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Modern approaches to studying the accuracy of determination of deformation values in geodesic monitoring of crane equipment

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Abstract

The purpose of the research, the materials of which are presented in this paper, is to reveal modern approaches to combat the deformation of geometric parameters in the construction of electric overhead cranes. This issue is quite relevant in terms of compliance with safety requirements at work. To solve this issue, it is proposed to use the improved technique of geodetic monitoring of geometric parameters of constructions of overhead and electric gantry cranes. The paper describes a laser-mirror system for controlling geometric parameters, which allows considering fairly strict requirements. This method, as demonstrated by experimental data, is one of the most reliable and accurate. The authors developed and used the installations of the “Laser beam – mirror” system, which shall meet clear methodological requirements. It is shown that the deviation from the correct installation of the mirror in the vertical plane leads to an increase in measurement errors. The research was carried out with the help of a laser mirror device. As a result of the research and using the procedure developed by the authors, a rectangular scale for fixing the laser beam was proposed. The implementation of the results obtained by the authors will allow establishing the accuracy of measurements within the limits of permissible values. In addition, the existing permissible deviations of the geometric parameters of the constructions of overhead cranes at industrial enterprises were analysed. The authors identified the shortcomings of modern existing methods and proposed new geodetic equipment and methods of their implementation. The paper examines the accuracy of the developed methods that can ensure and increase the guarantee of safe operation of overhead cranes.

Keywords: overhead crane; gantry crane; tower crane safety; measurement method; geodetic control; geometric parameters.

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Statement of the problem

Electric overhead cranes are the most widely used in industry for movement of goods. Problems for normal and trouble-free operation and lifting of vehicles are caused by the deformation of geometric parameters in the construction of the crane equipment.

Now, a few different types of geodetic measurements and methods have been developed to determine the deviation from the design position of constructions of overhead cranes [1]. However, in practice, the problem of improving the technique of geodetic monitoring of the crane equipment is urgent and insufficiently addressed.

To ensure safety under industrial conditions, there are regulatory documents that specify permissible deviations in the construction of overhead cranes, gantry cranes, and others.

The task of this work is to improve and increase the accuracy of measurement methods and geodetic control of geometric parameters of constructions of overhead and electric gantry cranes to comply with safety requirements when performing work at industrial enterprises.

Analysis of recent research and publications

When determining the transfer angles of the running wheels of overhead and electric gantry cranes,

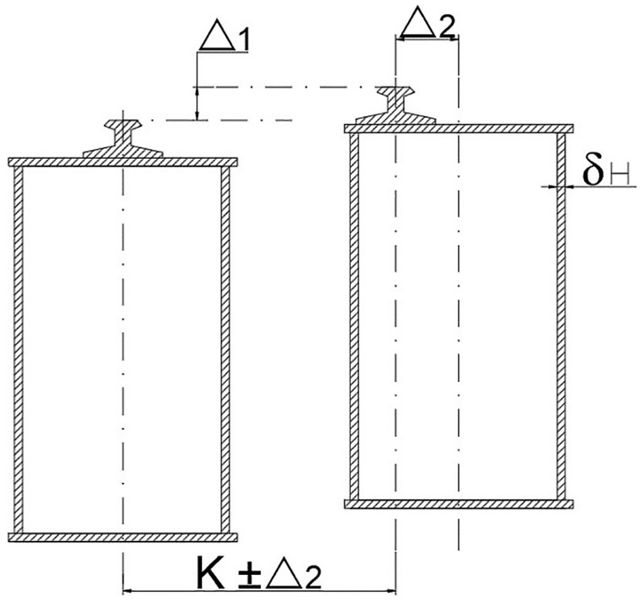

Fig. 1. Permissible deviations of crane constructions

methods and tools based on laser-mirror devices, considered in works [2], were proposed.

A safety inspection is an important procedure for the operation of overhead cranes. However, to ensure effective verification, quite a few issues should be addressed [3].

The monitoring of structural damage for large structures such as overhead and electric gantry cranes is inconvenient and difficult. The problem of predicting buckling boom damage for cranes can be solved using a Gaussian process regression model. This approach will help to obtain better results in point and interval forecasting, thus improving the accuracy of the model [4–7].

The paper [8] analyses the problems of damage to the under-crane track because of the operation and describes the inspection of beams of the under-crane track and the determination of residual durability. Based on the obtained data, it is possible to determine the residual resource of the construction under consideration.

Outline of the main material

Recently, a few various geodetic measurements, methods, and devices have been developed to determine the degree of deviation from the design position of the construction of overhead cranes. However, in practice, the problem of improving the technique of geodetic monitoring of the crane equipment is urgent and insufficiently addressed.

To comply with safety regulations, there are permissible deviations in the construction of overhead, gantry, and other cranes. Fig. 1 shows the permissible deviation of the rails of the bridge of the electric overhead crane in a cross-section. It should not exceed [9]:

$$\Delta_2 \le \frac{1}{500} K, \tag{1}$$

where K is the width of the span between the undercarriage rails (at K = 2.0 m, $\Delta_2 \le \pm 4$ mm).

The deviation of the axis of the undercarriage rail from the design position in height should not exceed [9]:

$$\Delta_1 \le \pm 1.0 * \delta_H, \tag{2}$$

where δ_H is the thickness of the structure of the longitudinal beam of the crane bridge.

The permissible deviation of the running wheels of the crane Δ from the theoretical straight axis should not exceed [9]:

$$\Delta = K * D, \tag{3}$$

where $K \le 0.0006$.

With the diameter of the running wheel D = 500 mm, Δ = 0.30 mm.

When studying the existing tolerances, it should be noted that the deviations of the actual position of the crane constructions from the design position are quite strict, for example, within 0.3–4 mm. It is for these reasons that to comply with the standards, it is necessary to have high-quality, accurate and perfect methods and tools that allow determining the indicators of deviations with the necessary and guaranteed accuracy.

The method of measurement accuracy based on the proposed method is a complex process that depends on many factors and requires constant improvement in observations and research.

The purpose of the proposed method is to determine the magnitudes of errors in measuring

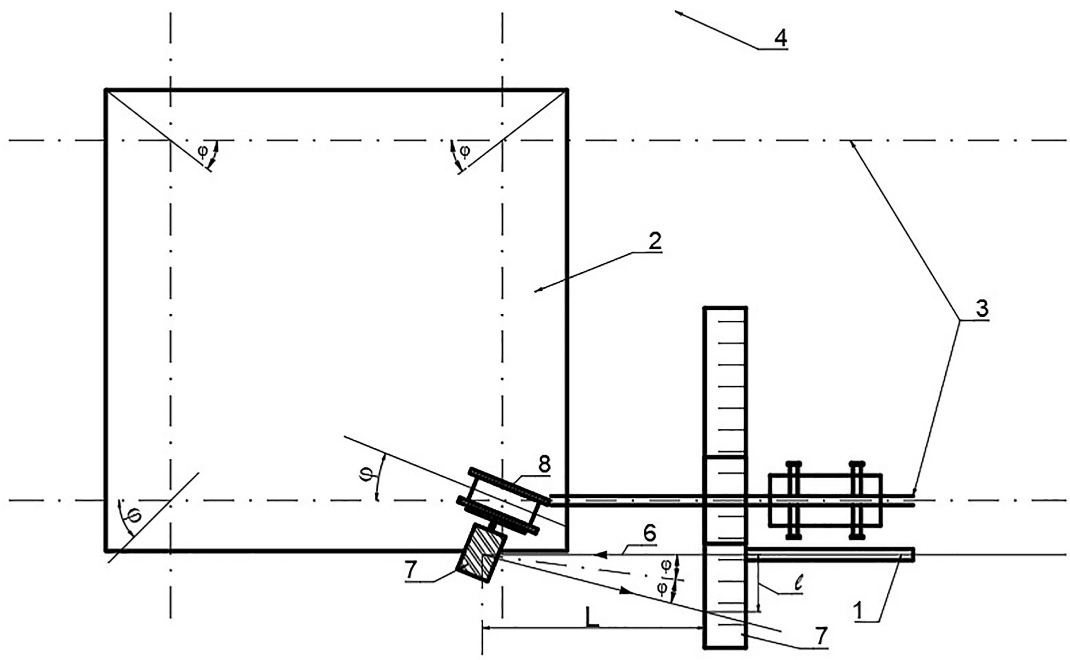

Fig. 2. Determination of the misalignment angles of the running wheels

deformations of crane equipment, their dependence on the position of the laser beam in real, rather complex production conditions.

Let us consider the influence of the installation error of the mirror of the laser-mirror device in a vertical position on the accuracy of measuring the angles of misalignment of the running wheels of overhead cranes.

Fig. 2 shows the general view of the laser-mirror installation 1, which is installed on the track 3 of the trolley 2 of the overhead crane 4.

To determine the deformation of geometric parameters of the crane construction, and in particular the skew angles φ of the running wheels 8, the laser beam 6 is directed parallel to the rail axis at the mirror reflector 7, which is attached to the running wheel 8. The angle φ will be determined by the formula [10]:

$$\varphi = \frac{l * \rho'}{2L}, \tag{4}$$

where l is the reading on scale 7 of the installation;

L is the distance between the running wheel and the scale of the laser installation; ρ' is the radian in minutes.

In this case, it is important to determine the accuracy of measuring the skew angles, which will be done by the formula:

$$M_\varphi = \frac{M_l * \rho'}{2L}, \tag{5}$$

where M_φ is the error of determining the angle φ; M_l is the measurement error of distance l on scale 7 (Fig. 2).

Based on formula (5), the accuracy directly and proportionally depends on the accuracy of readings of the laser beam reflected from the mirror 5. The accuracy can depend on various factors.

Let us consider the correlation of errors from the setting of the mirror in a vertical position.

Fig. 3 shows mirror A installed in a vertical position with an error of δ. The horizontal beam of the OK laser device is directed at the mirror.

After reflection from the mirror, the ray leaves the light point M on the screen B. The ray is

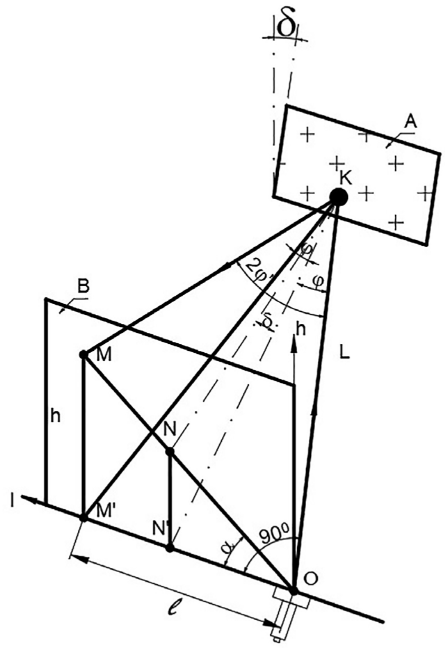

Fig. 3. Scheme of correlation of errors from mirror installation

Table 1

Dependence of the correlation value of errors relative to the screens

Numbers of running wheels of crane equipment	Counts l across the screen		The values of the skew angles		Value of angular deviations, minutes
	On a rectangular scale, mm	On the scale at an angle, mm	On a rectangular scale, minutes	On the scale at an angle, minutes	
1	30.5	38.3	4.1	5.2	1.1
2	23.0	34.1	3.2	4.7	1.5
3	40.7	47.3	5.5	6.4	0.9
4	17.5	28.8	2.3	3.3	1.0
5	15.0	25.0	2.1	3.4	1.2
6	8.0	17.0	1.1	2.3	1.2
7	48.0	57.5	6.6	7.8	1.2
8	92.4	96.8	25.4	26.6	1.2

incident and reflected. It lies in the same plane with the normal N relative to the mirror and points O, N, M lying on the same straight line. With the vertical position of the mirror A, the true value of the angle 2φ is the angle OKM'. Because the mirror is deviated from the vertical with an error of δ, instead of the angle $OKM' = 2\varphi$, we get the angle $OKM = 2\varphi'$. The difference $\Delta\varphi = \varphi' - \varphi$ is the error of measuring the angle φ, due to the error δ of setting the mirror in the vertical position.

The correlation between φ and φ' can be established based on Fig. 3 as follows:

$$\mathrm{tg}2\varphi = \frac{l}{L},\ \mathrm{tg}2\varphi' = \frac{l}{\cos\alpha * L}. \quad (6)$$

Due to the smallness of the angles φ and φ', we can write:

$$\varphi' = \frac{\varphi}{\cos\alpha}. \quad (7)$$

It can be seen from equation (7) that the angle φ is the horizontal projection of the angle φ'. To obtain it, it is necessary to obtain readings $l = OM$ on the screen B from the light point M. This can be solved if a rectangular coordinate system is created on the screen B. This coordinate system is followed according to the proposed procedure. In this system, the installation in the ideal position is ensured with high accuracy along the reflected beam. By rotating the mirror around the horizontal axis the reflected beam from the OK mirror is directed to the scale l.

For more reliable information about the accuracy of measurements of geometric parameters of the crane equipment, let us consider an example of the use of two types of screens: rectangular and at a given angle. The laser device was installed at 12.5 meters from the running wheels. When determining the readings for accuracy on the scales, special recording devices were used, which allowed taking readings with an accuracy of $m_l = \pm 1.0$ mm with a permissible error [10]:

$$M_l = \frac{M_\varphi * 2L}{\rho'} = \frac{0.3' * 25000\mathrm{mm}}{3438'} \pm 2.2\mathrm{mm}. \quad (8)$$

All experimental measurements are listed in Table 1.

The value of the angle of misalignment of the running wheels was determined according to formula (4).

According to the data in Table 1, the difference between the values of the skew angles φ and φ' is on average within 0.9'–1.5' at the permissible error of the difference [9, 11]:

$$M_{\varphi\ \text{доп}} = \pm\frac{\Delta\varphi}{3} = \frac{2.1'}{3} = \pm 0.7', \quad (9)$$

where Δφ is the value of the permissible error of the deviation of the travelling wheel of the overhead crane, equal to 2.1'.

Thanks to the experimental studies given in Table 1, the difference in the values of the misalignment angles of the running wheels is almost two times greater than the value of the permissible error. These results confirm the use of a new rectangular laser beam fixation scale.

Results

The authors proposed a method of measurement and geodetic control of geometric parameters of overhead and electric gantry cranes using the proposed laser-mirror device.

Conclusions

The use of a laser-mirror system for controlling the geometric parameters of the crane equipment allows considering strict requirements. Thus, the method proposed in the paper is one of the most reliable and accurate when performing measurements.

Installation of the "Laser beam – mirror" system shall meet clear methodological requirements. The research carried out by the authors shows that the deviation from the correct installation of the mirror in the vertical plane leads to an increase in measurement errors.

The conducted research has shown that the optimal distance between the scale and the mirror should be within 12.5 m.

The introduction of a rectangular scale for fixing the laser beam reflected from the mirror allows establishing the accuracy of measurements within permissible values.

Сучасні підходи до дослідження точності визначення величин деформації при геодезичному моніторингу кранового устаткування

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Анотація

Метою дослідження, матеріали якого викладено в цій статті, є розкриття сучасних підходів боротьби з деформацією геометричних параметрів у конструкції мостових електричних підіймальних кранів. Це питання досить актуальне в розрізі дотримання техніки безпеки на виробництві. Для вирішення цього питання пропонується використання вдосконаленої методики геодезичного моніторингу геометричних параметрів конструкцій мостових і козлових електричних підіймальних кранів. Для цього використовується лазерно-дзеркальна система контролю геометричних параметрів, яка дозволяє враховувати досить жорсткі вимоги. Цей метод, як продемонстрували експериментальні дані, є одним із найбільш надійних і точних. Було розроблено й використано установку системи "Лазерний промінь – дзеркало", яка має відповідати чітким методичним вимогам. Виконані дослідження демонструють, що відхилення від правильної установки дзеркала у вертикальній площині призводить до збільшення похибок вимірювань. Дослідження виконувалися за допомогою лазерного дзеркального приладу. Внаслідок виконаного дослідження та керуючись розробленою методикою, було запропоновано прямокутну шкалу фіксації лазерного проміння. Це дозволить встановити точність вимірювань у межах допустимих значень. У дослідженні виконано аналіз наявних допустимих відхилень геометричних параметрів конструкцій мостових підіймальних кранів на промислових підприємствах. Визначено недоліки сучасних наявних методів і запропоновано нові геодезичні устаткування та методи їх виконання. Було проведено дослідження точності запроєктованих методів, які зможуть забезпечити й підвищити гарантію безпеки експлуатації мостових підіймальних кранів.

Ключові слова: мостовий підіймальний кран; козловий підіймальний кран; безпека баштового крана; методика вимірювань; геодезичний контроль; геометричні параметри.

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