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DEVELOPMENT OF CALCULATION METHODOLOGY FOR TRIANGULATION MEASURING DEVICES

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ABSTRACT

The paper presents a methodology for simplified energy calculation in triangulation measuring devices. Parameters calculation taking into account the influence of the shape and size of the research object on the efficiency of the developed device. One of the tasks solved by triangulation devices is the constant monitoring of the load-bearing structures of hydroengineering structures technical condition. Displacement measurement of control points of vertical strings, allows to observe the state of hydroengineering structures and to monitor the displacement of the dam body. The triangulation method of measuring the distance from the measuring device (strings) to the surface of the object assumes that the monitored object itself is included in the optical scheme of the measuring device. Its characteristics (shape, surface character and location relative to the measure) can significantly influence on the results of triangulation measurements. A functional diagram of the control instrument was developed. A methodology for calculating energy based on the specific nature of the task was proposed.

Keywords: triangulation, measuring systems, position control, hydraulic engineering constructions.

INTRODUCTION

Laser triangulation has been increasingly used in the development of precision measuring sensors and systems for solving a wide range of dimensional control problems in the range from millimeter units to one meter with errors ranging from sub-micron counts to hundreds of microns.

One of the tasks solved by triangulation sensors is the state monitoring of the load-carrying structures of hydraulic constructions dams. Since dams are objects of increased danger, they need constant monitoring. Observations of the hydraulic structures state is a control of the displacement of the dam body, which is carried out by measuring the displacement of the control points of vertical plumb. These plummets are laid in the dam construction during the construction phase.

Despite the great variety of automatic systems for visual control, now control and measurement tasks are solved with the help of visual meters constructed according to the Katyrev-Brekhman scheme [1]. Disadvantages of the sensors constructed according to the Katyrev-Brekhman scheme are the large weight and dimensions, as well as errors in taking samples by the operator, and as a result, low accuracy. On some hydraulic structures, photovoltaic displacement convertors are used to solve the monitoring tasks. Devices based on them are more accurate, but their cost is high.

Proceeding from all of the above, it follows that it is necessary to create a mobile control and measuring system, with high accuracy of operation, small dimensions, with the ability to provide measurements in two planes, and the device must be simple to operate and have a quick tuning function. Such device should simplify the control and measurement operations carried out on hydraulic structures and improve their accuracy [1].

OBJECT OF THE STUDY

The object of the study is a plumb line of load-bearing structures of hydroconstructions and a device based on a triangulation method. Due to ease of implementation in optoelectronic devices, triangulation is one of the most common methods of measuring distances to an object [1]. The triangulation method of measuring the distance from the control system to the object surface assumes that the controlled object-the string, is included in the optical circuit of the sensor. Its characteristics (shape, surface character and location relative to the meter) can significantly affect the results of the triangulation measurements.

The measurement principle is that any change in the position of the string causes a corresponding change in the position of the light spot on the photodetector. Knowing the parameters of the optical system, we can derive a formula relating the change in the position of the object with the change in the position of the light spot on the photodetector. This can be explained using Figure-1.

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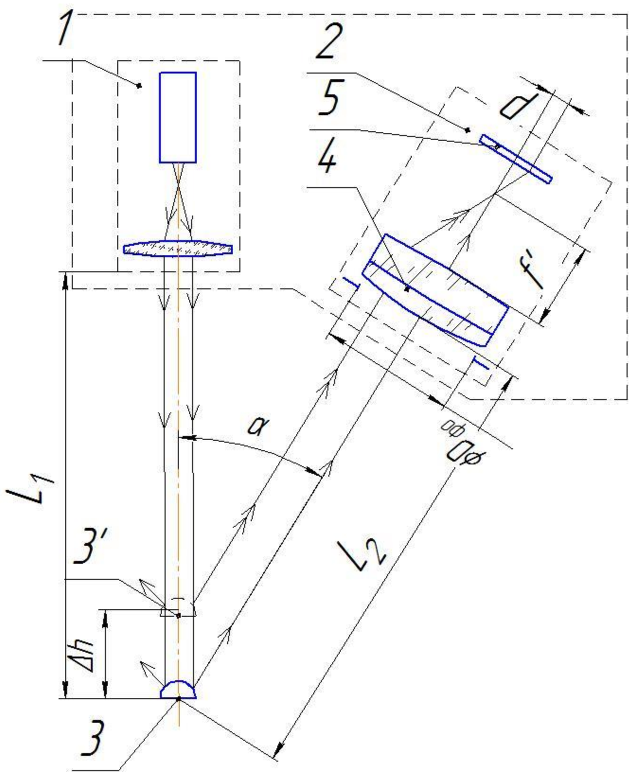

Figure-1. Triangulation measurement method

where L_1 - distance to the zero position of the string, L_2 - distance from the string to the main plane of the photodetector assembly objective, f' - focal length of the objective, p - displacement of the light spot on the phase transition, Δh - displacement of the string, α -triangulation angle.

The laser beam from the illuminator 1 falls on the surface of the string 3. The rays reflected from the string are gathered by the objective 4 on the photodetector 5, which is set at some triangulation angle α to the illuminator so that the illuminator, string and photodetector unit 2 form a triangle. In real triangulation systems, these beams are projected onto a multi-element photodetector 5 [3]. During the string displacement Δh, a proportional displacement of its image P takes place on the photodetector, along which the true value of the displacement of the string is judged, namely [5]

$$\Delta h = \left(\frac{f' \cdot P}{M \cdot P \cdot \cos(2\alpha) + f' \cdot M^2 \cdot \cos(2\alpha) \cdot \sqrt{\frac{M^2 + \tan^2(2\alpha)}{M^2}}} \right), \quad (1)$$

where M - magnification of the optical system, f' - back focal length of the system.

There are two types of triangulation devices: in the first case, the plane of the device is perpendicular to its optical axis, and in the second - it is inclined to it at a certain angle in accordance with the principle of Scheympflug [4].

Depending on the properties of the surface of the string, different schemes of triangulation measurement should be used [2]. When working with a string, you can use any of the schemes, because on the one hand, the string reflects well the radiation incident on it, and on the other hand, because of the circular (in the cross section) shape and the presence of roughness, the incident beam of light is scattered.

A schematic diagram of the proposed triangulation sensor is shown in Figure-2. It contains the following components: illuminator 1, objective 2, photodetector (PD) 3.

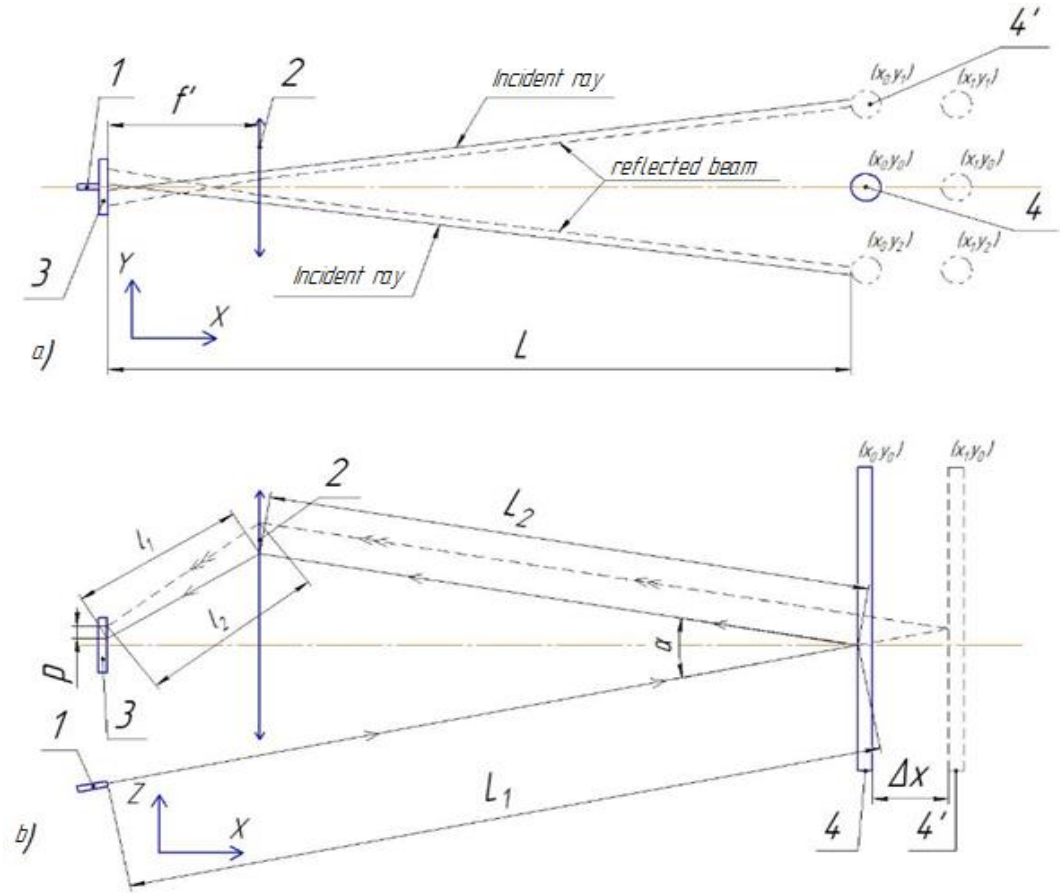

Figure-2 a, b. Schematic diagram of a triangulation test device
L_1 - distance to the zero position of the string, L_2 - distance from the string to the main plane of the objective of the photodetector unit, Δx - string displacement, α - triangulation angle, l_1 и l_2 - distance from the main plane of the objective to the photodetector area.

METHODS OF RESEARCH

In order for the projected device to satisfy the conditions of the task, it is necessary to set the initial parameters, calculate the illuminator, the objective and select the photodetector, and then evaluate the calculated values.

The efficiency of the control and measurement system, which is based on the triangulation method of measuring the distance to the object, depends heavily on the shape and dimensions of the string. Therefore, much attention should be given to the choice of a pair of illuminator-photodetector, so that the signal-to-noise ratio on the photodetector allows us to isolate a useful signal against a background of noises. Also, do not forget that in addition to the losses associated with the shape of the string, there are still a number of factors that affect the incident radiation, for example, loss on scattering and absorption when passing the air path to the string and back.

The cross-section of the beam of rays illuminating the string is an ellipse whose area S1 is determined by the following known formula

$$S_1 = a_1 b_1 \pi, \tag{2}$$

where a_1 и b_1– small and large semiaxes of the ellipse, calculated from formulas

$$a_1 = d_0 + L_1 \tan(\varphi_1), \tag{3}$$

$$b_1 = d_0 + L_1 \tan(\varphi_2). \tag{4}$$

In formulas (3) and (4) - d_0 - diameter of the radiation beam at the output from the illuminator, L_1 - distance from the illuminator to the string, φ_1 *and* φ_2- angles of divergence of the laser radiation.

The reflected radiation from the string propagates in a wide solid angle. In the first approximation, we can assume that the reflection is uniform throughout the diameter of the string. And with the help of the coefficient K, we can calculate that part of the reflected radiation, which will lie in a solid angle, limited by the entrance pupil of the objective. To calculate the total reflection from the string, which is determined by the area S2 (see Figure-3), we use the following formula.

$$S_2 = K a_2 b_2 \pi, \tag{5}$$

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where a_2 - diameter of the string, b_2 - size of the light spot in the longitudinal section of the string, which is calculated by the following formula

$$b_2 = 2\sqrt{b_1^2 - \Delta y^2}, \quad (6)$$

where, Δy – displacement of the string relative to the zero point (see Figure-3).

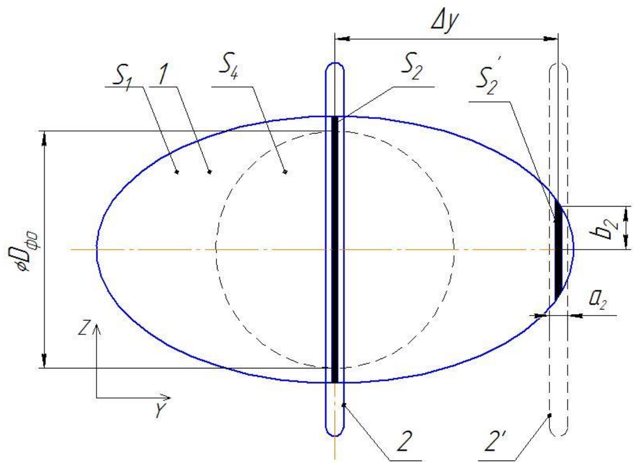

Figure-3. The ratio of the cross section of the radiation beam to the area of the string.
1 - Section of the beam, 2 - string in the zero position,
2 '- string in the extreme position

The coefficient K, which takes into account the change in the area of S_2 on S'_2, is found from

$$K = 2\tan\left(\frac{D_{\phi o}}{2L_2 + a_2}\right), \quad (7)$$

which is easily deduced from the analysis of Figure-1.

The radiation from the illuminator, reflected from the string, is "cut off" once more at the entrance to the photodetector unit. The fact is that the entrance diameter of the objective is much smaller than the cross-section of the radiation beam.

The radiation at the entrance to the photodetector unit will be determined by the area S_3 (in the section, too, the ellipse), which can be calculated from the formula

$$S_3 = a_3 b_3 \pi, \quad (8)$$

where a_3 and b_3 – small and large semi-axes of the ellipse at the entrance to the photodetector unit, calculated by formulas

$$a_3 = 2(a_2 K + L_2 \tan(\varphi_1)) \quad (9)$$

$$b_3 = 2(b_2 + L_2 \tan(\varphi_2))$$
(10)

To determine the total loss factor K_n, it is necessary to determine the area of the entrance pupil S_4 of the lens, whose role is performed by the first lens rim. It is easy to see that it is equal (see Figure-3)

$$S_4 = \frac{{D_{\phi o}}^2 \pi}{4}, \quad (11)$$

then

$$K_п = \frac{S_2}{S_1}\frac{S_4}{S_3}. \quad (12)$$

It is obvious that the radiation power P_k incident on the photodetector is defined as the product of the radiation power of the illuminator $P_н$ and the loss coefficient K_p, i.e.

$$P_k = P_н K_п. \quad (13)$$

RESULTS OF THE STUDY

For preliminary calculations, the circuit shown in Figure-2 was taken. The initial data presented in Table-1 were also given.

Table-1. Initial data for the preliminary calculation of the triangulation measuring system.

Power of illuminator, *Pн*, mW	**Working distances, mm**		**Measurement range, *z* mm**	**String diameter, *a2* mm**	**Diameter of the exit pupil, *d0* mm**	**Divergence angle, degrees**	
	L1	***L2***				α_1	α_2
4000	1000	950	-75 .. +75	2	5	9,6	9,6

This system is designed to automatically record the displacement of load-bearing structures of hydraulic objects. According to the proposed algorithm, the energy calculation was performed, the results are shown in Table-2.

Table-2. Results of calculation of a triangulation measuring system.

Radiation power at the surface of a string, mW	**Radiation power reflected from a string, mW**	**Radiation power at the photodetector, μW**
4000	5,234	59

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The following pair of illuminator-photodiode was chosen for the calculation. As the illuminator was chosen two coordinate PSD receiver DL100-7 SMD from "First sensor". The laser module KLM-H808-x-5 was chosen as an illuminator. The signal-to-noise ratio for a given pair is $2{,}3 \cdot 10^4$.

CONCLUSIONS

Approbation of the developed technique was carried out on the installation described in [1], in which these photodetectors and illuminator were installed for the given parameters. At the same time, it was possible to reliably remove and process information from the photodetector, it was not even necessary to specifically screen it, which is an indirect confirmation of the fact that the signal-to-noise ratio of this pair is significantly higher than one order. In Figure-4 shows the level of the signal taken from the photodetector depending on the position of the string.

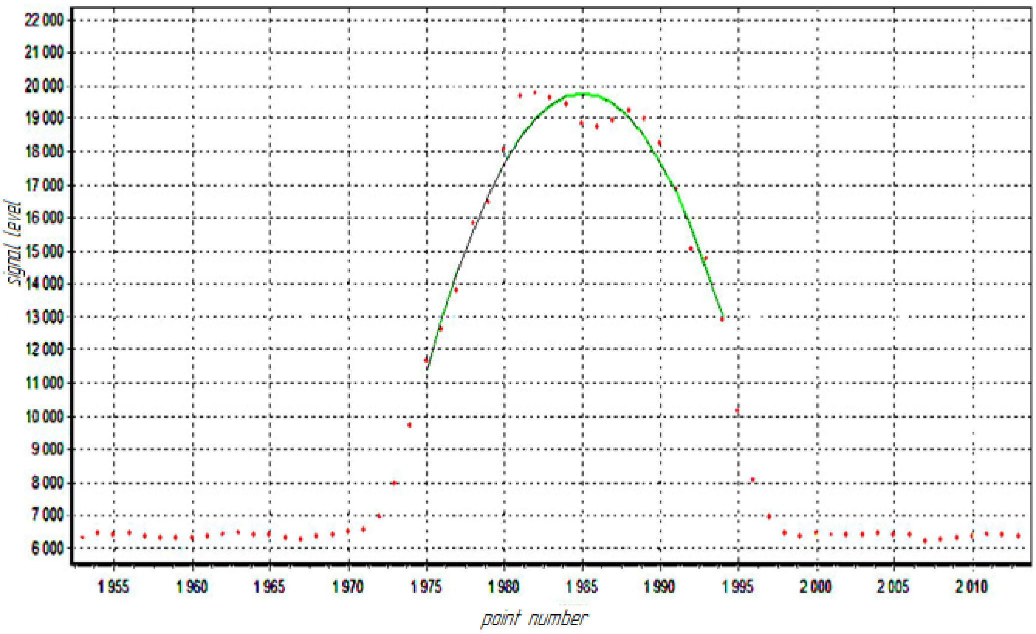

Figure-4. Dependence of the signal level on the photodetector on the position of the string.

The dots represent the graph constructed from the experimental data obtained, the solid line is the approximation of the experimental data.

More accurate data is planned for the next stage of work. Another positive point of application of the technique is possible to simulate various combinations of the photodetector / radiation source and the selection of the optimal combination.

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