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# Design and Preliminary Calculation of the Accuracy of Special Geodetic and Mine Surveying Networks

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**Abstract.** The article deals with issues of creation of high precision mine surveying networks. They can be used for the building and equipment installation. Also there is a method of joint adjustment of satellite, geodetic and mine surveying measurements.. To solve this problem, we propose a mathematical apparatus for converting measurements into a local rectangular coordinate system. The joint system of linear equations of satellite and geodetic measurements is solved by the method of least squares by the method of conjugate gradients in a special software package. The complex has the ability to strictly precomputation the accuracy of mixed networks, taking into account all the geometric conditions that arise in the network. The articles shows the design technique of mine surveying base network for cable-belt conveyor, its precision estimation depending on methods and equipments for geodetic measurements.

## 1. Introduction

The technology development of industrial production requires especial demands to building, installation and alignment of the mine and metallurgical equipment. At the same time there is a tendency to increase the sizes of it and the required accuracy of its installation. The higher the production and installation accuracy of such equipment, the more reliable will be its work and maintenance-free period. For example, now the installation accuracy of the equipment in mine and metallurgical industry is 0,1..0,5 mm. To provide such accuracy by traditional geodetical methods [1, 2] is impossible.

In mine surveying instruction [3] there is no requirements for high accuracy measurements. This is due to the new conditions that demand a design proof for geodetic network and an appropriate technique of measurement.

The authors believe that the development of such works will be due to two main components – joint adjustment of all kinds of measurements (geodetic, mine surveying and satellite) and preliminary accuracy calculation of designed geodetic and mine surveying networks. Such approach leads to correct technique and measurement equipment selection and respectively to the quality results.

In recent years there is an unprecedented increase of satellite and navigation systems and respectively the improvement of accuracy measurements by their joint use [13-18]. These measurements are quite ordinary for any surveyor. Wide use of satellite measurement system for geodetic purposes allows talking about occurrence of so-called geodetic navigation space. It can gradually slow down and move out the space of geodetic base points. Because the full transfer to the satellite technologies cannot be performed in short period, all kinds of traditional geodetic



measurements are performed using geodetic equipment as well as satellite navigation receivers [4, 5, 6, 7].

The satellite measurements in present geodetic networks are used mainly for [4-12]:

- improving the accuracy and reliability of the networks;
- transferring the coordinate system from base points, which are far from the local network;
- combining the local networks into the united common network.

The satellite measurements requires open area around the network placements, that is why in geodetic production pure satellite measurements are not used, just in combination with another technique. In a built-up area or enclosed ground it is necessary to set the receiver quite far from the control or defined points. In this case its snap men makes using additional units of the network. As a result we obtain complicated and various geometric constructions which require more flexible and intellectual algorithms of calculation and adjustment. In addition the satellite and geodetic measurements have the similar accuracy that is why they should be adjusted jointly.

Wide use of total stations in geodetic production broke the traditional rule of networks creation. As a result we have just one network type – linear-angular network and do not use any network type division for different types - theodolite traverse, trilateration survey, analytical networks etc. The accuracy of geodetic measurements increased and new methods for estimating the quality of geodetic networks [19-21].

During the handling of such networks as a rule man uses a separate processing for satellite and geodetic measurements, i.e. after the satellite measurements adjustment the obtained coordinates of the points are used as control for the geodetic measurement adjustment. In such cases we lose the accuracy and have some kind of ambiguity of the results estimation. That is why there is a wide interest in scientific articles to joint adjustment of geodetic and satellite measurements [4, 5, 6, 7, 8, 9]. Often there is a recommendation to perform such adjustment using spatial geocentric coordination system, which is used for satellite determination as well as for geodetic terrain measurements processing. Theoretically it is quite correct but the modern conditions of geodetic and mine surveying production do not let to perform a rigorous calculations. First of all it is necessary that the initial ground stations were linked to some coordinate reference ellipsoid and must be known the exact parameters of the transition to the reference ellipsoid, which are defined with respect to a coordinates of satellite observations. Providing of these requirements in terms of construction the engineering local networks difficult to fulfill: there are some restrictions on access to the complete coordinates, moreover, used coordinate system SC-42 and SC-63 do not have the exact parameters of the transition in WGS-84, which performs a specific origin satellite system GPS.

The result of satellite definitions are the accurate projections of the vectors in the geocentric coordinate system between the base station and the current positions of the receivers, as well as the approximate geodetic coordinates of the end points of the vectors. Projections of the vectors can be considered as independent measured values that have to be adjusted. The direct accurate recalculation of the vector projections from geocentric coordinate system to the system coordinate of terrain points is practically impossible for the following reasons:

- global transformation parameters between the geocentric coordinate system of satellites and use different reference ellipsoid, the relative position between them in the body of the Earth is known with insufficient accuracy;
- the coordinate system of ground points can be local and not related to the reference ellipsoid;
- end point vectors have very approximate coordinates, so the transition to geodetic coordinates on the ellipsoid will be accompanied by prominent projections of systematic errors.

## 2. The solution of the problem

For local geodetic networks that have a diameter of 50 km effective use of the following two-step solution. At the first phase using the geodetic coordinates of the vector ends man choses S – the middle point of the network on where the topocentric coordinate system have been established

$SX^T Y^T Z^T$ , axis  $Z^T$  is normal to the ellipsoid at the point S, axes  $X^T$  and  $Y^T$  are orthogonal and lie in the plane which is tangent to ellipsoid.

If the axis  $X^T$  will be positioned in the plane of the meridian passing through the point S, then the projections of the vectors from  $OX^T Y^T Z^T$  – the geocentric system into topocentric  $SX^T Y^T Z^T$  will be recomputed by the following formulas

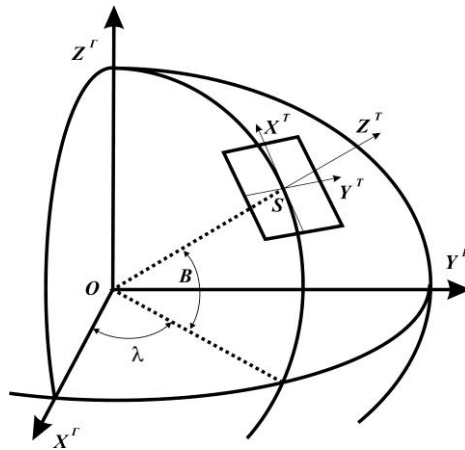
$$\begin{bmatrix} \Delta X^T \\ \Delta Y^T \\ \Delta Z^T \end{bmatrix} = \begin{bmatrix} -\sin B \cos \lambda & -\sin B \sin \lambda & \cos B \\ -\sin \lambda & \cos \lambda & 0 \\ \cos B \cos \lambda & \cos B \sin \lambda & \sin B \end{bmatrix} \begin{bmatrix} \Delta X^r \\ \Delta Y^r \\ \Delta Z^r \end{bmatrix} \quad (1)$$

where  $\lambda, B$  – accordingly the latitude and the longitude of the point S;  $\Delta X^r, \Delta Y^r, \Delta Z^r$  and  $\Delta X^T, \Delta Y^T, \Delta Z^T$  – projections of the vectors in geocentric and topocentric coordinate systems.

The projections of the vectors onto plane coordinates topocentric coordinate system with enough accuracy can be converted into a projection on the plane coordinates of the local system using orthogonal transformation, while the planes of topocentric coordinates and local systems usually form a small dihedral angle. Therefore, for each vector from satellite observations there are the following equation:

$$\begin{cases} x_{k_1} + \Delta X_i^T \omega_1 - \Delta Y_i^T \omega_2 - x_{k_2} = v_i^X \\ y_{k_1} + \Delta Y_i^T \omega_1 - \Delta X_i^T \omega_2 - y_{k_2} = v_i^Y \end{cases} \quad (2)$$

where  $\omega_1, \omega_2$  – parameters of orthogonal transformation vectors satellite observations;  $\Delta X_i^T, \Delta Y_i^T$  – projection of the vector between the points  $k_1$  and  $k_2$ ;  $v_i^X, v_i^Y$  – residuals due to measurement errors in the parametric equation of the  $i$ -th vector.



**Figure 1.** Geocentric and topocentric coordinate systems.

The equations of the form (2), composed for all measured vectors, form the following system of parametric equations

$$BX + D\delta\Omega + L_\omega = V_\omega \quad (3)$$

where  $B$  – the matrix coefficients of the unknown point coordinates network;  $X$  – vector of unknown origin and orientation parameters stations;  $\delta\Omega$  – vector of amendments to the parameters of the orthogonal projection transformation vectors;  $D$  – the matrix coefficients of the unknown vector amendments  $\delta\Omega$ ;  $L_\omega$  – vector of free members, calculated on the coordinates of control points and the approximate values of the parameters:  $\omega_1 = 1$  and  $\omega_2 = 0$ ;  $V_\omega$  – vector of residuals equations (2).

When you combine the system of parametric equations for the coordinates of the points defined parameters and orientation stations from geodetic measurements [20] and parametric equations (3) satellite measurements and solve jointly on the condition:

$$[V^T V] + [V_\omega^T V_\omega] = \min \quad (4)$$

where  $V$  – vector of residuals parametric equations of point coordinates and orientation of lines composed for the geodetic measurements.

The normal equation in this case will look like:

$$\begin{vmatrix} A^T A + B^T B & B^T D \\ D^T B & D^T D \end{vmatrix} \begin{vmatrix} X \\ \delta\Omega \end{vmatrix} + \begin{vmatrix} A^T L + B^T L_\omega \\ D^T L_\omega \end{vmatrix} = 0 \quad (5)$$

By removing vector  $X$  from the equation (5), we can obtain for the unknown  $\delta\Omega$  following equation:

$$[D^T D - D^T B(A^T A + B^T B)^{-1} B^T D] \delta\Omega + D^T L_\omega - D^T B(A^T A + B^T B)^{-1} (A^T L + B^T L_\omega) = 0$$

To determine the approximate coordinates of the network points is permissible to use the measured projection vectors.

The considered algorithm calculates the approximate coordinates of points of the local geodetic network without entering into the original data more information about the topology of the network and allows the software to move to rigorous adjustment of all measurements. Algorithmically the parametric method of adjustment is simpler, so we consider its application in current conditions. Parametric equations are divided into two groups. The first group includes the parametric equations of terrestrial geodetic measurements, namely: directions, lengths, bases, azimuth (directional angles). The formulas of these equations in a linear form is well known [22], so we can write them in matrix form

$$A_T \delta X_T + L_T = V_T \quad (6)$$

where  $A_T$  – the coefficient matrix of parametric equations of terrestrial geodetic measurements;  $\delta X_T$  – vector of amendments to the approximate coordinates of points and orientation angles;  $L_T$  – vector of free members;  $V_T$  – vector of corrections to the measured values.

The second group includes equations of the form (2)

$$B \delta X_T + D \delta\Omega + L_\omega = V_\omega \quad (7)$$

Equations (6) and (7) are solved by the method of least squares under the condition

$$[V_T^T P_T V_T] + [V_\omega^T P_\omega V_\omega] = \min \quad (8)$$

where  $P_T$  and  $P_\omega$  – weight matrix, respectively, terrestrial and satellite geodetic measurements.

Normal equations for the solution of equations (6) and (7) have the form:

$$\begin{vmatrix} A_T^T P_T A_T + B^T P_\omega B & B^T P_\omega D \\ D^T P_\omega B & D^T P_\omega D \end{vmatrix} \begin{vmatrix} X \\ \delta\Omega \end{vmatrix} + \begin{vmatrix} A_T^T P_T L_T + B^T P_\omega L_\omega \\ D^T P_\omega L_\omega \end{vmatrix} = 0 \quad (9)$$

The system (9) is solved by the conjugate gradient in the software package "MGSeti." The software has the ability to perform a rigorous precalculation of precision for mixed networks, including all geometric conditions occurring on the network.

Let us demonstrate these features on the example of a geodetic network of an long object and high accuracy requirements. It is necessary to proof the geometrical configuration of the network and the method of implementation of geodetic and satellite measurements.

### 3. Object of research

That object is the main cable-belt conveyor (CBC), which was designed by the company METSO Minerals [23] between the skip shaft mines and processing plants. The conveyor has three curved parts with a small turning radius as for such objects (440 meters), so the accuracy of the foundation blocks installation of the conveyor should meet the high requirements. The error in determining the coordinates of the centers of the foundation must not exceed 6 mm throughout the pipeline, whose length is 5200 meters (660 poles foundations) and two bridge crossings (Fig. 2). Other words the relative error for this object is 1: 860 000, it is a very high accuracy for mine surveying and geodetic works.



a) overpass to the processing plant

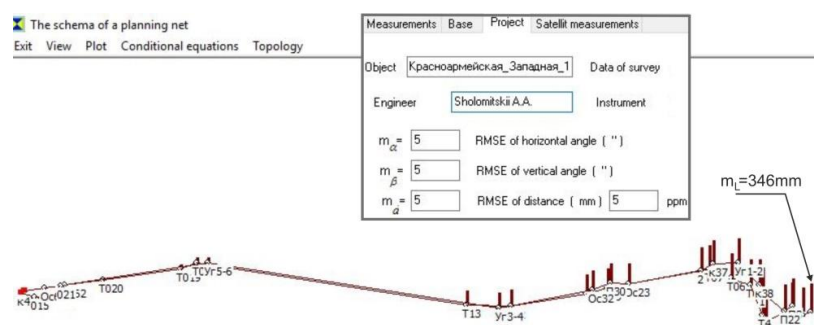


б) construction elements

**Figure 2.** Fragments of the cable-belt conveyor.

### 4. Assessment of the object

To assess the accuracy of geodetic network was used the software MGSeti [24]. It was modeled the network of 1-st category polygonometry in which the measurement of the horizontal and vertical angles were performed by optically theodolite. Used standard errors for angles 5". All length were measured by electronic roulette DISTO. For this network was performed the accuracy calculation, Fig. 3 shows the distribution bar graph of planned network error. The graph shows that the errors values increase from left to right, increasing to the control points and reaches 346 mm in the direction perpendicular to the line.



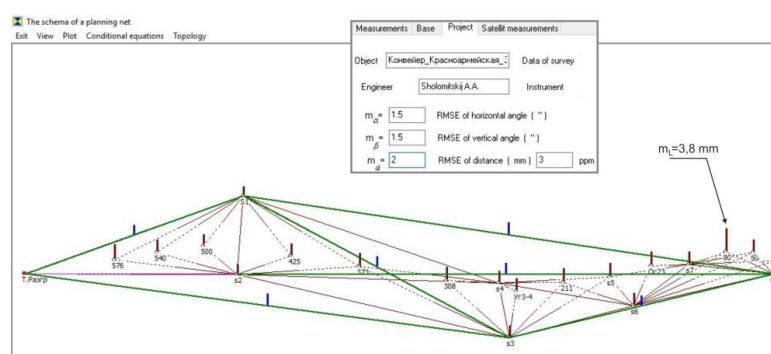
**Figure 3.** Diagram of distribution of planned network errors.

The resulting accuracy of the network cannot provide the necessary accuracy of installation of conveyor foundations and therefore traverse method cannot be applied in this case.

Therefore, the initial problem was to find a network configuration and a measurement technique that will provide the greater rigidity of the network and higher accuracy measurements.

## 5. Design of mine surveying basic network

However, the authors did not have such a tool, so it was necessary to achieve the necessary accuracy with the help of existing geodetic instruments. Therefore, to improve the accuracy of the network it was decided to use high-precision satellite measurements (Fig. 4).



**Figure 4.** The diagram error distribution of the network with satellite measurements.

If to the mine surveying network add 6 vectors of satellite measurements (in Fig. 5 are shown in green) measured with errors  $m_x = 0,005m$ ,  $m_y = 0,005m$ ,  $m_z = 0,005m$ , then the error distribution of the point positions becomes evenly (Fig. 5), and errors in determining the position of the coordinate plane will not exceed 3,8 mm

## 6. Conclusions

After work on the creation of surveying basic network for CBC we can make the following conclusions:

- 1) To create a geodetic and mine surveying for unique objects it is not enough to use just the Instructions recommendation [3], it is necessary to make a rigorous accuracy calculations which will show the possibility to provide the necessary accuracy with the current methods and technique.
- 2) Maximum accuracy of special high-precision geodetic surveying networks on the surface can be achieved only using the joint adjustment of geodetic and satellite measurements.
- 3) Surveying and mine surveying measurements should be made with greater accuracy than was set during the precalculation with "reserve" in the 15 - 20% since precalculation uses perfect accuracy, which is not possible to achieve in practice, especially in complicated weather conditions.
- 4) To perform high-precision measurements in surveying and geodetic networks it is necessary to produce special equipment.
- 5) Using the on-line measuring software "Vizir 3D" allowed to reduce measurement time in 3-5 times and improve accuracy by statistical processing and reject poor quality measurements «on-line».

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