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**ACCURACY ASSESSMENT OF GEOMETRICAL ELEMENTS FOR SETTING-OUT IN HORIZONTAL PLANE OF CONVEYING CHAMBERS AT THE BAUXITE MINE »KOSTURI« SREBRENICA****OSZACOWANIE DOKŁADNOŚCI ELEMENTÓW GEOMETRYCZNYCH PRZY WYTYCZANIU KOMÓR W PŁASZCZYŹNIE POZIOMEJ W KOPALNI BOKSYTU „KOSTURI” W SREBRENICY**

Setting-out of objects on the exploitation field of the mine, both in surface mining and in the underground mines, is determined by the specified setting-out accuracy of reference points, which are best to define spatial position of the object projected. For the purpose of achieving of the specified accuracy, it is necessary to perform a priori accuracy assessment of parameters, which are to be used when performing setting-out. Based on the a priori accuracy assessment, verification of the quality of geometrical setting-out elements specified in the layout; definition of the accuracy for setting-out of geometrical elements; selection of setting-out method; selection of the type and class of instruments and tools that need to be applied in order to achieve predefined accuracy. The paper displays the accuracy assessment of geometrical elements for setting-out of the main haul gallery, haul downcast and helical conveying downcasts in shape of an inclined helix in horizontal plane, using the example of the underground bauxite mine »Kosturi«, Srebrenica.

**Keywords:** underground mining, mine surveying, accuracy assessment, setting-out

Wytarczanie obiektów na polu wydobywczym w kopalniach, zarówno podziemnych jak i odkrywkowych, zależy w dużej mierze od określonej dokładności wytarczania punktów referencyjnych, przy pomocy których określane jest następnie położenie przestrzenne pozostałych obiektów. W celu uzyskania założonej dokładności, należy przeprowadzić wstępną analizę dokładności oszacowania parametrów które następnie wykorzystane będą w procesie wytarczania. W oparciu o wyniki wstępnej analizy dokładności dokonuje się weryfikacji jakości geometrycznego wytarczenia elementów zaznaczonych na szkicu, uwzględniając te wyniki dobrać należy odpowiednią metodę wytarczania i rodzaj oraz klasę wykorzystywanych narzędzi i instrumentów, tak by osiągnąć założony poziom dokładności. W pracy przedstawiono oszacowanie dokładności wytarczania elementów geometrycznych dla głównego chodnika transportowego, chodnika upadowego oraz szybów wlotowych, naniesionych na płaszczyznę poziomą, dla podziemnej kopalni boksytu „Kosturi” w Srebrenicy.

**Słowa kluczowe:** górnictwo podziemne, geodezja górnicza, szacowanie dokładności, wytarczanie

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## 1. Preface

Completion of the Main Mining Project (Faculty of Mining and Geology, 2008) in surveying-measuring terms includes spatial setting-out of the defined, characteristic points of the structure located on the axis of the conveying mine chambers.

Characteristic points setting-out within the vertical plane is made on the basis of calculated altitude difference between design altitudes of points; however this is not the subject matter of this paper.

Within the horizontal plane, setting-out of characteristic points, which are to display points of the mine traverse, is to be performed by means of direction angles and horizontal lengths respectively refracted angles within the traverse and horizontal lengths of traverse sides, values of which are given in the design. Generally, it is crucially to know, while performing setting-out, what is the accuracy, which was applied while setting-out points, i.e. what was the accuracy applied while setting-out the structure, and if it is within the tolerance permitted by the project. This information is particularly significant while construing new underground mine structures and chambers, primarily in terms of security and safety of the mine chamber and people therein and indirectly also because of the security of structures on surface within the influence zone of mining works. This is even more significant if one bears in mind hard and specific working conditions, under which setting-out is performed, as well as the fact that there is no possibility to perform independent accuracy control.

Therefore, it is necessary to make a priori accuracy assessment for point setting-out. This analysis shall indicate not only the magnitude of standard deviation of the marked points coordinates, but also what instruments and measuring methods should be applied in order to achieve required accuracy. The paper presents accuracy assessment of geometrical elements for setting-out of the Main haul gallery (GIP), haul downcast 2 (IN-2), helical conveying downcasts 2 and 2a (STN-2 and STN-2a) (Fig. 1). For the purpose of spatial visualization of the ore body and the underground rooms, done is a 3D model, which will be used for geotechnical testing and stability (Majcherczyk et al., 2012).

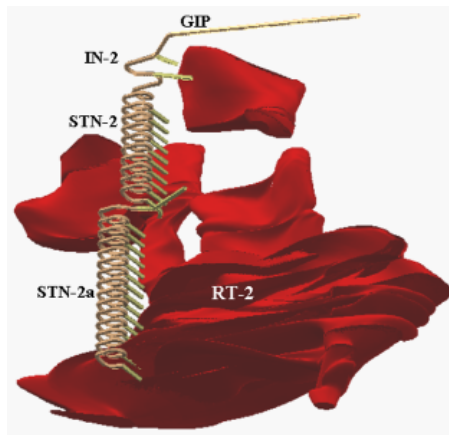


Fig. 1. Bauxite ore body with underground development chambers and deposits preparation

## 2. Basic Data on the Structure

Exploitation field of the mine consists of a bauxite deposit »Kosturi« comprising of three ore bodies. The development for all three deposits is basically the same. Basic model of the proposed development is to construe conveying corridor (TH) from helical conveying downcast to the ore body bench. After the TH enters into the ore body, a bench corridor (EH) is to be made at the floor section of bauxite till detour towards the ventilation corridor (VH). All ore bodies have the same distribution as per their height in shape of benches with the difference in altitude of 8 m (Fig. 2).

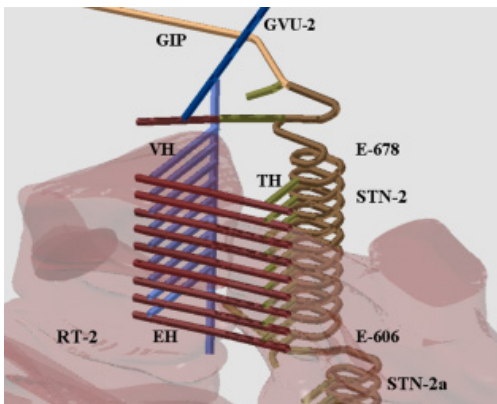


Fig. 2. Helical conveying downcasts

The structures, for which elements for setting-out and the assessment of setting-out accuracy were presented, are mine opening chamber and minde development chambers for the ore body 2 (RT-2), whose completion is yet to come, so that this paper also represents the proposal for the method, instruments and tools for setting-out of the said mine chambers.

From the terrain surface, the entrance into the deposit is from the point located at the entrance into the Main haul gallery representing the opening chamber for all three ore bodies. Traverse point at the entrance into the GIP bears the sign P695 and it has the defined spatial coordinates ( $y = 1001.96$  m,  $x = 2230.25$  m,  $H = +695.00$  m) as well as initial grid bearing of the longitudinal axis of GIP ( $n = 141^{\circ}44'08''$ ).

The project provides for that the RT-2 should be entered into by the previously described Main haul gallery, with length of 311.17 m and ascent of 2.25%, in order to reach the level  $H = 702$  m (onto the bench E-702-2). The projected opening chamber is designed in such a way that the larger part of it passes through limestone, i.e. through the floor of ore body. The chamber is designated for the haulage of blasted material from the work-site – excavation onto the surface, for bringing of fresh air into the pit, conveyance of production materials, servicing of pit, drainage of the pit during the opening stage, as well as for the movement of workers. Based on the purpose, dimensions of means of transportation and the quantity of air needed for pit ventilation, the sizing of the GIP cross section was made. The shape of the cross section was determined on the basis of physical and mechanical features of the rock mass. Based on the afore said, the shape of the low arched cross section of GIP, with the following sizes:  $b \times h = 3.40 \times 3.45$  m, daylight surface  $S_{sv} = 10.92$  m<sup>2</sup> (Fig. 3), was adopted.

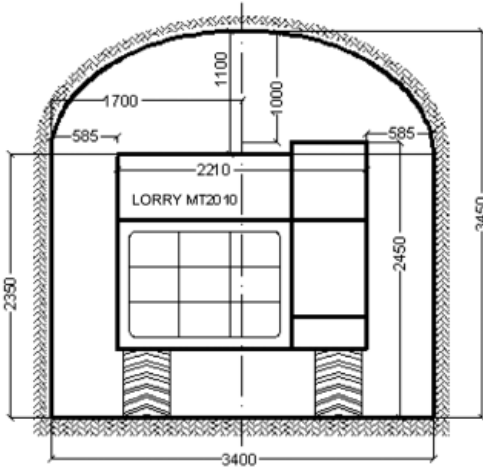


Fig. 3. Cross-section of GIP

Based on the examined physical and mechanical features of the rock mass (floor limestone), timbering of the GIP is not necessary. In case of the occurrence of sections with poorer physical and mechanical features, timbering is to be carried out by using anchorages or anchorages combined with scrim.

The main haul gallery ends at the point P702, where from the haul downcast 2 (IN-2) is to be construed, with length of 123.60 m and with the descent of 12% to point PK<sub>1</sub> (Fig. 4), where from the construction of helical conveying downcast 2 (STN-2) till bench 606 m, begins.

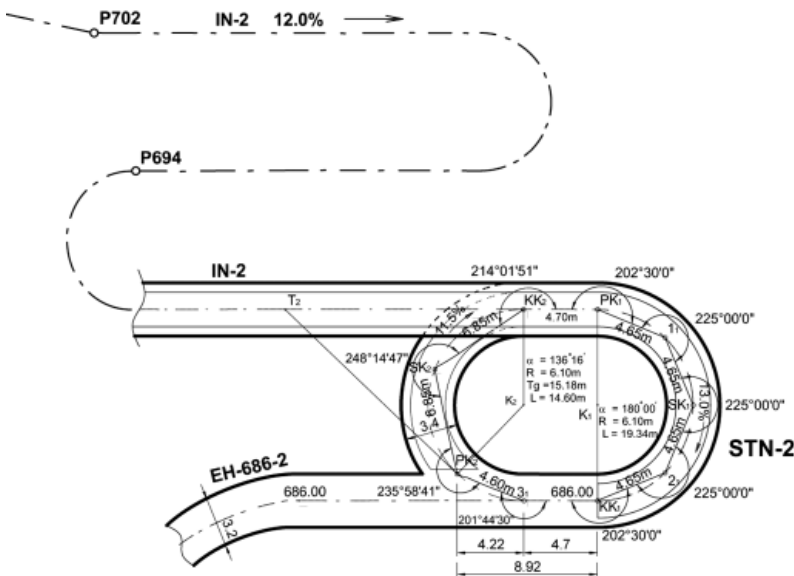


Fig. 4. Geometrical elements for setting-out of the first STN-2 ramp

Considering the unfavourable geological conditions in terms of tectonics, i.e. the presence of fault beneath level 606 m, the construction of helical downcast STN-2 is not reliable from the level 606 m up to level 486 m, up to which the ore body lies. For the purpose of dislocation of works at the construction of helical downcast beneath level 606 m out of the unfavourable working environment, the downcast with length of 43.57 m is to be constructed from conveying corridor TH-606, which is to be located south to the STN-2, from which point the construction of STN-2a through homogeneous rock mass (Fig. 5) continues.

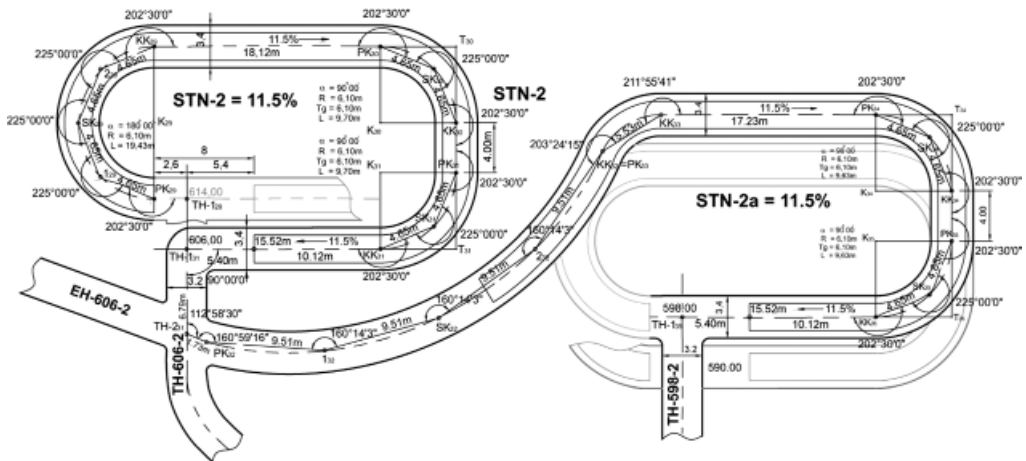


Fig. 5. Geometrical elements while setting-out the downcast for the STN dislocation

Ore body 2 is massive with dip angle of cca  $65^\circ$  (from bench 702 m up to bench 630 m), i.e. cca  $44^\circ$  (from bench 630 m up to bench 486 m), which is the reason why helical downcasts are made in shape of inclined helix for the purpose of following the floor section of ore body at approximately same distance, which makes that also the lengths of conveying corridors are of approximately same value, cca 15 m. Working environment, where helical conveying downcasts are to be construed, is Triassic limestone, which provides good working conditions in terms of stability of rock mass, so that timbering is to be done where necessary.

The length of each helix (designed with 9/10 winding) of helical downcast is  $D_h = 69.44$  m with constant descent of 11.5% and horizontal part with length of 8m where the ore is to be loaded into the truck. The loading place is also the junction of downcast with conveying corridor. The width of helical downcasts is 3.4 m, and of the conveying corridors 3.2 m (Fig. 6).

The second feature of the ramp is that three circular arcs of small radius (6.10 m) are applied, with one direction between two arcs with length of 4 m, which enables “underpassing” of the next helix in “staggered order”, i.e. an inclined helix was obtained in order to follow the floor section of ore body at approximately equal distance, cca 15 m. The centers of all arcs are within two parallel vertical planes, i.e. at three slant lines whose vertical angle is  $63^\circ 26' 06''$ .

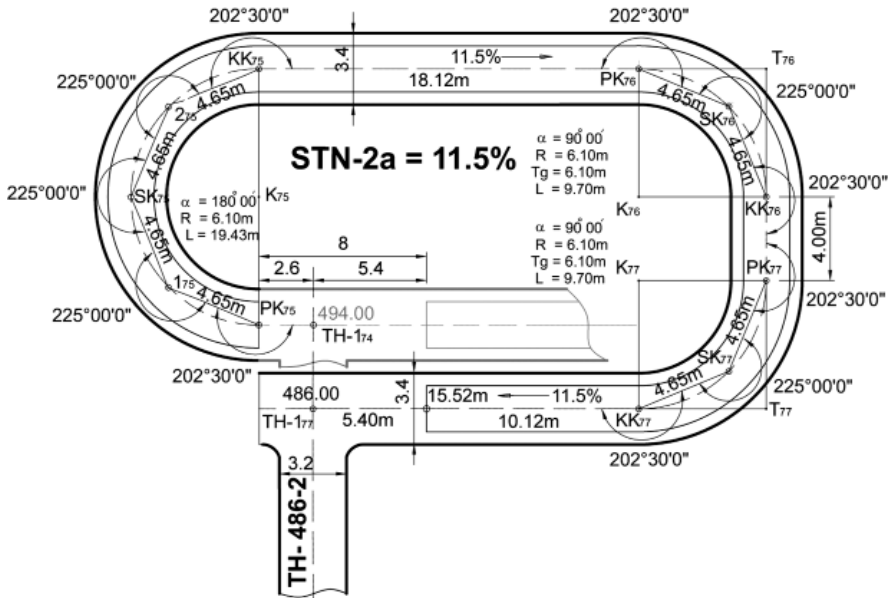


Fig. 6. Geometrical elements for setting-out of the last curve from level E-492 to level E-486

### 3. Accuracy Assessment

The total horizontal length of the projected corridor is 2420.00 m. At this length it is necessary to mark 317 traverse points. The average length of traverse sides is 7.63m, and they range from 94.70 m within GIP up to mere 1.73 m in chamber connecting helices STN-2 and STN-2a. There are 25 helices altogether. Each pitch of the helix has horizontal length of 77.44m and in each of them there are 12 traverse points. Mean length of traverse sides within helices is 6.45 m.

All of this indicates that it is relatively long traverse, with large number of traverse points and extremely short traverse sides, where setting-out accuracy considerably influences the position of the last point within the traverse (Ganić & Đorđević, 2005) (Fig. 7).

The permissible error of construction, i.e. of setting-out of the conveying corridor was not given in the design (Faculty of Mining and Geology, 2008). Therefore, the permitted relative linear tolerance of the last point within the traverse of 1:5000 in relation to the traverse length was adopted pursuant to the Rulebook on the Method for Executing of Mine Surveying (The Government of the Republic of Serbia, 1997). Considering the designed length of mine chambers, the allowable linear tolerance of the last traverse point TH1-77 shall be:

$$\Delta = \frac{2420.00 \text{ m}}{5000} = \pm 0,484 \text{ m} \tag{1}$$

i.e., the value  $\Delta = \pm 48 \text{ cm}$  was adopted.

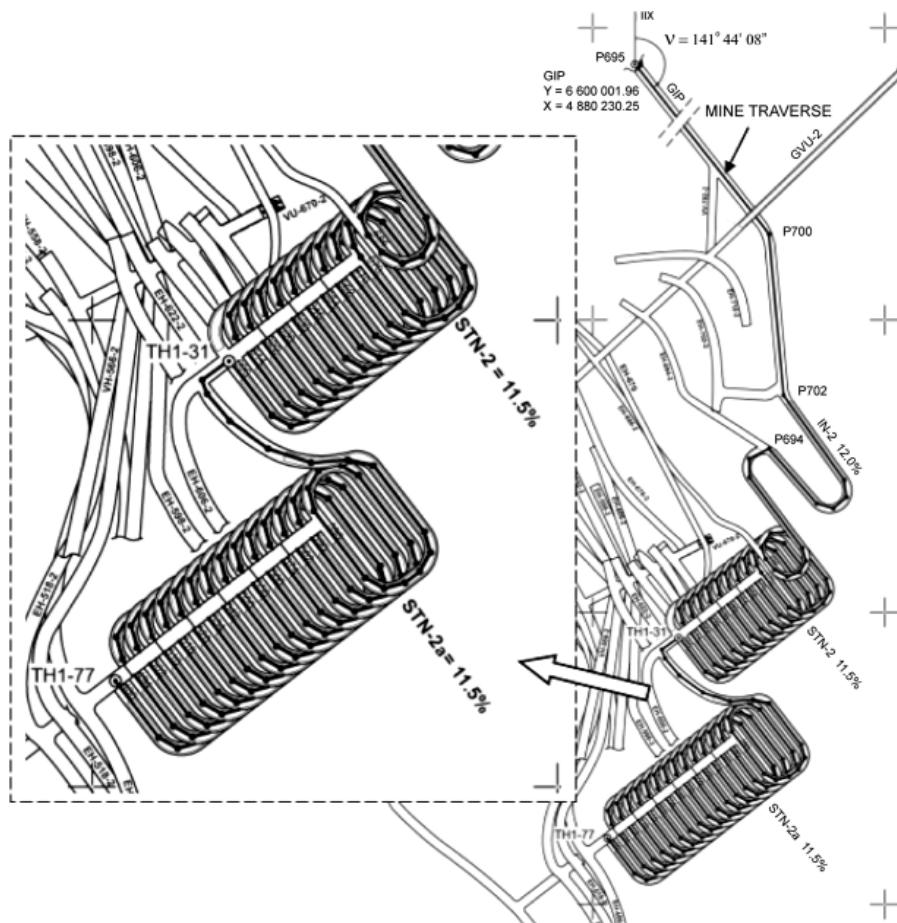


Fig. 7. Layout of the mine traverse for setting-out of helical downcasts STN-2 and STN-2a

Standard deviation for setting-out the position of the last point within the mine traverse for probability of 95% is:

$$\sigma_{x,y} = \frac{\Delta}{2} = \pm 24 \text{ cm} \quad (2)$$

The setting-out accuracy is affected by the errors of the given and measured parameters. In this case, errors of the given parameters are:

- standard deviation of the first traverse point on the terrain surface P695, and
- standard deviation of the initial grid bearing on the terrain surface  $v_A^{695} = v_p$ .

When analyzing this, it was adopted that given parameters were faultless, i.e. that it is:

$$\sigma_{695} = 0; \quad \sigma_{v_p} = 0$$

In this case, standard deviation for setting-out the last point of mine traverse is to be function of only standard deviation of the measured angular and linear parameters within the traverse:

$$\sigma_{x,y} = \sqrt{\sigma_{x,y(\beta)}^2 + \sigma_{x,y(d)}^2} \quad (3)$$

The implementation of the principle of equal influences  $\sigma_{x,y(\beta)} = \sigma_{x,y(d)} = \sigma_{ob}$  provides the same influence of angle and length setting-out onto the total standard deviation of the position of the last point:

$$\sigma_{ob} \sqrt{2} = \sigma_{x,y}$$

i.e.:

$$\sigma_{ob} = \frac{\sigma_{x,y}}{\sqrt{2}} = \frac{24 \text{ cm}}{\sqrt{2}} = \pm 17.0 \text{ cm} \quad (4)$$

Based on the calculated value in the equation (4), standard deviation defining the required accuracy when setting-out the angles  $\sigma_\beta$  and lengths  $\sigma_d$  are to be calculated. For the purpose of this, one proceeds from the General Law on Error Propagation (Ghilani & Wolf, 2012). The variance-covariance matrices of the assessment of coordinate differences in traverse side is of the following form:

$$K_{\Delta x, \Delta y} = A \cdot K \cdot A^T = \begin{bmatrix} \frac{\partial \Delta x}{\partial d} & \frac{\partial \Delta x}{\partial v} \\ \frac{\partial \Delta y}{\partial d} & \frac{\partial \Delta y}{\partial v} \end{bmatrix} \cdot \begin{bmatrix} \sigma_d^2 & 0 \\ 0 & \sigma_v^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{\partial \Delta x}{\partial d} & \frac{\partial \Delta y}{\partial d} \\ \frac{\partial \Delta x}{\partial v} & \frac{\partial \Delta y}{\partial v} \end{bmatrix} = \begin{bmatrix} \sigma_{\Delta x}^2 & \sigma_{\Delta x, \Delta y} \\ \sigma_{\Delta x, \Delta y} & \sigma_{\Delta y}^2 \end{bmatrix} \quad (5)$$

where:

- $A$  — represents the coefficient matrix (Jacobian matrix) that represents matrix of partial derivatives when compared with the variables,
- $K$  — represents variance-covariance measurement matrix.

In the covariance measurement matrix  $K$ , members outside the main diagonal are zeros, because the measurements are independent from each other. Standard deviation of the traverse side grid bearing is to be calculated according to the expression:

$$\sigma_v = \sqrt{\sigma_{v-1}^2 + \sigma_\beta^2} \quad (6)$$

where:

- $\sigma_{v-1}$  — represents standard deviation of the grid bearing at the previous traverse side,
- $\sigma_\beta$  — represents standard deviation of the measured corresponding refracted angle within traverse.

Standard deviation of the position of traverse point is to be calculated according to the equation (Ašanin, 2003):

$$\sigma_{x,y} = \sqrt{\sigma_x^2 + \sigma_y^2} = \sqrt{(\sigma_{x-1}^2 + \sigma_{\Delta x}^2) + (\sigma_{y-1}^2 + \sigma_{\Delta y}^2)} \quad (7)$$



where:

- $\sigma_x$  — represents standard deviation of traverse point in the direction of the  $x$ -axis,
- $\sigma_y$  — represents standard deviation of the traverse point in the direction of the  $y$ -axis,
- $\sigma_{x-1}$  — represents standard deviation of the previous traverse point in the direction of the  $x$ -axis,
- $\sigma_{y-1}$  — represents standard deviation of the previous traverse point in the direction of the  $y$ -axis,
- $\sigma_{\Delta x}, \sigma_{\Delta y}$  — represents standard deviation of coordinate differences calculated according to the equation (5).

The equations shown indicate that successive calculation of standard deviation for each traverse point is required. Setting-out is to execute at the same principle. Namely, setting-out of the next traverse point is to be made from previously marked traverse point. The results of calculations based on the equations (5), (6) and (7) are shown in Table 1. Projected traverse has a large number of traverse points (317), so that the Table shows only the coordinates of traverse points and their standard deviation within the GIP, mine chamber connecting helical conveying downcasts STN-2 and STN-2a, as well as points within the last 25<sup>th</sup> helix of the conveying downcast.

Calculated standard deviation  $\sigma_y = \pm 17.51$  cm and  $\sigma_x = \pm 16.24$  cm are in accordance with previously defined tolerance of position of the last traverse point (2):

$$\sigma_{x,y} = \sqrt{\sigma_x^2 + \sigma_y^2} = \sqrt{16.24^2 + 17.51^2} = \pm 23.88 \text{ cm} \quad (8)$$

Standard deviation for the measurement of angles of  $\sigma_\beta = \pm 19.0''$  determines standard deviation of the position of the last point as follows:

$$\sigma_{x,y(\beta)} = \sqrt{\sigma_{x(\beta)}^2 + \sigma_{y(\beta)}^2} = \sqrt{10.67^2 + 13.06^2} = \pm 16.86 \text{ cm} \quad (9)$$

and standard deviation for the measurement of lengths of  $\sigma_d = \pm 0.95$  cm:

$$\sigma_{x,y(d)} = \sqrt{\sigma_{x(d)}^2 + \sigma_{y(d)}^2} = \sqrt{12.31^2 + 11.79^2} = \pm 17.05 \text{ cm} \quad (10)$$

which is in accordance with the set condition on the equal influence of the measured parameters (4) onto the position of the last traverse point within the traverse (Kavanagh, 2010).

As the conditions set are fulfilled, it could be concluded that it is necessary to measure – mark refracted angles within the projected traverse with standard deviation of  $\sigma_\beta = \pm 19.0''$  and the lengths of traverse sides with  $\sigma_d = \pm 0.95$  cm.

The requirements shown, referring to the measurement accuracy, as well as the working environment that permits the use of electronic instruments, indicate that a total station of average class, with the specified accuracy of angular measurements is  $\pm 10''$  and the accuracy of linear measurement is  $\pm 5$  mm+5 ppm, is sufficient for the purposes of setting-out and construing of the designed downcast.

Calculated standard deviation of the measured angles and length shall determine standard deviation of the position of the last point in the direction of coordinate axes amounting to (Table 1):

$$\sigma_x = \pm 16.2 \text{ cm} \quad \text{and} \quad \sigma_y = \pm 17.5 \text{ cm}$$

Coordinates of traverse points and standard deviation of their locations

Point	y [m]	x [m]	$\sigma_\beta$ ["]	$\sigma_v$ ["]	$\sigma_d$ [cm]	$\sigma_{\Delta y}$ [cm]	$\sigma_{\Delta x}$ [cm]	$\sigma_y$ [cm]	$\sigma_x$ [cm]
P695	1001.96	2230.25	0					<b>0.00</b>	<b>0.00</b>
1	1051.50	2167.44	19	20.0	0.95	0.85	0.89	<b>0.85</b>	<b>0.89</b>
P700	1101.73	2103.76	19	27.6	0.95	1.04	1.00	<b>1.34</b>	<b>1.34</b>
2	1160.37	2029.41	19	33.5	0.95	1.34	1.21	<b>1.90</b>	<b>1.81</b>
P702	1165.36	1974.26	19	38.5	0.95	1.03	0.95	<b>2.16</b>	<b>2.04</b>
3	1186.19	1945.23	19	42.9	0.95	0.82	0.89	<b>2.31</b>	<b>2.22</b>
4	1186.88	1939.23	19	47.0	0.95	0.17	0.94	<b>2.32</b>	<b>2.42</b>
5	1182.15	1935.48	19	50.7	0.95	0.75	0.60	<b>2.43</b>	<b>2.49</b>
6	1176.47	1937.52	19	54.1	0.95	0.90	0.35	<b>2.59</b>	<b>2.51</b>
P694	1160.39	1955.93	19	57.3	0.95	0.81	0.84	<b>2.72</b>	<b>2.65</b>
⋮									
TH1-31	1128.78	1892.57	19					<b>9.60</b>	<b>9.34</b>
TH2-31	1123.34	1888.51	19	221.7	0.95	0.88	0.82	<b>9.64</b>	<b>9.37</b>
PK32	1123.76	1886.83	19	222.5	0.95	0.29	0.92	<b>9.65</b>	<b>9.42</b>
1-32	1128.91	1878.83	19	223.3	0.95	1.01	0.97	<b>9.70</b>	<b>9.47</b>
SK32	1136.46	1873.05	19	224.1	0.95	0.98	1.00	<b>9.75</b>	<b>9.52</b>
2-32	1145.52	1870.17	19	224.9	0.95	0.96	1.03	<b>9.79</b>	<b>9.58</b>
KK32	1155.03	1870.52	19	225.7	0.95	0.95	1.04	<b>9.84</b>	<b>9.63</b>
KK33	1160.18	1868.51	19	226.5	0.95	0.91	0.66	<b>9.88</b>	<b>9.66</b>
⋮									
TH1-74	1106.61	1826.34	19					<b>17.01</b>	<b>15.81</b>
PK75	1105.06	1828.42	19	332.4	0.95	0.66	0.80	<b>17.02</b>	<b>15.83</b>
1-75	1103.91	1832.93	19	333.0	0.95	0.76	0.94	<b>17.04</b>	<b>15.86</b>
SK75	1106.29	1836.93	19	333.5	0.95	0.81	0.90	<b>17.06</b>	<b>15.88</b>
2-75	1110.79	1838.07	19	334.0	0.95	0.94	0.77	<b>17.08</b>	<b>15.90</b>
KK75	1114.79	1835.70	19	334.6	0.95	0.90	0.81	<b>17.11</b>	<b>15.92</b>
PK76	1125.64	1821.18	19	335.1	0.95	2.43	1.92	<b>17.28</b>	<b>16.04</b>
SK76	1126.79	1816.68	19	335.7	0.95	0.77	0.94	<b>17.30</b>	<b>16.07</b>
KK76	1124.41	1812.68	19	336.2	0.95	0.81	0.90	<b>17.31</b>	<b>16.09</b>
PK77	1121.21	1810.28	19	336.7	0.95	0.86	0.77	<b>17.34</b>	<b>16.11</b>
SK77	1116.70	1809.14	19	337.3	0.95	0.94	0.77	<b>17.36</b>	<b>16.13</b>
KK77	1112.70	1811.51	19	337.8	0.95	0.90	0.81	<b>17.38</b>	<b>16.15</b>
TH1-77	1103.41	1823.94	19	338.3	0.95	2.12	1.70	<b>17.51</b>	<b>16.24</b>

Mine corridors, where traverses are to be positioned, are large lengthwise but small widthwise. Therefore, larger practical significance when analyzing the position of the last traverse point, has the breakdown of the standard deviation into two components: in the direction of longitudinal and transversal axis of the chamber.

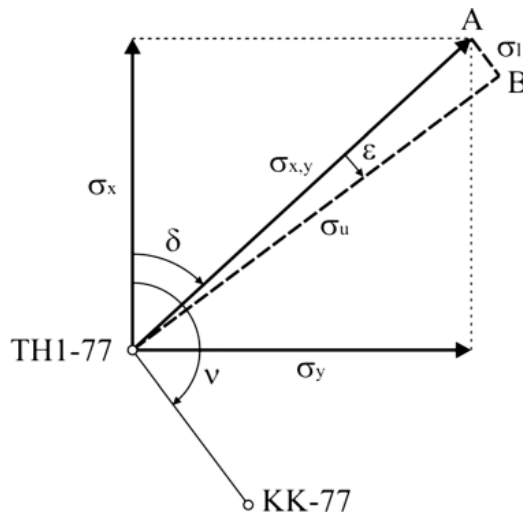


Fig. 8. Transversal and longitudinal tolerances of the last traverse point

Grid bearing of the last side of the designed mine traverse is  $v_{TH1-77}^{KK77} = 143^{\circ}13'27''$ , and according to values  $\sigma_y$  and  $\sigma_x$  and according to the Figure 8 it is:

$$\tan \delta = \frac{\sigma_y}{\sigma_x} \Rightarrow \delta = 47^{\circ}12'33'' \quad (11)$$

The angle  $\varepsilon$  (Figure 8) is:

$$\varepsilon = (\nu - 90^{\circ}) - \delta = 6^{\circ}00'54'' \quad (12)$$

so that the longitudinal component of the standard deviation is:

$$\sigma_l = \sin \varepsilon \cdot \sigma_{x,y} = \pm 2.5 \text{ cm} \quad (13)$$

and the transversal component of the standard deviation for the position of the last point is:

$$\sigma_u = \cos \varepsilon \cdot \sigma_{x,y} = \pm 23.9 \text{ cm} \quad (14)$$

Practically, the entire standard deviation for the position of the last traverse point shall be expressed through transversal component. The large transversal component of standard deviation for the position of a point could be the risk factor for all future geodetic and surveying works in reference to such traverse point.

Calculated standard deviation of angles and lengths ( $\sigma_{\beta} = \pm 19.0''$ ;  $\sigma_d = \pm 0.95 \text{ cm}$ ) characterize only the internal accuracy of the measured parameters. This does not include the whole range of other factors occurring during measurement, which influence the accuracy thereof. This primarily refers to the errors resulting from alignment of instruments and alignment of signals during measurement of angles.

In this case, signaling of points, representing benchmarks in order to measure horizontal directions, is performed by using plumb bob. Traverse sides are short, so that the collimation lines could be achieved according to the top of the string, at the same traverse point, so that there is no error in alignment of the signal and their influence onto the measurement of angles with this kind of measurements.

However, the situation is completely different when referring to the error by the alignment of instruments. Instruments are to be aligned beneath traverse points to be stabilized within the roof of the mine chamber. Designed height of the corridor is 3.45 m. Normal average height of the instrument (collimation line) over the terrain is approximately 1.5–1.6 m. This means that the instrument is to be aligned beneath the points by using plumb bob descending from the roof with height of approximately 1.85–1.95 m. When the influence of ventilation onto the plumb bob skewness is added to the pendulum oscillation, it is obvious that the alignment error is going to have large influence onto the error of the position of the last traverse point.

As already known from the literature (Borshch-Komponiets et al., 1989), the error of the measured angle due to the error in alignment of the instrument, depends on:

- the size of eccentricity  $e$ ,
- the size of the measured angle  $b$ ,
- the length of collimation lines  $d_1$  and  $d_2$ ,

according to the equation:

$$\sigma_{\beta_i} = \frac{e \cdot \rho}{\sqrt{2} \cdot d_1 \cdot d_2} \sqrt{(d_1^2 + d_2^2 - 2d_1d_2 \cos \beta)} \quad (15)$$

As shown in equation 15, the error in the angle due to the error in the alignment of the instrument is inversely proportional to the collimation line lengths and the shorter collimation lines are the larger it is going to be. Moreover, the error in the angle is going to be larger if the difference in the length of collimation lines forming the angle is large. Unfortunately, all those adverse influences are very evident within the designed traverse. The lengths of collimation lines are very short and the shortest one is 1.73 m. The relations between the adjacent collimation lines in terms of the influence of the alignment error onto the measured angle are also adverse, because their relation ranges up to 1:6.5 when compared to the recommended 1:2 to 1:3.

Should it be adopted that the error in alignment of the instrument is to be  $e = 1$  mm and should this parameter together with all other values from the traverse be replaced in the equation (17), we obtain the errors in angle ranging within the limits from 3.3" up to 98.9". Within the helices, this error is to vary from 38.9" up to 85.9", i.e. the average error in the measured angle within the helical section of the corridor due to the error in alignment of the instrument amounting to 1 mm, shall be 57.7".

Those errors are large and random, which means that they cannot be eliminated from the measurement results. Therefore, when executing setting-out of the designed traverse points, it is necessary to perform instrument alignment very carefully. In order to reduce the influence of the error in alignment onto the accuracy of measurement of angles, it is required to align the instrument again between gyros, because in that case, measurements are less dependent.

## 4. Conclusion

The main mining project in surveying and measuring terms fulfills all graphic and numerical standards for the purposes of top quality interpretation of the projected mine chambers. The accuracy of the spatial and geometric presentation of mine chambers has provided a quality basis for the elaboration of the accuracy assessment when setting-out the helical conveying downcasts.

Due to the shape of the designed mine chambers, at the horizontal length of 2420.00 m, the total of 317 traverse points was provided for, with average length of traverse sides of 7.63 m.

Standard deviation in setting-out of the position of the last point within the mine traverse, for probability of 95%, amounts to  $\sigma_{x,y} = \pm 24$  cm.

When assessing the accuracy of the position of the last point within the traverse, it was accepted that given sizes are faultless. As already known, the error in traverse alignment (standard deviation of the initial connecting point of the traverse) moves the traverse parallelly, it does not depend on the traverse length and it does not have any significant influence on standard deviation for the last traverse point. The error in traverse orientation affects proportionally the standard deviation of the last traverse point. However, due to the large number of the measured refracted angles within the projected traverse and accumulation of errors thereof, the error in traverse orientation shall not significantly affect the position of the last traverse point.

When assessing the accuracy, for the initial grid bearing of the GIP axis standard deviation of 20" was accepted.

In order to provide equal influence of errors in measurement of angles and lengths onto the total error in setting-out of the last point, it is necessary to measure angles by using gyros method with two gyroses with standard deviation of  $\sigma_{\beta} = \pm 19.0''$ , and to measure lengths in two directions forward-backward with standard deviation of  $\sigma_d = \pm 0.95$  cm.

Working environment, where mine chambers are to be marked, as well as required accuracy of angular and linear measurements, enable to perform measurement by using electronic total stations of average accuracy class ( $\pm 10''$  and  $\pm 5$  mm + 5 ppm).

Extremely short lengths of traverse sides and often unfavourable relation between the lengths of the adjacent sides shall determine that the influence of the error in instrument alignment is to be very distinctive. For the purpose of reduction of this influence, it is necessary to realign instrument between gyroses. Therefore, default standard deviation in measurement of angles is often not so easy to achieve. Short collimation lines and the way of signaling result in the fact that the error of signaling is minor and thereby also the influence thereof onto the position of the last traverse point is not significant.

Required accuracy when performing linear measurement shall be easier to achieve, however it is necessary to make alignment of the instrument and signaling of the target point more carefully. It is necessary also to take dustiness of the mine air into account when performing measurements, as well as other metal object that could affect the distortion of laser beam, which could increase the error in the measurement of length.

Positional error  $\sigma_{x,y} = \pm 24$  cm of the last point of mine traverse (point at the level 486 m) has no influence on spatial position and the geometry of the preparation mine chambers (helical conveying downcasts and conveying corridors) so it is possible to achieve solutions given by the Main Mine Project in terms of technical and technological parameters of the chamber development and their stability, loading technology and transport of overburden and bauxite, geological conditions and position of mine chambers in relation to ore body.

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