New method of swing observation to determine accurate plummet position at the plumb line for both connecting surveys and orientation measurements

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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.

Key words: *connecting survey and orientation measurement, swing observation, plummet, omnidirectional prism, plumb line*

Introduction

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. Plummet 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. After mined minerals has to consider on the aspects of further use mine galleries, for example in [19].

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

The inconveniences of the traditional observation of plummet swings and length measurement in connecting surveys and orientation measurements in shafts, for example in [4], [6], 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 is comprised of a suspension for the coaxial insertion of the omnidirectional prism (Fig. 1), which is composed of screws for central fastening of the wire (1), a casing with bearings allowing the orientation of the suspension (2), supporting plates (3), a pivot for the attachment of the surveying prism (4), an omnidirectional prism (5), bars connecting the top and the bottom supporting plate of the suspension (6) and an adjusted plummet with a sheet-metal coating (7). The suspension is equipped with the coating in order to guarantee constant wind force exerted on the plummet in the case of use of different weights.

During the projection of the point from the surface to the connected horizon, it is necessary to first fix a pulley and a wire lock at the pit bank. The weighted wire is slowly lowered into the shaft so that it does not swing and get caught 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 observation of all safety rules and measures approved by the mine manager. The following step is to check whether the wire did not get caught in the equipment of the shaft.

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Fig. 1. Suspension for an omnidirectional prism coaxially inserted above the plummet.

After the check, the omnidirectional prism is attached to the suspension on the connected level. For the purposes of length measurement at the pit bank, the wire is equipped with a reflective stick, its use is often in mechanical engineering, for example in [15], archeology for example in [3]. Some aspects of the length measurement by means of laser telemeters on the basis of passive reflection are described, for example, in [7]. The method of length measurement using a device for an omnidirectional prism inserted coaxially is outlined in [4].

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

The initial points to determine the position of the plummet in the plumb line on the surface are the points on the basic orientation line (a minimum of three points) and the position of the plummet on the surface is subsequently defined using the arithmetic mean of the adjusted direction, which is calculated from the data obtained through three sets of measurements.

The station of the robotised universal measuring instrument on the connected horizon is situated on the point of the basic orientation line, from which the survey of the set of directions for the points on the basic orientation line is performed in two rounds of measurements. A part of them consists in the continual measuring of the polar coordinates of individual positions of the plummet in the swing. The measuring procedure is as follows (the first set of measurements):

1. 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. Survey the set of directions for the points on the basic orientation line in two rounds of measurements;
3. 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. Survey the set of directions for the points on the basic orientation line in two rounds of measurements.

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

The described measuring method requires the use of a robotised instrument equipped with the ATR (automatic target recognition) and the LOCK (prism lock) functions. It is also necessary to select the time interval between the measurements of individual positions of the plummet in the swing so that the density of the 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 electro-optical telemeter, the impact of systematic errors is mitigated as it is possible to enter the physical reductions directly into the software of the instrument and the abovementioned effect of errors is already corrected in the measured lengths. For the purposes of further calculations, it is necessary to correct the measured lengths to reflect also mathematical reductions, in particular the altitude correction.

Other conditions having an adverse effect on the characteristics of geodetic networks are mentioned, for example in [10], [13], [17] and [18], the adverse effect of refraction on the estimate of the geodetic network parameters is described, for example, in [2] and in [7]. Also important is the compatibility of connecting points on the surface, which is described for example in [8], [16], [20].

The connecting surveys and orientation measurements performed in this manner also involve the determination of the bearing of at least two points on the basic orientation line using a gyrotheodolite, for example, in [14][7].

The position of the plummet in the plumb line is calculated for each set separately and is determined for individual weights as an arithmetic mean established on the basis of the data obtained through all three sets of measurements. The corrections of the position of the plummet in the plumb line as suggested by Wilski are defined for each weight and the resulting position of the plummet in the plumb line is calculated as the mean of the corrected positions of the plummet for the given weights. The measurements are processed within the local coordinate system referenced to the points on the basic orientation line.

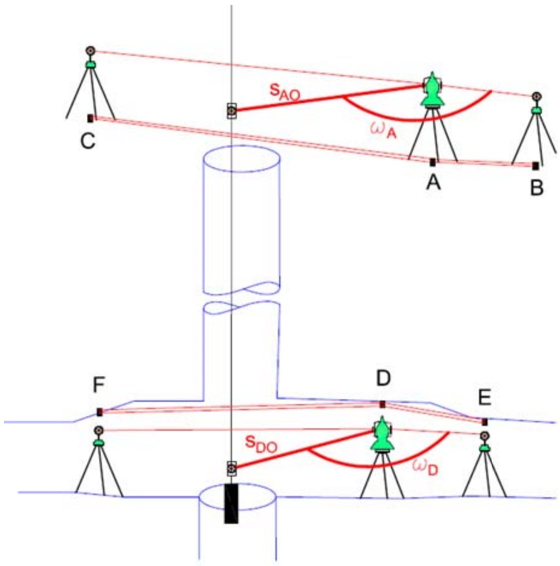

Fig. 2. Schematic sketch of connecting surveys on the surface and on the connected horizon.

On the basis of the calculated coordinates of the plummet position in the plumb line, length s_{DO} between point D and the plummet position in the plumb line (Fig. 2) are determined as well as angle ω_D between the points on basic orientation line D, E and the plummet position in the plumb line.

On the basis of bearing σ_{DE} determined by the gyrotheodolite and angle ω_D, the bearing from the projected point to point D, from which the measurement was performed, is calculated. On the basis of the bearing so calculated, length s_{AO}, lengths and angles measured on point D, the coordinates of points D, E and F on the basic orientation line are subsequently calculated.

The method of swing centre determination for the purposes of the determination of the accurate position of the plummet in the plumb line was tested in the IGDM training shaft. The shaft has the form of a 1.2 x 2.0 m rectangle and no equipment is installed in it. It is 35 m deep. The diameter of the suspension wire was 1.2mm and the weight of the plummet, above which a suspension for a omnidirectional prism was attached, was 20 kg. The tests were performed using a Leica TS 30 robotised universal measuring instrument, set to automatically register measured data at an interval of 0.3 s. A GRZ101, 360°, Mini Reflektor omnidirectional prism was inserted in the suspension above the plummet. A total of 40 observations were made (20 in one direction and 20 in the direction perpendicular to the first one). One observation involved 10 swings.

Swing measurements using a robotised universal measuring instrument

Measurements can be performed either from a point on the basic orientation line or from a station selected arbitrarily so that the position of the instrument guarantees good visibility of the surveying prism within the entire range of plummet swings. Measurements carried out from a point on the basic orientation line are more appropriate for the calculations of the coordinates of the other points on the basic orientation line as provided below. When opting for a station outside the points on the orientation line, it is advisable that we have visibility of all points on the basic orientation line.

In cases where visibility between the station and the points on the basic orientation line cannot be achieved, it is more difficult to process the measurement results afterwards. This can be resolved by the calculation of oriented lengths or by the calculation of a micronetwork. The points on the basic orientation line are calculated in the local coordinate system.

Before swing measurements are carried out, it is first necessary to survey the lengths and the set of directions in two groups in relation to the points on the basic orientation line. This procedure is repeated after the observations of each series of plummet swings are terminated.

Before performing the measurements, we first need to set the telemeter. This involves setting the following functions:

- LOCK (prism observation) – this function allows observing the prism. The Leica TS30 can observe a prism moving in a distance of 20 m and at the speed of 9 $m.s^{-1}$ in the horizontal direction and 5 $m.s^{-1}$ in the vertical direction.
- Low visibility (poor visibility) – this enhances the automatic focus function of the instrument in poor climatic and visibility conditions. Setting the low visibility function in mines is necessary. Otherwise, measurements are often interrupted and the final swing trajectory is only partial.
- SynchroTrack – this is a mode for interpolation of angle measurements using the LOCK function. This interpolation method enhances the accuracy of the values obtained through measurements for all dynamic applications (e.g., machine guidance).
- Additionally, it is necessary to set the measurement speed of the individual points in the automatic measurement mode. The TS30 enables automatic point measurements at the minimum interval of 0.3 s.

At this stage, it is necessary to focus the instrument on the prism and start point measurement. The instrument then automatically measures individual plummet swings and records the following data regarding the individual points: point number, horizontal angle, zenith angle, distance, and time. The data so obtained can be easily downloaded to a computer for subsequent processing.

Graphical processing and evaluation of data

On the basis of the data obtained through the measurements, we will calculate the coordinates of the points describing the swing trajectory in the local coordinate system.

Given the accuracy of the instrument used and for the sake of better description of the ellipse and the subsequent mathematical calculation of the ellipse centres, the point coordinates need to be stated in metres rounded off to four decimal places. Fig. 3 shows the connecting lines of the points and their coordinates in millimetres (in black), in tenths of millimetres (in red) and a graphically determined ellipse (in blue). The figure demonstrates that the final ellipse better corresponds to the points whose coordinates were rounded off to four decimal places.

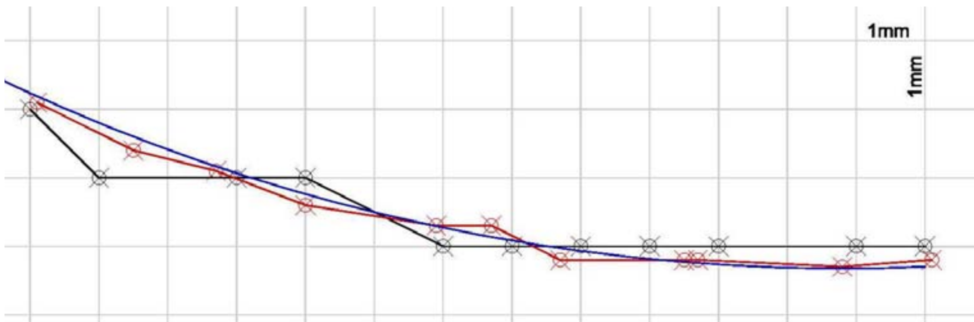

Fig. 3. Connecting lines of the points and a graphically determined ellipse.

Upon graphical evaluation of the swings, we first need to connect the points surveyed and describe the trajectory of the plummet swings. For this, we use the AutoCAD software, enabling to automatically draw the curve (the "curve" command) from the coordinates entered in the text format. The "curve" command requires the use of a decimal point, with a comma being the separator of the x, y coordinates. The presented methodology approach can also be analyzed through GIS systems. Application of GIS can solve supports for the modelling of curves and surfaces, at which are expressed oscillating movements [1], [9], [12].

In view of the large number of the connected points, the automatic curve drawing function helps to speed up the work significantly. Fig. 4 shows the entire set of data from one connected level (approx. 6,500 points). During the first attempts at swing evaluation, curves were drawn manually, which was very time consuming.

Fig. 4. Graphical representation of a set of points from one connected level.

Individual swings can best be replaced by an ellipse. For the subsequent processing, it is necessary to split the curve into individual parts resembling ellipses, (Fig. 5).

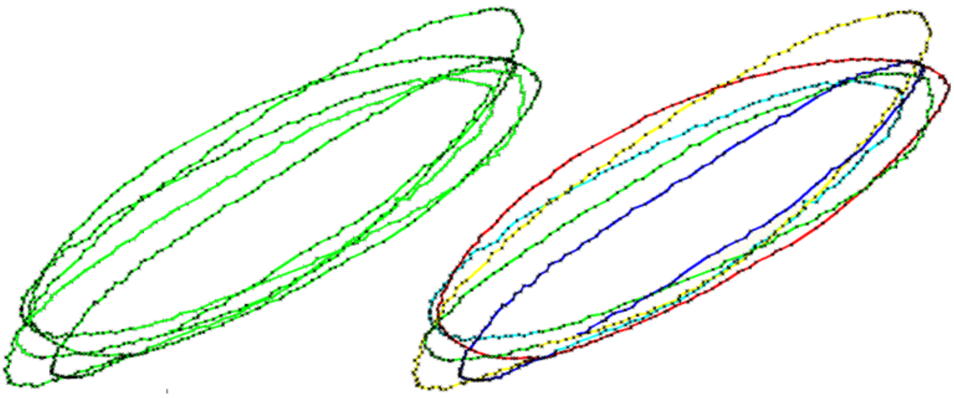

Fig. 5. Individual swings replaced by an ellipse.

The swing centre is determined as the centre of the ellipse which best corresponds to its trajectory. It is necessary to pay adequate attention to drawing the ellipse.

Based on our experience, an ellipse should be drawn in accordance with the following principles:

- The ellipse should have minimum deviations from the swing pattern;
- The ellipse should touch the curve only at its vertices;
- The deviations of the ellipse should be compensated in the swing pattern;
- We should prefer that the osculating circles of the ellipse touch the swing pattern.

Ellipses can be placed differently, but if we adhere to the principles defined above, deviations of the ellipse (swing) centres are minimal. An example is shown in Fig. 6. The swing pattern is shown in light blue, with ellipses drawn in accordance with the principles outlined above being illustrated in blue and red. The deviation of the ellipse centres is 0.3mm. If the ellipse was drawn inaccurately (as shown in green), the deviation of its centre would be 1.6 mm.

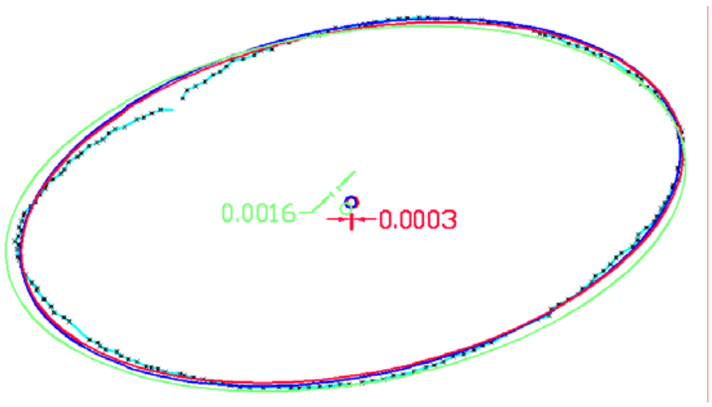

Fig. 6. Deviations of ellipse centres.

This procedure is then applied to processing all swings, and the projected point (shown in violet) is determined as the arithmetic mean of the centres of individual ellipses, (Fig. 7).

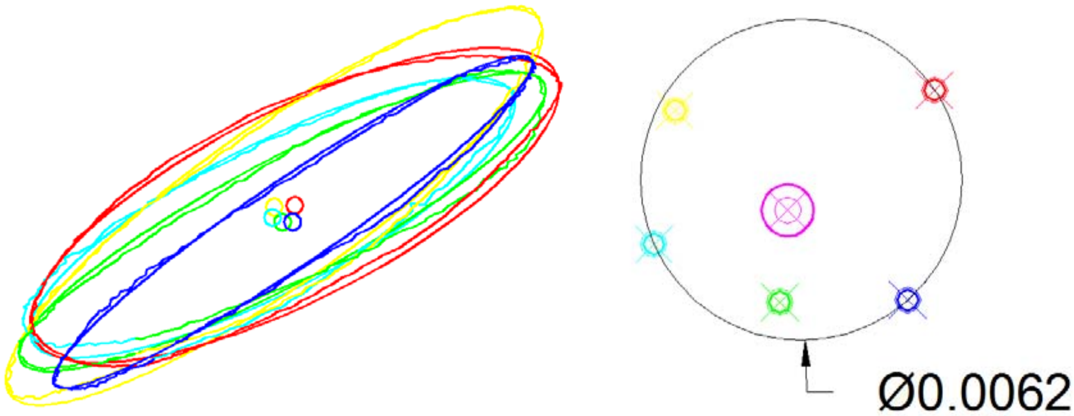

Fig. 7. Arithmetic mean of swing centres.

Conclusion

The innovation of the technique consists in observing the entire trajectory of the plummet swing by means of a robotised universal measuring instrument.

The most appropriate method for evaluating the swing centre on the basis of the data obtained through measurements seems to be the graphical evaluation of the swing centre, both due to the fact that processing a large volume of data is very time consuming and that this method allows checking visually the swing trajectory. The swing trajectory in the underground is affected by adverse factors; graphical data processing permits to analyse and eliminate its discontinuities easily. The graphical processing method has also been verified by means of a mathematical calculation which, however, is significantly more time consuming and its solution is based on the assumption that the plummet trajectory constitutes a continuous and closed curve. For the purposes of mathematical processing, we also need to divide the set of the data obtained through measurements based on the individual swings, which can again be done by means of the graphical method.

The connecting survey technique using the proposed solution was applied in practice in the completion of the connecting underground crosscut between the ČSA2 and Mír 5 shafts , for example, in [7]. The achieved deviations are in line with the legislation, specifically Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended. Therefore we can conclude that this method can be used in great depths in spite of the adverse effect of external factors, such as airflow and climatic conditions in the shaft.

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