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Review / Pregledni znanstveni članak

Research of the Accuracy in Defining an Exceeded Value between the Diametrically Opposite Points, when Using the Electronic Levelers on a Polar Crane

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ABSTRACT. This research paper offers and tests the methods of applying the electronic levelers, meant for leveling the rails under polar cranes at a Nuclear Power Plant, which ensures the required accuracy of geodetic control over polar crane tracks. The exceeded values were directly measured between the typical points of a crane track, made up of 4 (four) points ("virtual" stations), by using the precision electronic leveler Sprinter 150M and high-precision leveler Topcon DL-501. When processing the results, such main error limits were calculated: taking the readings, tilting of the rail, measuring the exceeded value present due to an angle and due to unevenness of levers at the station. The results were analyzed in comparison with the tolerances for determining an exceeded value between the diametrically opposite points of a rail track, thus confirming the reasonability and convenience of using the high-precision and precision electronic levelers.

Keywords: engineering geodetic methods, an electronic leveler, a polar crane, accuracy in defining an exceeded value.

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1. Introduction

The presence of extra-harmful work conditions in the premises of Nuclear Power Plants makes its corrections in the process of geodetic works. Human access to the Reactor Compartment (RC) is possible only during a shutdown period of the reactor. Therefore, the developed methods of geodetic control over the rail tracks of polar cranes must ensure the highest productivity and reliability of the results obtained, partial or full automation of the measurements taken. The results of geodetic measurements are significantly influenced by air fluctuations, vibration, temperature drop, crane movement, etc. (Burak and Shpakivskyi 2011, Burak et al. 2012). As of today, it is recommended to use electronic levelers (EL) instead of high-precision optical levelers, which were applied for leveling the rail tracks of polar cranes, because electronic levelers (EL) have a number of great advantages (easy to use, far higher labor productivity, absence of observer's errors when taking the readings, etc.). The permitted height difference of rail heads between the diametrically opposite points of Reactor Compartment rail tracks is ±5 mm. The range of methods are suggested to provide this accuracy in using the precision and high-precision digital levelers.

2. Analysis of recent studies and publications regarding the solution to this problem

The deformations of crane rail tracks can lead to operation shutdown in a crane and, as a result – impossibility to perform any scheduled and preventive maintenance works (SPW). There exist many research works on cranes at present. Taking into account the trolley moving, the control over load deflections was studied in some sources of literature (Kim et al. 2004, Kim and Hong 2009, Belunce et al. 2015). Various methods are used to determine the planned height position of a crane track. Such scientists as Burak K.O. (Burak 1993, Burak 1995, Burak and Shpakivskyi 2012), Ruskov (Ruskov and Boglov 1984), Baran, Ganshin and Repalov (Baran et al. 1980) were dealing with the issue of determining the planned position of a crane track, paying little attention to height position. The research paper (Zhaohui and Huitao 2017) offers a systemic method of analyzing the movement trajectory of a hook block of polar crane at Nuclear Power Plant (NPP), which provides the dynamic equations of a system and the compatibility conditions of drum parameters.

Scientists often pay attention to the methods based on photo-fixation of the typical points of crane rails, such as Terrestrial Laser Scanning (TLS) (URL 1) and Photogrammetry of Unmanned Aircraft System (UAS) (URL 2). The methods of applying Laser Scanning are being improved by means of determining the scanning geometry (Soudarissanane et al. 2011), thus significantly increasing the quality of Terrestrial Laser Scanning points. Apart from that, this method is also user-friendly in monitoring the condition of engineering structures (Park et al. 2007, Schofield and Breach 2007). The research work (Mill et al. 2015) indicates that earlier the usage of Terrestrial Laser Scanning data was tested for deformation monitoring, although the conventional geodetic technologies are still more effective; in their research work, the authors focused on studying the metrological advantages of Terrestrial Laser Scanning technology for monitoring the deformation of structures. Such methods are very promising and ensure sufficient accuracy in open engineering objects.

In the research work (Marjetič et al. 2012), a general method of defining the position of rails in horizontal and vertical position was used to measure the geometry of crane rails in one of industrial buildings of the Brestanica Thermal Power Plant (TPP) via using the electronic tacheometer Leica Geosystems TS30. Electronic tacheometers are user-friendly for simultaneous defining both the horizontal and vertical position of axis points of crane rails in a controlled section of crane tracks.

In the above-listed works, it is suggested to use both optical devices and electronic ones, in particular – tacheometers, but there exist no well-grounded methods of using electronic levelers, to which this research work is dedicated.

3. Scientific novelty and practical significance

The geometric parameters of crane rail tracks are to be controlled in the first days of scheduled and preventive maintenance works (SPW), prior to the start of technological repair operations (SOU-N MEV 40.1-00013741-79 2012). The cyclicality of determining the parameters of a polar crane depends on its operation conditions and performance reliability of crane structures. On an average, it is one cycle per year during the scheduled and preventive maintenance works (SPW) in accordance with the requirements of regulatory documents. An extremely important and topical task is the increasing of promptness of geodetic control over the operational reliability of Reactor Compartment crane tracks by introducing new methods and technologies. Therefore, there rises a need to work out the methods of measurements that would ensure the accuracy of defining an exceeded value between the diametrically opposite points of rail track $m_h = \pm 2$ mm. It is suggested to perform this measurement from the service platform with a polar track thereon.

4. Presentation of the main material

With the appearance of new up-to-date electronic levelers, the task arose consisting in developing and substantiating a range of methods used to measure a rail track under a polar crane sited in the Reactor Compartment. It goes about measuring the exceeded values between the typical points of a crane track by using an electronic leveler, namely the four points ("virtual" stations), located on the service platform of a crane track. It is necessary to ensure the accuracy of determining the exceeded value between the diametrically opposite points of crane track $m_h = \pm 2$ mm. Let's ground the method of measurements, when using the precision electronic levelers (Sprinter 150M) and high-precision levelers (Topcon DL-501).

Periodically specialized a technological equipment passes testing in the accredited scientifically metrological center State Enterprise „Ivano-Frankivsk Scientific and Production Center for Standardization, Metrology and Certification" (SE „Ivano-Frankivsk Standard Metrology"). Corresponding quality certificates testify to it. Testing results in calculations were not taken into account, as they are considerably less the declared exactness of device.

As the rail track of polar crane is 41.5 m in diameter, the lever length does not exceed 25 m during leveling (Ruskov and Boglov 1984, Baran et al. 1980), whereas the stroke length is approximately equal to 66 m. between the diametrically opposite points.

In general, the sources of leveling errors can be divided into 3 (three) groups (Baran et al. 1980). The first group includes the errors related to a leveler, the second group includes the errors related to a rail, and the third group includes the errors related to impact of external environment.

Having analyzed the effect of the above sources, it was established that the following errors will be relevant when leveling a polar crane track:

1. Taking the readings.
2. Due to rail tilt.
3. Measuring the exceeded value present due to an angle and due to unevenness of levers at the station.

The BGS 40 fiberglass rail with a GS60L level is used for vertical installation during the leveling of the crane track. The manufacturer provides a scale of corrections for the temperature expansion of the rail.

The track of the polar crane is located in the facility with a stable ambient temperature of 20–25 °C. As exceeding between points at the station of leveling does not exceed a 1 cm and the temperature of environment is stable, then the size of amendment according to the scale in the measured exceeding for temperature expansion of rail does not exceed a 0.001 mm. That is why this amendment it is possible to ignore.

Before starting the measurements, the 48 (forty-eight) holes 3 mm in diameter are marked with a core and drilled at the distance of 20 mm from the inner edge of rail track, with the interval of 2.81 m (as the track length is ≈ 135 m) (Fig. 1).

The obtained points are numbered in such a way that the points 1, 25 would approximately coincide with the direction of construction axis I – I, while the points 37, 13 – with the direction of construction axis II – II (Fig. 1).

We install a polar overhead crane as shown in Fig. 1. Its service platform (item 4) has a rack with an electronic leveler, which is installed in the midline between the points 10–11. Successively, we install a rail at all visible points and determine the exceeded value in sector 1÷20. After the measurements are taken, we shift the electronic levelers between the points 35–34. Similarly, we take measurements in sector 25÷44 (Fig. 2).

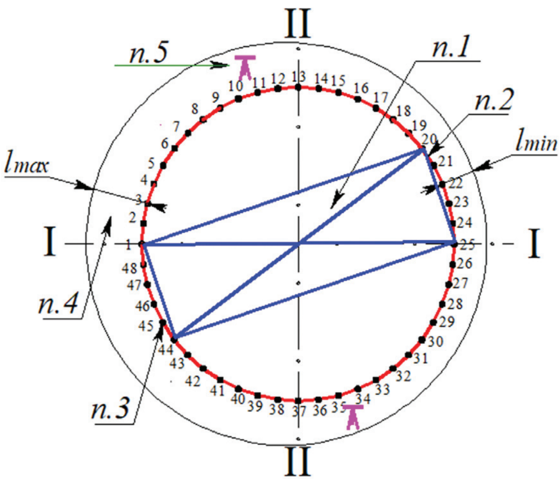
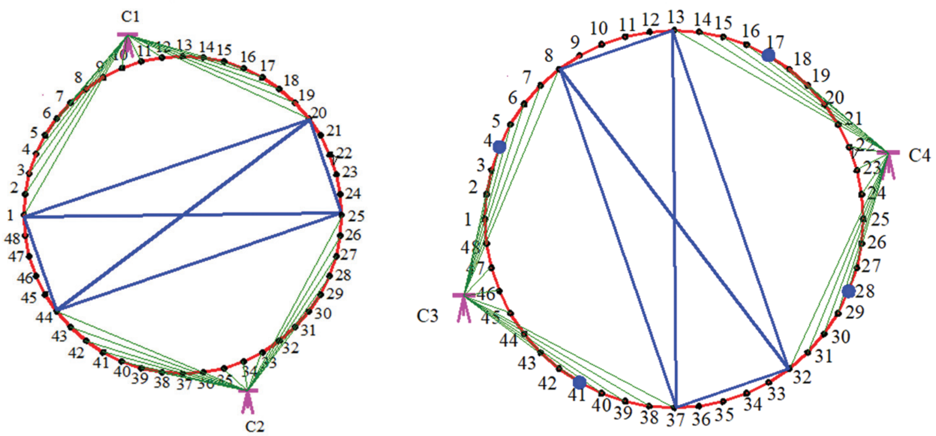


Fig. 1. *Numbering of points on the under-crane track: 1 point – circular bridge crane; 2 point – circular sub-crane track; 3 point – points on the track; 4 point – service area; 5 point – "virtual stations".*

Next, the crane is turned in such a way as to free the sector 37÷8 for observation, as well as the sector 13÷32 (Fig. 2b). The electronic levelers are first of all installed between the points 45–46, and afterwards – between the points 22–23, meanwhile measuring an exceeded value in corresponding sectors. In this case, the transition points will be 4, 17, 28, 41. The distance from the leveler to the transition points is $D_1 \approx 17$ m in sectors 1÷20, 25÷43, and $D_2 \approx 15$ m in sectors 37÷8, 13÷32.



a) b)

Fig. 2. *Placement of a polar crane to monitor the sector a) 1÷20, 25÷43, b) 37÷8, 13÷3; C1, C2, C3, C4 – leveling stations.*

The research work (Burak and Hrynishak 2014) describes the mathematical relations that enable to calculate a reading error, arising in presence of a certain number of readings n for different lengths of levers D. If using the precision electronic leveler Sprinter 150M:

$$m_{\text{reading}} = 0.004 \cdot D - 0.007 \cdot n + 0.042 \tag{1}$$

Then, providing the equal accuracy of readings taken on the back and front rails ($n_1 = n_2 = n$, where n – number of readings), we will have as follows: if $n = 1$, $D_1 \approx 17$ m and $D_2 \approx 15$ m: $m_{\text{readingD17}} = 0.102$ mm and $m_{\text{readingD15}} = 0.094$ mm. In case of the rank of leveling stroke A (Table B.2 in (SOU-N MEV 40.1-00013741-79 2012)), such misreading error will arise due to inaccuracy of automatically-taken readings, when measuring an exceeded value at the station:

$$mh_{\text{A}} = m_{\text{reading}} \cdot \sqrt{2} \tag{2}$$

For instance, for $D_1 \approx 17$ m we have $mh_{\text{A}} = 0.144$ mm.
The reverse weight of equivalent stroke πh_{Equ} (SOU-N MEV 40.1-00013741-79 2012) between the 2 (two) diametrically opposite points of rail track (4 and 28), taking into account the values D_1, D_2 and the quantity of stations $n = 2$: $\sum \pi h_{\text{A}} = \pi h_1 + \pi h_2 = 3.024$.

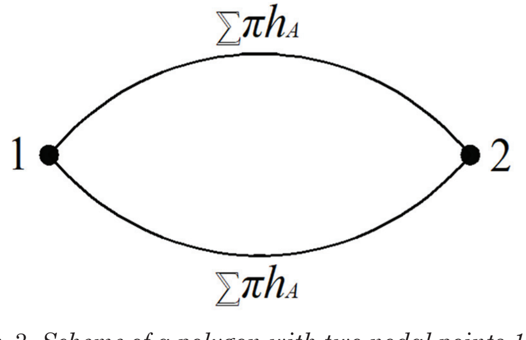


Fig. 3. *Scheme of a polygon with two nodal points 1, 2.*

$$\pi h_{\text{Equ}} = \frac{\pi h_1 \cdot \pi h_2}{(\pi h_1 + \pi h_2)} = 1.512 \tag{3}$$

Let's find the tolerance of mean squared error per unit of weight:

$$\mu_E \leq \underline{\Delta} H_E / \left(\sqrt{\pi h_{\text{Equ}}} \cdot t\right) \tag{4}$$

where $\underline{\Delta} H_E$ – the tolerance defined by the operating organization, which is ±2 mm, and t – normalizing factor (as recommended – equal to 2). By substituting the relevant values, we get $\mu_E \leq 0.813$ **m** .

Let's calculate the tolerance of closure error for a leveling network polygon of crane track:

$$m_{\text{tolerance}} = t \cdot \mu_E \cdot \sqrt{[\pi h_{\text{A}}] \cdot \pi h_{\text{A}}} \tag{5}$$

where $[\pi h_{\text{A}}]$ – the total amount of reverse weights of exceeded values on a polygon, calculated for the case of measuring by rank A; πh_{A} – reverse weight of exceeded value at the station, given that these measurements are taken by rank A. Upon substitution, we get $m_{\text{tolerance}} = 4.92$ mm.

A significant error is the error due to rail tilt. Let's define the requirements for the permissible length of a rail and the method of its erection on a deformation point during supervision:

$$b = 6m_1 \cdot \frac{\rho'^2}{v^2} \tag{6}$$

The tolerance m_1, on basis of which the error limits of individual sources are calculated: $m_1 = \mu_E / K$, where K is the accuracy assurance coefficient (let's accept $K = 5$ according to the recommendations (SOU-N MEV 40.1-00013741-79 2012)). It is also recommended to accept the value of rail tilt angle from the vertical line as $\upsilon = 25'$ at the time of taking the readings.

Then, $m_1 = 0.163$ and $b = 18$ m. The tolerance b is met by all the leveling rails.

The maximum guidance height, when measuring the exceeded values in our case, is $S = 1.80$ m.

Then the error limit for rail tilt will be:

$$m_{\text{rails}} = S(1 - \cos v) = 0.048 \text{ m} \tag{7}$$

Let's analyze the impact of exceeded error limit that appeared due to presence of an unevenness of levers at the station.

Let's fix the permissible value for difference of levers at station D_1–D_2, using the formula recommended in (SOU-N MEV 40.1-00013741-79 2012):

$$D_1 - D_2 = 3m_1 \cdot \frac{\rho''}{i''} \tag{8}$$

In our case, D_1–D_2 = 5.0 m (the value i = 20”). Thus, when leveling a crane rail track, the levers of the station may differ up to 5 m between the transition points.

The overall error limit of exceeded value measurement per one stroke between the transitional diametrically opposite points (4–28 or 17–41) will be the total amount of reading errors and errors arising due to rail tilt:

$$m_{(4-28)} = \sqrt{2m^2_{\text{reading}(D17)} + 2m^2_{\text{reading}(D15)} + 4m^2_{\text{rail}}} \quad (9)$$

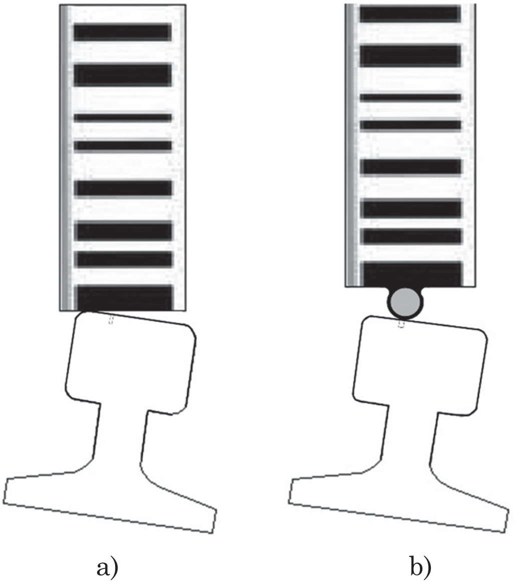
For example, when using the precision electronic leveler Sprinter 150M, we get $m_{(4-28)} = 0.218$ mm. Since we have 2 independent strokes (4–17–28 and 4–41–28) between the diametrically opposite points, the error limit of exceeded value measurement between point 4 and point 28 will be $m_h = 0.218/\sqrt{2} = 0.154\ \mathbf{m}$, if the tolerance is 2 mm.

When using the high-precision leveler Topcon DL-501, the error of determining the weakest point is $m_h = 0.075$ mm.

In order to ensure the definition of exceeded value between the diametrically opposite points of rail track $m_h = \pm 2$ mm, one can use the precision and high-precision levelers; in order to reduce the occurrence of gross errors, it is necessary to take the readings at least 3 times.

When leveling on a polar crane, there appears an error of erecting a rail on the track under the crane. Since the rail base is a plane, and the rail head is not always placed in a horizontal position, some error limits often occur due to improper erection of a rail (Fig. 4a).

Therefore, before starting the work, one should mark the places of rail erection near each drilled point. A metal ball with a diameter of 13 mm is fixed to the rail base, which will allow to erect the rail at the desired point even if the crane tracks head is tilted (Fig. 4b). Owing to this, there will occur no error in erecting a rail on the crane track.



a) b)

Fig. 4. *The method of installing the leveling rail on the track.*

Apart from the transition points, the intermediate height marks are additionally set during leveling of a crane track. Let's give the results of calculation $m_{reading}$ for each point at station C1 (see Fig. 5, Table 1).

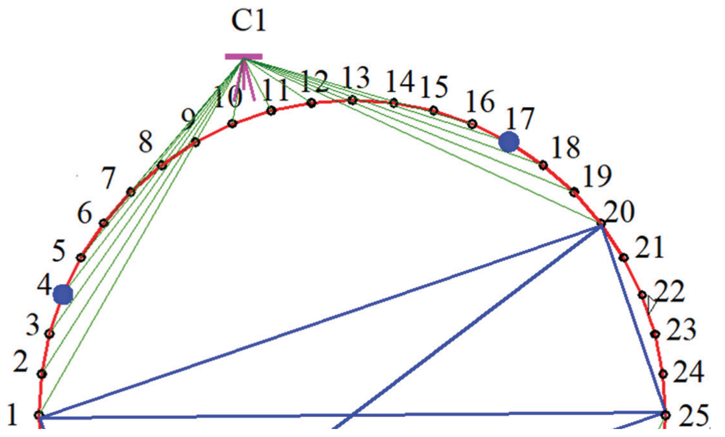


Fig. 5. *Scheme of measurement by an electronic level in the sector 1÷20 from station C1.*

Since the distance from the leveler to the transition point in this sector is $D \approx$ 17 m, $D_{min} \approx 1.5$ m and $D_{max} \approx 25$, here the significant component will be an error due to unevenness of levers. As we can see from Fig. 5, the points are located symmetrically in relation to the device station. Therefore, the distances $D_{C1-p1} = D_{C1-p20}$, $D_{C1-p2} = D_{C1-p19}$, and so on.

Table 1. $m_{reading}$ *for all points at station C1 when using the precision electronic leveler Sprinter 150M.*

$m_{reading}$ [mm]									
p1, p20	p2, p19	p3, p18	p4, p17	p5, p16	p6, p15	p7, p14	p8, p13	p9, p12	p10, p11
0.13	0.13	0.11	0.10	0.09	0.09	0.07	0.06	0.05	0.04

As calculated above, $m_{rail} = 0.048$ mm.

Let's calculate the error component of exceeded value that appears due to unevenness of levers at station C1 (Table 2), taking the value i = 20" and using the expression:

$$m_{\Delta h} = \left(d_1 - d_2\right) \cdot i'' / \rho'' \qquad (10)$$

Table 2. $m_{\Delta h}$ *for all points at station C1.*

Station name	$m_{\Delta h}$ **[mm]**									
C1	p1, p20	p2, p19	p3, p18	**p4, p17**	p5, p16	p6, p15	p7, p14	p8, p13	p9, p12	p10, p11
	0.80	0.61	0.33	**0.16**	0.25	0.42	0.69	0.98	1.27	1.51
C2	p25, p44	p26, p43	p27, p42	**p28, p41**	p29, p40	p30, p39	p31, p38	p32, p37	p33, p36	p34, p35
	0.80	0.61	0.33	**0.16**	0.25	0.42	0.69	0.98	1.27	1.51
C3	p8, p37	p7, p38	p6, p36	p5, p40	**p4, p41**	p3, p42	p2, p43	p1, p44	p48, p45	p47, p46
	0.99	0.79	0.51	0.25	**0.15**	0.24	0.50	0.79	1.07	1.31
C4	p13, p32	p14, p31	p15, p30	p16, p29	p17, **p28**	p18, p27	p19, p26	p20, p25	p21, p24	p22, p23
	0.99	0.79	0.51	0.25	**0.15**	0.24	0.50	0.79	1.07	1.31

Let's calculate the overall error of defined exceeded value between the transition point and intermediate point at the station, using the formula:

$$m_{\mathrm{st}}^2 = \sqrt{m_{\mathrm{reading}(D17)}^2 + m_{\mathrm{reading}(Di)}^2 + 2m_{\mathrm{rail}}^2 + m_{\Delta h}^2} \tag{11}$$

The results of calculations for all stations are shown in Table 3 for precision electronic leveler Sprinter 150M and in Table 4 for high-precision leveler Topcon DL-501.

Table 3. m_{st} *when measuring with the precision electronic leveler Sprinter 150M.*

Station name	m_{st} **[mm]**									
C1	p1, p20	p2, p19	p3, p18	**p4, p17**	p5, p16	p6, p15	p7, p14	p8, p13	p9, p12	p10, p11
	0.80	0.61	0.33	**0.16**	0.25	0.42	0.69	0.98	1.27	1.51
C2	p25, p44	p26, p43	p27, p42	**p28, p41**	p29, p40	p30, p39	p31, p38	p32, p37	p33, p36	p34, p35
	0.80	0.61	0.33	**0.16**	0.25	0.42	0.69	0.98	1.27	1.51
C3	p8, p37	p7, p38	p6, p36	p5, p40	**p4, p41**	p3, p42	p2, p43	p1, p44	p48, p45	p47, p46
	0.99	0.79	0.51	0.25	**0.15**	0.24	0.50	0.79	1.07	1.31
C4	p13, p32	p14, p31	p15, p30	p16, p29	**p17, p28**	p18, p27	p19, p26	p20, p25	p21, p24	p22, p23
	0.99	0.79	0.51	0.25	**0.15**	0.24	0.50	0.79	1.07	1.31

Table 4. m_{st} *when measuring with the high-precision electronic leveler Topcon DL-501.*

Station name	m_{st} [mm]									
C1	p1, p20	p2, p19	p3, p18	**p4, p17**	p5, p16	p6, p15	p7, p14	p8, p13	p9, p12	p10, p11
	0.78	0.59	0.30	**0.08**	0.21	0.39	0.68	0.97	1.26	1.50
C2	p25, p44	p26, p43	p27, p42	**p28, p41**	p29, p40	p30, p39	p31, p38	p32, p37	p33, p36	p34, p35
	0.78	0.59	0.30	**0.08**	0.21	0.39	0.68	0.97	1.26	1.50
C3	p8, p37	p7, p38	p6, p36	p5, p40	**p4, p41**	p3, p42	p2, p43	p1, p44	p48, p45	p47, p46
	0.97	0.78	0.49	0.21	**0.07**	0.21	0.49	0.78	1.07	1.31
C4	p13, p32	p14, p31	p15, p30	p16, p29	**p17, p28**	p18, p27	p19, p26	p20, p25	p21, p24	p22, p23
	0.97	0.78	0.49	0.21	**0.07**	0.21	0.49	0.78	1.07	1.31

Let's find the maximally-possible error limits in determining an exceeded value between the diametrically opposite points of polar crane track m_h, providing the measurements are made using the above-mentioned electronic levels (Table 5). At the same time, it should be taken into account that for all transition points, the optimal route (which ensures the minimum value of error) will be the transition route between the diametrically opposite points through 3 stations:

$$m_h = \frac{\sqrt{m_{st1}^2 + m_{st2}^2 + m_{st3}^2}}{\sqrt{2}} \tag{12}$$

where m_{st1}, m_{st2}, m_{st3} – relevant height values (from Table 4), defined by the optimal route between the diametrically opposite points.

Table 5. m_h *when measuring with the precision electronic leveler Sprinter 150M and high-precision leveler Topcon DL-501.*

Electronic leveler	m_h [mm]											
	p1–p25	p2–p26	p3–p27	p4–p28	p5–p29	p6–p30	p7–p31	p8–p32	p9–p33	p10–p34	p11–p35	p12–p36
Topcon	0.8	0.5	0.2	0.1	0.2	0.4	0.7	1.0	1.3	1.5	1.5	1.3
Sprinter	0.8	0.5	0.3	0.1	0.2	0.4	0.7	1.0	1.3	1.5	1.5	1.3
	p13–p37	p14–p38	p15–p39	p16–p40	p17–p41	p18–p42	p19–p43	p20–p44	p21–p45	p22–p46	p23–p47	p24–p48
Topcon	1.0	0.7	0.4	0.2	0.1	0.2	0.5	0.8	1.1	1.3	1.3	1.1
Sprinter	1.0	0.7	0.4	0.2	0.1	0.3	0.5	0.8	1.1	1.3	1.3	1.1

The calculation results given in Table 5 confirm the expediency of using the electronic levelers Sprinter 150M and Topcon DL-501 to define the height position of polar crane tracks at the Nuclear Power Plant. Thus, as shown, the accuracy required for defining an exceeded value between the diametrically opposite points of a rail track is ensured even by 1 (one) read-out of data per rail.

Nevertheless, the authors suggest taking the readings 3 (three) times for each point, in order to avoid gross errors.

5. Conclusions and consequences of the research

1. The methods of geometric leveling of a rail track of polar crane, suggested in this research paper, provides the required accuracy of determining an exceeded value between the diametrically opposite points of rail track; increases the efficiency and promptness of the results obtained.

2. The above calculations indicate the reasonability of using the high-precision and precision electronic levelers, which ensure the mean squared error in defining an exceeded value between the most distant points of track $m_h < \pm 2$ mm, even in case of critical values of the main sources of error.

3. The possibility of regular supervisions is ensured at the points, marked on a rail track, due to the fact that they are not placed on the track axis, but in the areas where the track is not deformed by transport wheels.

4. The usage of the means of defining an exceeded value between the diametrically opposite points by following the suggested methods increases the promptness of geodetic surveying, the efficiency of searching the geometric data; it causes the minimization of time spent on obtaining the result; at the same time, the usage of rail modifications allows to eliminate the conditions for occurrence of gross errors and systematic errors, to increase the accuracy of results of geodetic measurements. This, in its turn, contributes to saving both resources and funds of the enterprise.

References

Baran, P. I., Ganshin, V. N., Repalov, I. M. (1980): Geodetic works on the construction and operation of crane roads, Nedra, Moscow (in Russian).

Belunce, A., Pandolfo, V., Roozbahani, H., et al. (2015): Novel control method for overhead crane's load stability, Procedia Engineering, 106, 108–125.

Burak, K. (1993): On monitoring the condition of the sub-crane track of the polar crane of the reactor section of the NPP, Geodesy and Cartography, 5, 20–22 (in Ukrainian).

Burak, K., Burak, U. (1995): Control of the geometric dimensions of the polar cranes of reactors of the separate NPP, Geodesy and Cartography, 10, 13 (in Ukrainian).

Burak, K. Hrynishak, M. (2014): Study of the reference reading error during geometric leveling with a short beam using digital levels, Geodesy, cartography and aerial photography, 80, 30–39 (in Ukrainian).

Burak, K., Shpakivskyi, O. (2011): Experimental study of the influence of vibration on the results of high-precision leveling with a short beam using the SDL30M digital leveler, Modern advances in geodetic science and production, 2, 134–135 (in Ukrainian).

Burak, K., Shpakivskyi, O. (2012): From the experience of geodetic control of geometric parameters of crane tracks at Rivne AS, Geodesy, cartography and aerial photography, 76, 40–46 (in Ukrainian).

Burak, K., Biletskyi, Ya., Hrynishak, M., Kovtun, V., Mykhailyshyn, V., Shpakivskyi, O., Yavorskyi, A. (2012): Study of the operation of electronic devices (Leica DISTOTM A6 range finder, Sprinter digital level 150M and electronic total station Sokkia SET 630R) during a sharp change in the temperature of the device, Modern achievements of geodetic science and production, I (23), 72–76 (in Ukrainian).

Kim, C. S., Hong, K. S. (2009): Boundary control of container cranes from the perspective of controlling an axially moving string system, International Journal of Control, Automation and Systems, 7 (3), 437–445.

Kim, Y. S., Hong, K. S., Sul, S. K. (2004): Anti-sway control of container cranes: inclinometer, observer, and state feedback, International Journal of Control Automation and Systems, 2, 435–449.

Marjetič, A., Kregar, K., Ambrožič, T., Kogoj, D. (2012): An alternative approach to control measurements of crane rails, Sensors, 12 (5), 5906–5918.

Mill, T., Ellmann, A., Kiisa, M., Idnurm, J., Idnurm, S., Horemuz, M., Aavik, A. (2015): Geodetic monitoring of bridge deformations occurring during static load testing, Baltic J. Road Bridge, 10 (1), 17–27.

Mykhilyshyn, V. (2018): Improving the methods of polar crane runway rail parameters during a geodesic control, Archiwum Instytutu Inżynierii Lądowej, 27, 120–125.

Park, H. S., Lee, H. M., Adeli, H., Lee, I. A. (2007): New approach for health monitoring of structures: terrestrial laser scanning, Comput, Aided Civil Infrastruct, 22 (1), 19–30.

Ruskov, A. M., Boglov, I. F. (1984): Device for surveying the plan-height position of crane tracks, Geodetic control methods in construction, Kuibyshevsky State University, Kuibyshev, 55 (in Russian).

Schofield, W., Breach, M. (2007): Engineering Surveying of Transport Facilities, Linacre House, Oxford.

Soudarissanane, S., Lindenbergh, R., Menenti, M., Teunissen, P. (2011): Scanning geometry: influencing factor on the quality of terrestrial laser scanning points, ISPRS J. Photogramm, Remote Sens, 66 (4), 389–399.

SOU-N MEV 40.1-00013741-79:2012: “Instructions for conducting observations of foundation settlement, structural deformations of buildings and structures, and groundwater conditions at the sites of thermal and nuclear power plants”.

Zhaohui, Q., Huitao, S. (2017): Dynamic analysis of hook block for polar crane in nuclear power plant, Jve International Ltd. Journal of Vibroengineering, 19 (8), 3895–3910.

URLs

URL 1: Kregar, K., Možina, J., Ambrožič, T., Kogoj, D., Marjetič, A., Štebe, G., Savšek, S. (2017): Control measurements of crane rails performed by terrestrial laser scanning, Sensors, 17 (7), 1671, http://www.mdpi.com/1424-8220/17/7/1671/pdf, (21.7.2023).

URL 2: Ćmielewski, K., Gołuch, P., Kuchmister, J., Wilczyńska, I., Ćmielewski, B., Grzeja, O. (2021): Detection of crane track geometric parameters using UAS, Automation in Construction, 128, 103751, https://www.journals.elsevier.com/automation-in-construction, (27.7.2023).

Istraživanje točnosti u definiranju prekoračene vrijednosti između dijametralno suprotnih točaka pri upotrebi elektroničkih nivelira na polarnoj dizalici

SAŽETAK. U ovom istraživačkom radu ponuđene su i testirane metode primjene elektroničkih nivelira namijenjenih za niveliranje tračnica ispod polarnih dizalica u nuklearnoj elektrani, čime se osigurava potrebna točnost geodetske kontrole polarnih kranskih staza. Prekoračene vrijednosti su izravno izmjerene između tipičnih točaka kranske staze, sastavljene od 4 (četiri) točke ("virtualne" stanice), pomoću preciznog elektroničkog nivelira Sprinter 150M i visokopreciznog nivelira Topcon DL-501. Prilikom obrade rezultata izračunate su glavne granice pogreške: očitavanje, naginjanje tračnice, mjerenje prekoračene vrijednosti prisutne zbog kuta i zbog neravnina poluga na stanici. Rezultati su analizirani u usporedbi s tolerancijama za određivanje prekoračene vrijednosti između dijametralno suprotnih točaka tračnice, čime je potvrđena korisnost i pogodnost primjene visokopreciznih i preciznih elektroničkih nivelira.

Ključne riječi: inženjerske geodetske metode, elektronički nivelir, polarna dizalica, točnost definiranja prekoračene vrijednosti.

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