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THE IMPROVING OF THE ACCURACY OF ENGINEERING AND GEODETIC WORKS IN THE CONSTRUCTION AND CONTROL OF THE GEOMETRIC PARAMETERS OF HIGH-RISE BUILDINGS

Abstract. In the article, the authors had done a brief analysis of existing modern, traditional methods and tools that allow to determine the planned coordinates of geodetic signs, located on the last tier of super-high engineering structures, paid special attention to the disadvantages and concluded that it's necessary to develop a method and device for determining the geodetic coordinates on ultra-high engineering structures with high accuracy to provide engineering and geodetic works during the construction and operation of high-rise structures.

In the article, the authors propose their method and device for determining the planar coordinates of the upper geodetic sign of the line of vertical design on ultra-high engineering structures with high accuracy, which is based on the method of the straight linear resection by the light distance meter. The result of the proposed method is the enhancing of the accuracy of engineering and geodetic works during the construction and control of geometric parameters of high-rise structures.

This method of distance measurements allows getting the enhancing of the accuracy of the engineering and geodetic measurements by fixing the moment of occurrence of the double frequency with root mean square error (RMSE) above 0.5 mm, thus eliminating the need to measure the phase difference between direct and reflected pulses. A particular advantage of the proposed method is that the accuracy of the measurements depends on the comparison of the radiated f and double f_g frequencies, which makes the measurement precision.

Key words: geodetic monitoring, vertical design, light distance meter, planned coordinates, construction of high-rise structures.

Review. During construction and often during the operation period of the high-rise engineering structures, the task to determine the planned coordinates of the geodesic sign, which is located on the top (roof) of the high-rise structure arises.

Let's consider briefly the advantages and disadvantages of the well-known methods of determining and transmitting the planned coordinates vertically. The method of constructing the vertical by mechanical plumb-line is the simplest, however, for the geodetic maintenance of the construction of multistore high-rise structures, this method cannot be used due to the low accuracy (1:1000 under favourable measurement conditions) of coordinate transmission [1].

There is a method of determining the coordinates of the upper geodetic sign (UGZ) by constructing two collimation planes with the sight axes of the total station located on the construction site [2], in which the intersection of the collimation planes forms a vertical line through which the planned coordinates are transmitting from the lower geodetic mark (LGM) top sign. Insufficient accuracy is associated with the unacceptable error (for this measurement ≥±10 of angular seconds) of cylindrical instrument levels, which gives a vertical error of ~ ±20 mm at a building height of 100 m.

More accurate is the method of optical or laser vertical design, which provides an accuracy of 1-2 mm for a building height of about 100 m [2].

At the same time, the requirements for the root mean square error of vertical design devices for high-rise structures exceeding 100 m are $\sigma_{x,y} = 0.5\ mm + 1 \cdot H$ [3], where $H \leq 0{,}01 \cdot H_{IC}$ (H_{IC} is the height of the engineering structure) that are representing a serious technical problem of vertical design.

For the most part, during geodetic monitoring of engineering structures, considerable attention is paid to determining the deformations of the foundation part of the structure by traditional geodetic methods and devices [1,2], but recently at the time of full automation cases of using non-traditional optoelectronic photosystems to determine deformations of not only the fundamental part of the structure, but the structure as a whole [4,5] and the territory as a whole [6].

Formulation of the problem. It follows from the above that it's necessary to develop a method and a device for determining the planned coordinates of the upper geodetic sign-on ultra-high engineering structures with high accuracy.

The purpose of the article. The determination of the planned coordinates of the upper geodetic sign of the vertical line on ultra-high engineering structures with high accuracy.

Presentation of the basic material. The authors created a method for determining the planned coordinates of the upper geodetic sign of the line of vertical design on ultra-high engineering structures [7]. It is based on the method of the straight linear resection by the light distance meter. To do this, the geodetic anchor of the central points of the light distance meter and the lower geodetic sign in the engineering structure in plan and by the height with the required accuracy is doing. Light distance meters are oriented to optical reflectors, which are mounted on the upper geodetic sign of the engineering structure and, changing the frequency of the pulse emitter, fix the distances from the light distance meters to the reflectors of the upper geodetic sign on the building at the time of occurrence in the channels of the light-distance meters' receivers of the dual-frequency radiation, calculating these distances for each of the light distance meters by the formula:

$$S = \frac{V \cdot n}{4f}, \qquad (1)$$

where V is the speed of light propagation in the atmosphere; f - is the frequency of light pulses; n - an odd number of periods of double-pulse $f_g = 2f$ radiation frequency; the number n is determined by the approximate value of the S' distance on a large-scale plan taking into account the angle of inclination of the light distance meters' beam and rounded to an integer odd number:

$$n = \frac{4S'f}{V}, \qquad (2)$$

at the same time, taking into account the data of the geodetic anchorage of the light distance meters, the coordinates of the upper geodetic sign x and y in the coordinate system of the engineering structure are determined by the values of the directional angles of the directions "lower geodetic sign - centre of the rangefinder" for at least two directions [7].

The method of determining the planned coordinates of the upper geodetic sign is implemented as follows [7].

In figure 1 it is shown a diagram of the location of geodetic signs of light distance meters.

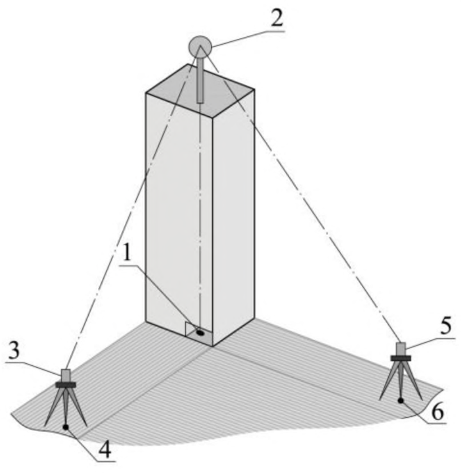

Figure 1 –
The scheme of location of geodetic signs
of light distance metres

The diagram (figure 1) indicates: 1 - lower geodetic vertical sign (LGS); 2 - upper geodetic vertical sign (UGS); 3, 5 - light distance metres; 4, 6 - geodetic signs.

Places for the installation of light distance metres are choosing at some distance from the controlled structure, paying attention to a sufficiently sharp angle of incidence of the light distance metres and direct visibility, equip land-based geodetic signs and stable bases for light distance metres in centres' projections and do the high-precision geodetic reference in horizontal and vertical projections of the mentioned geodetic signs and the lower geodetic sign of the controlled vertical relative to the construction coordinate system.

The method of determining the planned coordinates of the upper geodetic sign of the vertical line on ultra-high engineering structures is implemented using a light distance metre device [5]. Thus, the authors proposed two options for determining the coordinates of the upper geodetic sign in the absence of rocking of the structure and the case of the rocking of the structure.

The block diagram of the light distance metre device (figure 2) contains [7]:

1 – the block of controlling and processing of the information;
2 – the block of the high-frequency generator;
3 – the block of modulation of the frequency;
4 –the block of radiation of light pulses;
5 – the reflector;
6 – the optical and electronic receiver;
7 – the mixer of frequencies of direct and reflected light pulses;
8 – the block of separation and comparison of the mixed frequency and the radiation frequency;
9 – the block of indication;
10 – the block of recording and storage of the information.

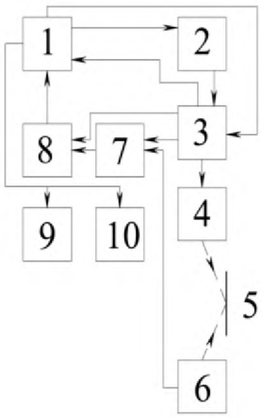

Figure 2 – Block diagram of the light distance metre device

All blocks, except block 5, are installed in the body of the light distance metre's channel. In Fig. 2 the electrical connections are indicated by solid lines and the optical connections by the dashed lines.

Consider the procedure in two ways:

1. In the absence of rocking of the structure.
2. When the structure is rocking.

The light distance meter works as follows. Block 1 activate other units of the device and sends the command to block 2, which generates a frequency $f$of the radiation. Block 2 through block 3 sends the frequency to block 4; block 4 emits pulses of the light signals which are coming to the reflector 5. The reflected light pulses reflected from the reflector come to block 6, where the pulsed light signals are converted to electric with the main frequency f of the reflected pulses and are transmitted to the block 7; at the same time, the block 7 receives electrical signals from block 3 with the fundamental radiation frequency f (direct pulses). During the changing of the frequency in block 3 the interval of the time between direct and reflected signals changes. At the moment when this time interval will be $\tau = \frac{T}{2}$, where

T is the period of frequency, in the mixer 7 the double frequency $f_g = 2f$ appears, which goes from block 7 to block 8. In block 8, the frequency is divided into two. Also block 8 receives from block 3 the current radiation frequency *f*, which is compared with the frequency $\frac{f_g}{2}$. At the moment of the coincidence of these frequencies, the signal of the presence of the equality of frequencies $f = \frac{f_g}{2}$ from block 8 comes to block 1. Into block 1 also comes from block 2 values of the current frequency at the time of the coincidence. The number *n* is determined by the approximate value of the distance on a large scale (2).

In the end, determine the distance from the device to the reflector just for the moment of the coincidence of frequencies $f = \frac{f_g}{2}$ according to the formula (1) is determining.

To determine the coordinates of the upper geodetic sign of the structure in conditions of wind sway on the upper floors, the proposed method is implemented within the schemes shown in figure 1 and 2. At the same time, into a light distance metre device the low-frequency modulation of the main high-frequency modulation of the light pulse radiation is putting, and it's performing by block 3 on the command of block 1 (figure 2). Low-frequency modulation allows with a small amplitude of the rocking of the upper geodetic sign and with the rocking of the main frequency *f* in small limits, leaving an known number *n* to be constant, to obtain a sufficient number of points of double current frequency $f_g = 2f$ and the moments of its appearance to graphic of deviation of the upper geodetic sign from the vertical in axis *X* and *Y*. Visualization of such a graphic makes it possible to do vertical control in dynamics.

The work of the light distance metre is doing mainly according to the scheme shown in figure 2 and differs from the mentioned above version of the work in that it turn on the low-frequency modulation in block 3 f_H and block 4 radiates pulses of signals from block 3 from which signals are received in block 7 (communication "block 2 - block 4" and "block 2 - block 7" in this case does not work). Otherwise, all the blocks work according to the scheme in figure 2.

The distances are determined by the formula (1) at a constant value *n*, only the frequency is changing. With the known value of the number *n* (which can be determined in advance, for example, when the engineering structure is in the state of calm), in advance, the values of deviations ΔS_i are calculating for the points of the trajectory of the upper geodetic sign, in which there is a double frequency f_{g_i} appears. That is, from formula (1) it turns out that, $\Delta S_i \approx \frac{\Delta f_i}{f_i} S_i$, so, defining moments t_i on the occurrence of double frequency f_{g_i} using the data ΔS_i, Δf_i and t_i build a graphic that shows the dynamics of the rocking of the upper geodetic sign and the moment of finding the upper geodetic sign on the vertical.

When the location of the light distance metre rays near the planes of the structure *XOZ* and *YOZ*, $\Delta x_{i_{UGS}}$ and $\Delta y_{j_{UGS}}$ will accordingly be equal to $\Delta x_{i_{UGS}} = K_1 \Delta S_{i_1}$ and $\Delta y_{j_{UGS}} = K_2 \Delta S_{j_2}$, where *K* is the coefficient that considers the angle of inclination of the light distance metre beam.

To evaluate the accuracy of the determining the distance *S*, we differentiate (1) the variables f_g and *V*, considering the number of wavelengths and, passing to the RMSE , we get

$$m_S = \frac{n}{4}\sqrt{\left(\frac{V}{f_g^2}\right)^2 m_{f_g}^2 + \left(\frac{1}{f_g}\right)^2 m_V^2} .$$

As it is known from the literature, the error of a single measurement of the distance of the phase light distance metre is determining by the [8]:

$$m_S = \sqrt{S^2\left(\frac{m_v}{v}\right)^2 + S^2\left(\frac{m_f}{f}\right)^2 + \left(\frac{v}{4\pi f}\right)^2 m_{\Delta\varphi}^2 + m_k^2} ,$$

where $\frac{m_V}{V}$ and $\frac{m_f}{f}$ are relative errors due to inaccurate determination of the speed of light propagation in the atmosphere and the inaccurate measurement of the radiation frequency; $m_{\Delta\varphi}$is the phase measurement error; m_k is the error of calibration of the light distance meter.

In the process of measuring the distance by the light distance meter, which is proposed by the authors of this article, the phase measurement operation is excluded, it remains:

$$m_S = \sqrt{S^2\left(\frac{m_v}{v}\right)^2 + S^2\left(\frac{m_{fg}}{f_g}\right)^2 + m_k^2}. \quad (3)$$

Thus, the composition of the errors, which depends on the measured distance, will be as follows:
1) $\frac{m_v}{v} = 10^{-6} \div 10^{-7}$. At short distances to 1-1,5 km $\frac{m_v}{v} = 1km \cdot 10^{-6} = 1mm$;
2) $\frac{m_{fg}}{f_g} = 10^{-6} \div 10^{-7}$. At short distances to 1-1,5 km $\frac{m_{fg}}{f_g} = 1km \cdot 10^{-6} = 1mm$.
Substitute the obtained values in (3) with the proviso that distances *S* = 1-1.5 km, we obtain

$$m_S = \sqrt{S^2\left(\frac{m_v}{v}\right)^2 + S^2\left(\frac{m_{fd}}{f_d}\right)^2} = 1.5\, mm. \quad (4)$$

Errors m_c and m_{in} are the errors of the centring of the light distance meter and the reflector installation, for the high-precision measurements should be taken tolerances for at least 0.1 mm. The error of calibration m_{cal} will be 0.2 mm.

Considering the components of the error we get:

$$m = \sqrt{m_c^2 + m_{in}^2} = \sqrt{0{,}1^2 + 0{,}2^2} = 0.22\, mm. \quad (5)$$

Considering (4) and (5), we obtain the general formula of the RMSE distance measurement for the pulse-frequency light distance metre proposed by the authors of this article:

$$m_S = \left(0.22 + 1.5 \cdot \mathrm{S} \cdot 10^{-6}\right) mm.$$

Thus, during the usage of the impulse-frequency light distance metre suggested by the authors, during the measurement of short distances for engineering and geodetic work (up to 1-1.5 km), the accuracy of the measurements will mainly be affected by the errors m_c, m_{in}, m_{cal}.

The conclusion. Therefore, this method of light-distance metre measurements allows obtaining an increase in the accuracy of engineering and geodetic measurements by fixing the moment of occurrence of the double frequency with RMSE above 0.5 mm, thus eliminating the need to measure the phase difference between direct and reflected pulses. A particular advantage of the proposed method is that the accuracy of the measurements depends on the comparison of the radiated f and double f_g frequencies, which makes the measurement precision.

According to the obtained data, the graphs of oscillations of the upper geodetic sign relative to the vertical in the directions of the axes *X, Z* of the engineering structure are constructed and they are used to control the verticality during the construction and installation of technological equipment. Equally useful will be the device and method to perform geodetic deformation control during the operation of engineering high-rise structures.

Thus, the method of light-distance metre measurements proposed by the authors allows doing the determination of the vertical with high accuracy in conditions of the oscillations of ultra-high engineering structures.

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БИІК ҚҰРЫЛЫСТАРДЫҢ ГЕОМЕТРИЯЛЫҚ ПАРАМЕТРЛЕРІН ТҰРҒЫЗУ ЖӘНЕ БАҚЫЛАУ БАРЫСЫНДА ИНЖЕНЕРЛІК-ГЕОДЕЗИЯЛЫҚ ЖҰМЫСТАРДЫҢ ДӘЛДІГІН АРТТЫРУ

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ПОВЫШЕНИЕ ТОЧНОСТИ ИНЖЕНЕРНО-ГЕОДЕЗИЧЕСКИХ РАБОТ ПРИ ВОЗВЕДЕНИИ И КОНТРОЛЕ ГЕОМЕТРИЧЕСКИХ ПАРАМЕТРОВ ВЫСОТНЫХ СООРУЖЕНИЙ

Аннотация. В статье авторы выполнили сжатый анализ существующих современных традиционных методов и устройств, позволяющих определять плановые координаты геодезических знаков, размещенных на последнем ярусе сверхвысоких инженерных сооружений, особенное внимание уделили недостаткам существующих способов. Общеизвестные способы, а именно способ построения вертикали с помощью механического отвеса, несмотря на то, что является наиболее простым в использовании – не обеспечивает необходимую точность при строительстве многоэтажных высотных сооружений, предельная точность этого способа составляет 1:1000 при условии благоприятных условий измерений; следующий способ определения координат верхнего геодезического знака при помощи построения двух коллимационных плоскостей визирными осями оптико-электронного тахеометра аналогично не обеспечивает требуемой точности, при высоте сооружения 100 м ошибка по вертикали составляет ~+20 мм; наиболее точный из известных способов на сегодняшний день является способ оптического или лазерного вертикального проектирования, который обеспечивает точность 1-2 мм для высоты сооружения приблизительно 100 м, но, как мы понимаем, этой точности также недостаточно. Авторы, проанализировав известные способы определения плановых координат геодезических знаков, размещенных на последнем ярусе сверхвысоких инженерных сооружений, пришли к выводу, что необходимо разработать способ и устройство определения плановых координат верхнего геодезического знака на сверхвысоких инженерных сооружениях с повышенной точностью для обеспечения инженерно-геодезических работ во время строительства и эксплуатации высотных инженерных сооружений.

В статье авторы предлагают собственные способ и устройство определения плановых координат верхнего геодезического знака линии вертикального проектирования на сверхвысоких инженерных сооружениях с повышенной точностью, который основан на методе прямой линейной засечки светодальномерными измерениями, при этом выполняют геодезическую привязку центральных точек светодальномеров нижнего геодезического знака в инженерном сооружении в плане и по высоте с необходимой точностью, светодальномеры ориентируют на оптические отражатели, установленные на верхнем геодезическом знаке инженерного сооружения и, изменяя частоту излучения импульсов, фиксируют расстояния от светодальномеров до отражателей верхнего геодезического знака, размещенного на сооружении, в моменты возникновения в каналах приемников светодальномеров двойной частоты излучения, вычисляя эти расстояния для каждого из светодальномеров.

Результатом предложенного авторами способа является повышение точности инженерно-геодезических работ при возведении и контроле геометрических параметров высотных сооружений.

Данный способ светодальномерных измерений позволяет получить повышение точности инженерно-геодезических измерений за счет фиксации момента появления двойной частоты со средней квадратической ошибкой не хуже +0,5 мм, при этом исключают необходимость измерения разницы фаз между прямыми и отраженными импульсами. Особенное преимущество предложенного авторами способа состоит в том, что точность измерений зависит от сравнения излучаемой и двойной частот, что делает измерения прецизионными.

Ключевые слова: геодезический мониторинг, вертикальное проектирование, светодальномер, плановые координаты, возведение высотных сооружений.

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REFERENCES

[1] Voytenko S.P. (2009) Engineering geodesy. Knowledge, Ukraine. ISBN: 978-966-346-895-2

[2] Baran P.I. (2012) Engineering geodesy. VIPOL, Ukraine. ISBN 978-966-646-125-7

[3] DBN B.1.3-2: 2010 "Geodetic works in construction". Ministry of Regional Development of Ukraine, 2010.

[4] Malik T., Bryk Ya., Zatserkovnyi V., Belenok V. (2019) Evaluation of engineering structures deformation (accuracy) // Visnyk Taras Shevchenko National University Of Kyiv Geology, 1 (84). P. 77-82. DOI: 10.17721/1728-2713.84.11 (in Eng.).

[5] Burachek V., Malik T., Kryachok S., Bryk Ya., Belenok V. (2018) Device for automated leveling / News of the National Academy of Sciences of the Republic of Kazakhstan, series of geology and technical sciences. Vol. 5, Issue 431. P. 95-99. DOI: 10.32014/2018.2518-170X.13 (in Eng.).

[6] Tereshchuk O.I., Korniyenko I.V., Kryachok S.D., Malik T.M., Belenok V.Y., Skorintseva I.B. (2019) Research of systematic errors according to the results of processing satellite observations by software complexes // News of the National Academy of Sciences of the Republic of Kazakhstan, series of geology and technical sciences. Vol. 4, Issue 436. P. 199-212. DOI: 10.32014/2019.2518-170X.115 (in Eng.).

[7] Bryk Ya., Burachek V.G., Malik T.M. (2017) The method of determining the planned coordinates of the upper geodetic sign of the vertical line at ultra-high engineering structures. Patent of the Ukraine № 114959 [Patent Ukrainy na izobreteniye] (in Ukr.).

[8] Voronkov N.N., Plotnikov V.S., Kalantarov E.I. (1991) Geodesy. Geodesic and Photogrammetric Instruments: Reference Guide; under. ed. Savinykh V.P., Yashchenko V.R. Nedra, M. (in Russ.).