Application of the New Mine Surveying Methods for Purposes of the Longest Crosscutting in the Czech Republic

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Abstract: - Purpose of connecting surveys and orientation measurements is to determine mutual position of underground mine working and building objects, situated on the surface and/or with other underground workings, situated on other horizons. Should a mine shaft is the development working, it is necessary to project a surface point to connected horizon. With respect to required positioning accuracy of project point as well as depths of connected horizons within the OKD (Ostrava-Karviná Collieries), the Institute of Geodesy and Mine Surveying developed a new plummet swing observation method during projecting the points into underground by means of a specially adjusted plummet. Measuring the lengths is a part of orientation measurement and connecting surveys, as well. Contemporary, standard length measuring is done using the measuring tape with protocol, which requires mine technician (surveyor) entering over the free depth, placing the tape to the plummet suspension, and measured length reading. Innovation of this procedure enables measuring the lengths using the omnidirectional prism, located into suspended structure by means of electronic distance meters (EDMs) resulting in improvement in measured length accuracy, simplification the works situated both on mine surface and on connected horizon, and especially increasing the safety of work and its economy. Swing observation is necessary to determine accurate plummet position within the plumb line being done from a single point of the basic orientation line by means of robotized electronic tachymeter and a plummet, in suspension wire of which an omnidirectional prism and a plummet are located axially. Plummets swings around its plumb line where its partial positions are determined continuously based on data measured by the tachymeter in local a coordinate system, being related to points of basic orientation line, situated at the connected horizon. Applying the plummet swing position coordinates, calculated this way, we are able to determine plummet positions in the plumb line, subsequently their length and direction towards the point of the basic orientation line. By means of a bearing determined by a gyrotheodolite on basic orientation line and based on calculated values we are capable to mark out point coordinates of basic orientation line in the valid coordinate system.

Key-Words: - underground mine, length, connecting survey and orientation measurement, swing observation, plummet, omnidirectional prism, plumb line.

1 Introduction

With the progressive extraction of coal seams in increasingly greater depths and with the effort to exploit efficiently the coal reserves between individual big mines in the Karviná part of the Ostrava-Karviná Coal District (OKR) it is necessary to interconnect the mining compounds (mines) with opening workings for economic, transport, extractions and ventilation purposes. Although all horizontal controls of the mines in the OKR mines are recorded in the Datum of Uniform Trigonometric Cadastral Network, it is necessary, for the interconnection of mine fields itself, to carry out new connecting surveys and orientation measurements. Given the depth of connected horizons of mine workings, climate conditions in the shafts and the required accuracy of the projected points position, the Institute of Geodesy and Mine Surveying at the Faculty of Mining and Geology of the VŠB – Technical University in Ostrava has developed a new plummet swing observation method.
The regulation of the Czech Mining Authority no. 435/1992 Coll. as amended lays down the obligation to survey all mine workings in the national reference system of the Datum of Uniform Trigonometric Cadastral Network. The aim of the connecting surveys and orientation measurements on the surface is to determine the position of the terminal points of the projected line segment and in particular their bearing. The connection of the horizon in a mine has an objective of projecting the coordinate values from the projected line segment to the points ensuring the basic orientation line of the connected mine working. The connecting surveys and orientation measurements using one or more shafts are performed by means of a plummet or plummets lowered into the shafts. In order to determine the coordinates of the plummets in the pit bank, it is necessary to set up an artificial scaffold in the shaft cross-section for purposes of the occupational safety of workers carrying out the distance measurement. The distance measurement is performed by means of a measuring tape with protocol. The inconvenient of this traditional solution is that the work consumes a considerable amount of time and the organization of work is difficult as the safety has to be ensured also on the connected horizon. The financial costs of the whole project are not negligible. Furthermore, the direct distance measuring by means of a tape is subject to various systematic errors and the measured distance has to be corrected.

In the proposed solution, the connecting survey and orientation measurement are carried out by means of a universal tachymeter with an omnidirectional prism coaxially located in the suspension over the plummet which determines the coordinates of terminal points of the projected line segment on the surface as well as in the mine. The distances are not measured using a tape but by means of an optical distance meter.

The new method uses for the swing observation a robotic universal tachymeter and a suspension for the coaxial position of the omnidirectional prism over the plummet. The plummet swings around its plumb line and its individual positions are continuously determined from the data measured in the local coordinate system which is applied to the points of the basic orientation line on the connected horizon. To define the coordinates of the basic orientation line points, the bearing is determined by use a gyrotheodolite. The abovementioned method of connecting surveys and orientation measurements allows a faster procedure of surveying works, increased occupational safety in mines and facilitation of the calculation process to determine the position of the plummet in the plumb line.

2 Principle of the connecting surveys and orientation measurements

The purpose of the connecting surveys and orientation measurements is to project the position of the basic orientation line points and its direction to the mine in order to connect the mine horizontal control to the surface one. The method of the connecting surveys and orientation measurements is selected depending on the kind of the opening mine working.

The measurement accuracy is defined by the maximum allowable deviation of the bearing of the orientation side underground and in the position of the terminal points of this orientation side. These deviations are set by the Regulation of the Czech Mining Authority no. 435/1992 Coll. on the Mining Survey Documentation for the Purposes of Mining Activities and Some Other Activities Performed by Mining Methods, as amended.

Under this regulation, it is possible to connect and orient horizons only by means of the following methods, namely by the connection and orientation of the horizon of an underground mine working with a traverse which is:

1. conducted between the points projected by two or more shafts;
2. conducted between the orientation lines stabilised on the surface near the shaft mouth or a pitch (underground) mine working;
3. running from one orientation line stabilised on the surface near the shaft mouth or a pitch (underground) mine working;
4. running from the point projected by one shaft and an orientation line using a gyrotheodolite.

In other cases, it is possible to connect the mine working horizon using an appropriate survey orientation method, in particular:

- connection by one shaft and two plummets; or
- connection by a gyrotheodolite and at least one plummet.

Fig. 1. Rough drawing of the connecting surveys and orientation measurements

The basic principle of the connecting survey and orientation measurement by [11] is to determine the position of two points A, B in the mine in the binding reference coordinate system in which at least two points on the surface P1 and P2 known (see Fig. 1). On the basis of the coordinates of points A[xA,yA], B[xB,yB], it is subsequently possible to calculate the bearing of the side AB in the same coordinate system as the one on the surface. The result of the connecting survey and orientation measurement are the coordinates of the terminal points A, B of the so called basic orientation line and the bearing of the side AB.

Fig. 2. Diagram of the connecting surveys and orientation measurements using the direction measurements

Fig. 2 depicts a diagram of the connecting survey and orientation measurement using the direction measurements when the position of a sole point A[xA,yA] is determined on the surface and the bearing αA is defined by means of a direct magnetic or gyroscopic measurement. As a precaution against the possible damage or destruction of one of the terminal points of the basic orientation line, it is convenient to determine the position of three points (so that it is possible to check the invariable position of the points by means of measuring the vertex angle in the inner point. The basic orientation line is usually selected in order to prevent the disturbance of its stability as a result of extraction works, i.e. in shaft bottoms, in shaft safety pillars. In horizontal or pitch workings, the basic orientation line is stabilised into the overlying strata of the deposit (roof of the galleries). For more details see [8].

The most suitable method is the connection by means of an adjusted traverse. The measuring of vertex angles in mine traverses is carried out in at least one set and the allowed deviation in the misclosure of the set depends on the required accuracy. In the case of adjusted traverses, the deviation is set up by the [13] at Up= ±10". If the opening of a mine field is done by two shafts, one plummet is lowered in each one of them. If there are more than two shafts in the mine field, the connection is performed by means of traverses without orientation also between those shafts and all orientation results
are compared on one common orientation line. The differences in the bearing values define the degree of accuracy of the measurements as well as the required control in accordance with the [13].

If the mine working is opened with one vertical shaft, the orientation is carried out using a gyrotheodolite or two plummets. In the case of raises, which are vertical workings connecting a level with another level, and less profound shafts (100-150 m) where the surrounding air is free, without water drops, it is possible to use survey patterns and steady plummets, however, this method can be used only as an orientation geodetic method. For a more detailed description of methods of connecting surveys and orientation measurements see among others [3].

### 3 Accuracy of the connecting surveys and orientation measurements

The accuracy of the connecting survey and orientation measurement is defined by the accuracy in the position of the basic orientation line, or rather by the values of mean errors in the position of the points of the basic orientation line: \( m_{x_B}, m_{y_B}, m_{x_B}, m_{y_B} \) and their bearing \( m_{\sigma AB} \). The required accuracy is defined by the accuracy of determined position of points of the mine workings on the border of the extraction area. It is defined by the mean error arising from an incorrect orientation of the basic orientation line and from errors generated during the measurement of the traverse without orientation which can be most easily characterized by the transverse deviation.

Assuming an adjusted traverse, the transverse deviation \( Q_\sigma \) caused by the error \( m_{\sigma AB} \) in the orientation line segment AB is defined by the following relationship

\[
Q_\sigma = m_{\sigma AB} \cdot L. \tag{1}
\]

Due to errors during the measurement of vertex angles \( m_\omega \) in the traverse, a transverse deviation \( Q_\epsilon \) occurs which is defined by the following relationship

\[
Q_\epsilon = m_\omega \cdot L \sqrt{\frac{L}{3s}}. \tag{2}
\]

In the abovementioned relationships (1) and (2):

- \( L \ldots \) is the total length of the traverse;
- \( s \ldots \) is the mean length of the traverse sides.

The total error, or uncertainty of the position of the point \( K \), is defined by the sum of both transverse deviations

\[
Q_c = Q_\sigma + Q_\epsilon. \tag{3}
\]

**Fig. 3. Derivation of the accuracy of the connecting survey and orientation measurement [11]**

The optimal accuracy of the bearing of the basic orientation line of the connecting survey and orientation measurement can be determined on the basis of the condition requiring the transverse deviation caused by the incorrect orientation \( Q_\sigma \) not to be higher than the transverse deviation of the traverse on the border of the extraction area \( Q_\epsilon \), i.e.

\[
m_{\sigma AB} = m_\omega \cdot L \sqrt{\frac{L}{3s}}, \tag{4}
\]

\[
m_{\sigma AB} = m_\omega \cdot L \sqrt{\frac{L}{3s}}. \tag{5}
\]

The a posteriori, i.e. real accuracy of the measurement can be calculated on the basis of deviations in the direction of the basic orientation line \( Q_\sigma \) and of the position deviations of the terminal points \( O_x, O_y \), or alternatively \( O_P \). The accuracy in determining the bearing of the basic orientation line is laid down by the [13] and from the theoretical perspective defined in [10].

### 4 Projection by plummets

An indispensible part of the connecting survey and orientation measurement, in the case where the one opening working is constituted by a shaft, is the
projection of the points from the surface to the
connected horizon. The projection of points can be
performed in two ways: optically and mechanically.

The optical projection of points can be
carried out by means of a vertical line of sight
marked out with a light beam or laser. The
optical projection is frequently used for
measurements in smaller depths. A greater
range is limited by the low visibility caused by
dusty air and water vapours. Among others
unfavourable factors range the refraction,
vibrations and condensation of water vapours
on the optical device. The accuracy of the
measurement also depends on the sensitivity of
the level or compensator adjustment.

As for the mechanical projection, specially
adjusted plummets lowered into the shaft are
used. This procedure is accurate but quite
laborious and in greater depths, the plummet
position is unfavourably influenced by the
wind, water drops and other factors. On the
horizon, that we intend to connect, we project
one or more points which create the connection
patterns, e.g. a triangle, a quadrangle (Fox's
connection) and a polygon.

According to [11], in order to be able to
survey the steady plummets on the connected
horizon, we first have to determine their
position in the plumb line conducted through
the suspension point. The projected point or the
connection pattern is defined by the plummet or
plummets which consist of a weight, a
suspension wire and a suspension. The weight
has to be selected so that the suspension wire is
straight in its position. The position of the
plummet in the plumb line is determined by a
calculation as the centre of swing of the
plummet in two mutually perpendicular
directions. The reading of the inflection points
must be performed using a theodolite on
accurate scales with length of 0.120-0.200 m
divided into millimetres. The number of swings
in one row should be of 9 -10 on each side of
the swing; the number of sets has to be of at
least 2 per plummet and per direction.

In accordance with the [13], the accuracy of
determining the plummet position in the plumb
line must not surpass the allowed deviation of ±
7·10⁻³ m. This method can be used for plummet
projection in shallow shafts without strong
ventilation and water drops in the cross section
of the shaft. For plummet suspensions longer
than 50 m, it is convenient to apply the method
using several different weights for each
plummet. This projection method, invented and
developed by professor Wilski, is based on the
idea that in a blast of air, the plummet doesn't
swing around the correct projection of the
suspension point due to the effect of the
constant force wind blast on the plummet. The
wind blast which deflects the plummet results in
the plummet swinging regularly to the right and
to the left but not around the correct projection
of the suspension point. The shift of the swing
centre increases with the kinetic energy of the
wind blast which depends on the amount of
winds going through the shaft and on their
speed. In order to determine this deflection and
incorporate it into the calculation, it is
necessary to use at least two different weights.
To determine the accurate position of the
plummet in the plumb line, a double
observation of swings with two different
weights is sufficient. If more weights are used,
then with a redundant number of observations it
is possible to determine the accurate plummet
position using the adjustment method of
Mean Squared Error. For more details regarding
the complex Wilski projection see among others

5 Substance of the new method of
swing observation for purposes of
determining the accurate position of
the plummet in the plumb line
during connecting surveys and
orientation measurements

The inconveniences of the traditional observation of
plummet swings and distance measuring during
connecting surveys and orientation measurements in
shafts are eliminated by the suggested solution
which consists of using a suspended omnidirectional
prism inserted into the plummet weight and which
was developed at the Institute of Geodesy and Mine
Surveying, Faculty of Mining and Geology, VŠB –
Technical University of Ostrava.

The device comprises of a suspension for the
coaxial location of the omnidirectional prism
(see Fig. 4) which is composed of screws for
central fixation of wire (1), casing with bearings
allowing the rotation of the suspension (2), supporting plates (3), pivot for the attachment of the surveying prism (4), omnidirectional prism (5), bars connecting the top and the bottom supporting plate of the suspension (6) and adjusted plummet with a sheet-metal coating (7). The suspension is equipped with the coating in order to guarantee a constant wind force having effect on the plummet with variable volume of the weight.

Fig. 4. Suspension for omnidirectional prism with plummet axially located

During the projection of the point from the surface to the connected horizon, it is necessary to start by fixing a pulley and a lock at the pit bank. The weighted wire is slowly lowered into the shaft so that it doesn’t swing and snag on the shaft equipment. A better and practice-tested way is to lower slowly the wire lead by a surveyor from the mine cage. However, this method requires the respect of all safety rules and measures approved by the mine administration.

After the wire is lowered to the connected horizon, the suspension is attached to the wire and individual weights are added one by one until the required weight is reached. While weights are being added, it is necessary to anticipate a considerable elastic extension of the wire that is compensated by winding the wire on the winch. The following step is to check whether the wire isn’t caught in the equipment of the shaft. The check can be also performed using a ring dropped down the wire from the pit bank to the connected level or by means of determining the period of swing of the plummet which can be considered mathematical pendulum. The following approximate formula applies to the period of a simple swing:

$$t \cong \sqrt{l},$$  

where

- $t$ - is the period of a simple swing of the mathematical pendulum [s],
- $l$ - is the length [m].

After the check, the omnidirectional prism is attached to the suspension on the connected level. For purposes of distances in the pit bank, the wire is equipped with a reflective stick. Some aspects of the distance measurement by means of laser distance meters on the basis of the passive reflection are described among others in [9]. The method of distance measuring using the device for omnidirectional prism located coaxially is indicated in [4].

The measurement itself (swing observation) on the connected level is performed using a robotized universal measuring instrument. Given that swings will not manifest themselves in the pit bank (the movement of the wire is negligible in relation with its length), it is possible for the measurements of the plummet position in the plumb line to use any universal measuring instrument suitable for required measuring accuracy.

The initial points to determine the position of the plummet in the plumb line on the surface are the points of the basic orientation line (at least three points) and the position of the plummet on the surface is subsequently defined using the arithmetic mean of the balanced direction from three groups of measurements.

The station of the robotized universal measuring instrument on the connected horizon is situated in the point of the basic orientation line in which the survey of the set of directions for the points of the basic orientation line is performed in two groups of measurements part
of which is the continual measuring of polar coordinates of individual positions of the plummet in the swing. The measuring is performed according to the following procedure (1st set of measurements):

1. to set the plummet swinging in one direction and survey individual positions of the plummet in the swing in the total number of 10 swings;
2. to survey the set of directions for the points of the basic orientation line in two rounds measurements;
3. to set the plummet swinging in the direction perpendicular to the previous one and to survey individual positions of the plummet in the swing in the total number of 10 swings;
4. to survey the set of directions for the points of the basic orientation line in two groups of measurements.

The abovementioned method is applied also to other two sets of measurements. After the three sets of measurements with one weight are performed, the identical procedure is applied in three sets of measurements to the second and the third weight.

The described measuring method requires the use of a robotized instrument equipped with the ATR (automatic target recognition) and the LOCK (prism lock) functions. It is necessary to select the time interval between the measurements of individual positions of the plummet in the swing so that the density of points represents adequately the trajectory of the plummet. In general it is possible to observe that the plummet trajectory is more accurate with shorter intervals between measurements. By using an optical distance meter, the impact of systematic errors is reduced as it is possible to insert the physical reductions directly to the software of the instrument and the abovementioned impact is already corrected in the measured distances. For purposes of other calculations, it is necessary to correct the measured distances also in terms of mathematical reductions, in particular the correction for elevation. Other unfavourable conditions having effect on the characteristics of geodetic networks are cited in v [2], [6], [7] and [12], the unfavourable effect of refraction on the estimate of parameters of the geodetic network is described in [5] and in [1].

The connecting surveys and orientation measurements performed under this method involve also the determination of bearing of at least two points of the basic orientation line using a gyrotheodolite.

The position of the plummet in the plumb line is calculated for each set separately and is calculated as an arithmetic mean from all three sets for individual weights. The corrections of the position of the plummet in the plumb line as suggested by Wilski are determined for each weight and the resulting position of the plummet in the plumb line is calculated as the mean of corrected positions of the plummet for given weights. The processing of the measurements takes place within the local coordinate system related to the points of the basic orientation line.

On the basis of the calculated coordinates of the plummet position in the plumb line, the distance $s_{DO}$ between the point D and the plummet position in the plumb line (see Fig. 5) is determined as well as the angle $\omega_D$ between the points of the basic orientation line D, E and the plummet position in the plumb line.

On the basis of the bearing $\sigma_{DE}$ determined by the gyrotheodolite and the angle $\omega_D$, the bearing from the projected point to the point D, from which the measuring, was performed is calculated. On the basis of thus calculated bearing, distance $s_{AO}$, distances and angles
measured in the point D, the coordinates of points D, E and F of the basic orientation line are subsequently calculated.

6 Conclusion

The described method of swing observation for purposes of determining the accurate position of the plummet in the plumb line which uses the suspension for the placement of an omnidirectional prism above the plummet was developed in view of conditions in the Ostrava-Karviná Coal District (OKR). The conditions for connecting surveys and orientation measurements in the OKR mines are specific in the depth of connected mine workings and the climatic conditions such as humidity, dustiness and changeable temperature in the shafts.

Compared to the currently used methods, the proposed solution uses the indirect distance measuring by means of optical distance meter and entails many advantages. These advantages are based on the fact that it isn’t necessary to perform certain operations which were necessary during connecting surveys and orientation measurements using the direct distance measuring and traditional observation of plummet swings. The first and essential advantage is the rapidity of the entire process of connecting surveys and orientation measurements. The speed of the process is increased by the fact that no scaffolds have to be built on the pit-bank level, on and under the connected level. As the direct distance measuring is not applied and there is no need to install any arresting mechanisms, no position calculation and subsequent arresting of the plummet in the plumb line takes place in the mine. Thanks to this fact, the working restriction of mining company employees is reduced. In the final consequence, as the work consumes less time, it entails economic savings, in particular the cost of employees and material necessary for setting up of the scaffolds. As for the occupational safety, the presence of workers in the shaft area is minimized since the workers enter only the safe space of the roof of the mine cage and do not enter over the open depth. The abovementioned facts show that the entire measuring is significantly simpler as the swing observation itself is performed automatically by a device without any intervention of a worker and all measured values are recorded into the memory of the device. The subsequent processing of the registered values is transferred to the office and takes place only after the measuring itself.

The use of the new method of swing observation for purposes of determining the position of the plummet in the plumb line is not limited to great depths, but can be used also for connecting surveys and orientation measurements in smaller depths, such as for utility tunnels, exploration mine workings and other underground constructions.

The described method of swing observation was used during the realisation of the connecting survey and orientation measurement between the shafts Mir 5 (Darkov Mine) and ČSA 2 (Karviná Mine) in July 2011. On the basis of the connected and oriented basic orientation lines of the abovementioned shafts, the teams of the Department of Survey and Geology of individual mining companies performed the drivage of the total length of 3.031 m, of which 1.580 m from the side of the Darkov Mine and 1.451 m from the side of the Karviná Mine.

In the end of 2012, precisely on the 12/12/2012 at 12 PM, the Darkov and Karviná Mines were connected in the depth of 870 meters. The punching was achieved by counter-excavations with the gradient of 6° approximately in the centre of direction of the mine working and of the length of 1.750 m with the difference of elevation of 196 m. The achieved deviations in the point of connection were \( m_{x,y} = 0.011 \) m in the position and \( m_h=0.005 \) m in the height.

By the punching of the crosscut, the connection of all active mines of the Karviná part of the Ostrava-Karviná Coal District was completed. The connecting crosscut will conduct the entire output from the ČSA - Karviná Mine to the coal preparation plant in the Darkov Mine and it will also serve as a transport channel for the two-way transport of material and persons.

The importance of the synergy between the science and the practical research is taking place also in the framework of the cooperation between the Institute of Geodesy and Mine Surveying, Faculty of Mining and Geology,
VŠB – Technical University of Ostrava and the Vítkovice Machinery Group, leading supplier of mining equipment in the Czech Republic and in the world.

The present article could have been drafted thanks to the support of the project SP2013/90 in the framework of the Student Grant Competition organized by the Faculty of Mining and Geology, VŠB – Technical University of Ostrava.

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