{-3} градусов.