Light rangefinder of “0” class

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Abstract. When the light-emitting diode meter is operating in the middle linear region of the light modulation characteristics in the microwave range, photodetectors of the photoelectron multiplier (PMT) type do not restore changes in the demodulated signal depending on the distance. The solution of this problem using optical frequency conversion by introducing a second identical modulator at the second frequency is considered. According to this principle, the functional construction scheme of a rangefinder "0" class is proposed, the accuracy of which is estimated to be \( m_\phi = 0.01-0.02 \text{ mm} \).

Introduction

Modern special engineering and geodetic works include a large volume of linear measurements with an accuracy of 0.05 mm on lines 100 m and longer. High requirements for the accuracy characteristics of linear measurements in special geodetic works also determine the requirements for the development of high-precision light rangefinders [1,2,3].

The well-known high-precision light-rangefinders such as Mekometer ME-3000, Geomensor 204 [4,5] and CD-1200 [6], the phase determination error of which were 0.2 and 0.1 mm respectively, in real conditions provided 0.4 and 0.3 mm respectively. However, the fundamental decisions underlying the development of these rangefinders allow the construction of rangefinder “0” class ensuring the phase determination error \( m_\phi = 0.01-0.02 \text{ mm} \) [7].

The use of two optical signals shifted in phase 180° as a more accurate method for determining \( m_\phi \) on two photo electronic multiplier tube (PMT) provided \( m_\phi = 0.06 \text{ mm} \) [8]. With the transition to one PMT, it became possible to get \( m_\phi = 0.04-0.045 \text{ mm} \) [9].

Potential opportunity of the light modulation-demodulation and heterodyne reception allow, in the region of the minimum of light, the linear dependence of the relative light intensity on the measured distance and thereby increase the measurement accuracy of the compensating light rangefinders to the level of the reference linear meter.

At the first stage, the transition to the midline portion of the light modulation characteristic (LMC) is required, as well as the separation of the modulation-demodulation channels of the light to the limit of the average diameter of the receiving-transmitting optics [10].

Methodology

The operation of the range finder by the compensation method shows that when the modulator's working point shifts to the middle linear portion of the light, modulation characteristic there is a change in light intensity at the modulation frequency \( f_m \), and it is necessary the dependence of the
change of the light intensity oscillation amplitude depending on the measured distance D shift to a low frequency within the bandwidth of a photo detector such as a photomultiplier tube (PMT). The known methods of receiving intensity-modulated light (optical heterodyning, photo heterodyning, etc.) are not very effective for light range. In this regard, the modulation-demodulation of light with an offset of $\varphi_0 = \pi/2$, despite a decrease in the modulation power and an increase in the accuracy of the phase determining, do not find practical application.

When considering the possibility of transferring changes in the light intensity at the modulation frequency in the compensation light rangefinder to a low frequency, it was found that for photo heterodyne reception it is advisable to apply electro-optical frequency conversion by passing demodulation light through the second modulator at a frequency $f_t$ different from frequency $f_m$ by a value slightly smaller than the bandwidth of the Photo detector type PMT. In this case, the formation of the intermediate frequency becomes possible at the beginning of the light modulation characteristics (LMC), when the voltage and power on electro-optical crystals are determined by the half-wave values $U_x$ and $P_x$, therefore the pulsed power supply of the light modulator is maintained.

The results of our research show that the main ways of reducing the modulation power of $P_m$ and voltage $U_m$ in volumetric electro-optical light modulators on KDP crystals are multiplication of the number of light passing through the crystal and transferring the operating point of the modulators to the average linear section of the LMC by applying light with circular polarization [11]. The modulation-demodulation of light and frequency transformation with circular polarization of light is possible with two analyzers, one of which is installed at the output of the first modulator and the second at the output of the second. The scheme of this option is shown in Figure 1.

$$\Gamma_1 = \varphi_0 + \pi \frac{U}{U_{\pi/2}} \cos \omega_m t,$$

$$\Gamma_2 = \pi \frac{U}{U_{\pi/2}} \left( \cos \omega_m t + \frac{4\pi D}{\lambda_m} \right),$$

$$\Gamma_3 = \varphi_0 + \pi \frac{U}{U_{\pi/2}} \cos \omega t$$

(1)

Where $\varphi_0$ – constant phase shift, $\pi \frac{U}{U_{\pi/2}}$ – light modulation coefficient, $\lambda_m$ – the modulation wavelength, $D$ – measured distance.
The solution of the matrix Jones equation for the scheme in Fig. 1 results in a relative intensity of light at the outputs of the analyzer in the form

\[
I_{\alpha_1} / I_0 = \sin^2 \left( \frac{1 + \Gamma_2}{2} \right) ; \quad I_{\alpha_2} / I_0 = \sin^2 \left( \frac{1 + \Gamma_2}{2} \right) \sin^2 \Gamma_3 / 2
\]  

(2)

The solution of \( I_{\alpha_1} / I_0 \) is known and when \( \varphi_0 = \pi/2 \) is equal to

\[
I_{\alpha_1} / I_0 = \frac{1}{2} \left[ 1 + 2 J_1 \left( m_1 \right) \cos \left( \omega_m t + \frac{2 \pi D}{\lambda_m} \right) \right]
\]  

(3)

Where \( m_1 = 2\pi U / U_{\pi/2} \cos 2 \pi D / \lambda_m \), \( \lambda_m \) – the modulation wavelength, \( J_1 \) – first order Bessel function.

The solution of the second equation after a series of transformations is represented as

\[
I / I_0 = \frac{1}{4} \left[ 1 - \cos \varphi_0 \left( \begin{array}{c} J_0 \left( m_1 \right) - 2 J_2 \left( m_1 \right) \cos 2 \left( \omega_m t + \frac{2 \pi D}{\lambda_m} \right) + \sin \varphi_0 2 J_1 \left( m_1 \right) \cos \left( \omega t + \frac{2 \pi D}{\lambda_m} \right) \end{array} \right) \right].
\]  

(4)

Taking \( \sin \varphi_0 = 1 \), we get

\[
I / I_0 = \frac{1}{4} \left[ 1 + 2 J_1 \left( m_1 \right) \cos \varphi_2 2 J_1 \left( m_2 \right) \cos \varphi_2 + 2 J_1 \left( m_1 \right) 2 J_1 \left( m_2 \right) \cos \left( \varphi_2 + \varphi_2 \right) \right]
\]  

(5)

The phase component \( 2 \pi D / \lambda_m \) is not taken into account. The current frequencies \( \omega_m \), \( \omega_\alpha \), and \( \omega_\nu + \omega_m \) at the output of the photomultiplier tube form constant current components, which can be disregarded, and for the difference frequency \( \omega_\nu - \omega_m \) from (5) we have

\[
\tilde{I} / I_0 = \frac{1}{4} \left[ 1 + 2 J_1 \left( m_1 \right) J_1 \left( m_2 \right) \cos \omega_\nu \right]
\]  

(6)

Where \( \Omega = \omega_\nu - \omega_m \).

The circuit in Fig. 1 can work with linear polarization of light, i.e. when \( \cos \varphi_0 = 1 \)

\[
\tilde{I} / I_0 = \frac{1}{4} \left[ 1 + 2 J_2 \left( m_1 \right) J_2 \left( m_2 \right) \cos 2 \omega_\nu \right]
\]  

(7)

In contrast to expression (3), after frequency transformation, instead of modulation frequency \( \omega_m \), whose amplitude is proportional to \( 2 J_1 \left( m_1 \right) \), there is a difference frequency \( \Omega \) with the amplitude \( 2 J_1 \left( m_1 \right) J_1 \left( m_2 \right) \) or \( 2 \Omega \) with amplitude \( 2 J_2 \left( m_1 \right) J_2 \left( m_2 \right) \). In addition, in expressions (6) and (7), the light intensity decreases by 2 times, but this does not mean that with expression (3), the reception efficiency is 4 times more. When photo heterodyning, the efficiency (3) also decreases 4 or more times and knowing that not every photo detector of the PMT type works in photo heterodyne mode, preference should be given to the construction principle according to the functional diagram indicated in Fig. 1, since the implementation of the second light modulator is technically simpler than the selection of a photomultiplier and its placement in the oscillator cavity. Thus, the implementation of electro-optical frequency transformation allows the light demodulation process to be transferred to a low frequency \( \Omega \) (expression 6), as a result of which the constant component becomes a variable with a frequency of \( 2 \Omega \).
(expression 7). The advantage should be given to the expression (6). Because the maximum of the function \( J_1 \) (\( \ldots \)) is greater and takes place for small arguments.

Taking in (6) the value \( 2J_1(m_2) = 1; \) \( U / U_{\pi/2} = 0.2 \) we get

\[
\tilde{I} / I_0 = \frac{1}{4} \left[ 1 + 2J_1 \left( \frac{2\pi U}{U_{\pi/2}} \right) \cos \lambda_m \right] (8)
\]

The change in the relative intensity of light at the first difference frequency is \( \tilde{I} / I_0 = 1.58 / 4 = 0.359 \), when \( U / U_{\pi/2} = 0.3 \) and \( \tilde{I} / I_0 = 0.375 \) when \( U / U_{\pi/2} = 0.2 \), i.e. the amplitude of the current at the PMT output will be 2 times less than when \( \phi = 0 \). However, the signal-to-noise ratio for the expression (8) is 2 times greater and the signal amplification is 2 times greater than with the case \( \phi_0 = 0 \). For the final determination of the voltage value on the KDP electro-optical crystals and the modulation power \( P_m \) generated by the oscillator on the combined modulator generator will be based on the possibility of the functional construction scheme of the light rangefinder that is shown in Fig.2.

The proposed circuit in Fig. 2 is extremely simplified by introducing a direct connection between the receiving and transmitting optics, the light source and the photo detector through a light demodulator modulator.

At the output of the analyzer, a modulated light is formed, the change in the amplitude of the intensity fluctuation of which depends on the distance

\[
I / I_0 = \frac{1}{2} \left[ 1 + 2J_1 \left( \frac{2\pi U}{U_{\pi/2}} \right) \cos \left( \omega_m t + \frac{2\pi D}{\lambda_m} \right) \right] (9)
\]

**Figure 2.** The Functional construction scheme of the light rangefinder on the electro-optical frequency transformation

The triode GI-22 of the generator in the meander mode can operate at power levels \( P_L = 2.25 \) W, but the KDP crystals will heat up, since the allowable power on the crystals, equal to about 0.6 W, is 2 times less than the average value of the modulation power equal to \( P_L / 2 = 1.12 \) W. In addition, due to
the multiplication of the passage of light through the crystal there are significant losses of light. Therefore, to implement the circuit in Fig. 2, it is necessary to increase the intensity of the receiving light, which is solved by applying transceiver optics in a range finder. A new light modulator with phase modulation accumulation has been developed for operation in the continuous mode of the optical range finder on the electro-optical frequency transformation.

For this scheme, the modulation coefficient is increased to the value of $3,4\pi U / U_\pi$ and for the ratio $U / U_\pi$ with $J_0(m) = 0.5$ we get, $3,4\pi U / U_\pi = 1,204$, $U / U_\pi = 0,125$. In this case, the modulation power and the voltage across the crystals with known values of $U_\pi = 9500$ V and $P = 900$ W for a combined modulator with a generator is $U = 0.125 \cdot 9500$ V = 1200 V.

Summary

There is not only a significant decrease in the values of U and P, but also a narrowing of the minima of the observed signal, because instead of the function $J_0(...)$, characteristic of the compensation light range finder, the function $J_0(...)$ appears in the expression (4), the which change in region $J_0(...)$ is linear. In addition, light modulators at similar frequencies $f_m$ and $f_r$ are of the same type, their frequency tuning necessary for the operation of a light rangefinder in a wide temperature range can be accomplished by rotating one axis.

Thus, another property of electro-optical modulation of light has been identified and implemented, namely, that additional modulation at the frequency $f_r$ of the demodulated light at the frequency $f_m$ transfers the properties of the light modulator-demodulator to a low frequency in the optical channel, which allows to realize the advantages of the linear section of the light modulation characteristic and which will be the basis of the functional construction scheme of the rangefinder "0" class with an error in determining the phase $m_\phi = 0.01 - 0.02$ mm.

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