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MAGNETIC PULSE METHOD APPLIED TO BOREHOLE DEVIATION MEASUREMENTS

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A magnetic method for borehole deviation measurements in certain cases of tunnelling and driving other underground workings is presented. The mutual positions of boreholes arranged in groups for driving underground mining and engineering workings in water-bearing layers by the freezing and grouting method are determined. In determining the distances between boreholes the pulse magnetic method is supplemented by accuracy analysis.

Keywords: magnetic induction, borehole deviation, accuracy analysis, Slovak Magnesite Mines

1. Introduction

Basically there are three operational causes of borehole deviations in long borehole drilling (*Fig. 1*), viz. alignment (d_a), collaring (d_c), and trajectory (d_t) (rod path/bit contact with rock). In this sense therefore, borehole deviation can be defined as the departure of a borehole from its designed starting point, its designed path, and its designed destination point.

Since operator/machine dependent causes, viz. alignment and collaring occur outside of boreholes and are hence easier to investigate and understand, this study concentrates on the third problem, i.e. trajectory borehole deviation, which is by far the most critical — especially for long boreholes. The source categories of factors contributing to trajectory deviation include pattern of boreholes, drill forces, equipment components, and rock properties.

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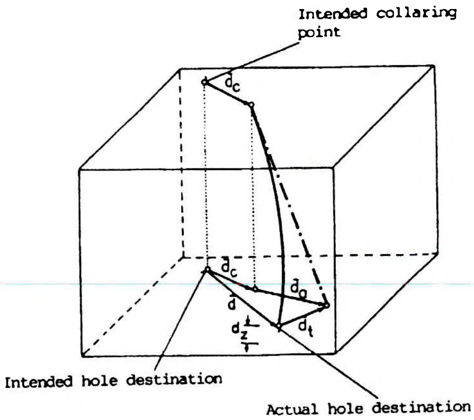

Fig. 1. Diagramatic representation of alignment (d_a), collaring (d_c), and trajectory (d_t) deviations

1. ábra. A d_a eltérés, d_c béléscsövezés, és a d_t elcsavarási-trajektoria diagramszerű vázlata

A great many studies have dealt with the problem of whether one can learn more about the rock dependent part of trajectory deviation and thereby influence the deviation by means of borehole patterns [SINKALA 1987].

Water-bearing cohesionless layers pose a considerable problem in tunnelling and driving underground workings and other engineering projects. The most extensively used methods of strengthening or sealing rock in these layers include rock freezing and the grouting of various suspensions and solutions. The factor which determines the efficiency of strengthening the rock by freezing and grouting is mainly the accuracy of drilling the position of the freezing and grouting boreholes.

In drilling a series of boreholes several tens of meters in length, these may deviate from the required direction. Such deviation and deflection of one of several boreholes e. g. boreholes Nos. 1 and 6 in *Fig. 2* in tunnelling, may cause

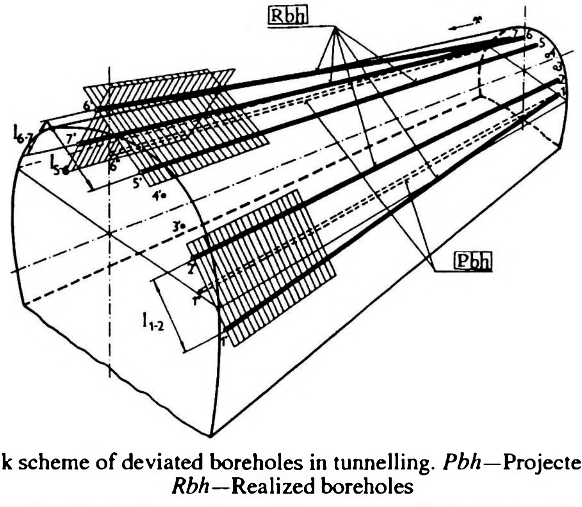

Fig. 2. Block scheme of deviated boreholes in tunnelling. *Pbh*—Projected boreholes; *Rbh*—Realized boreholes

2. ábra. Az elhajlott fúrólyukak vázlata. *Pbh*—tervezett fúrólyukak; *Rbh*—megvalósult fúrólyukak failure of the entire technological process. Boreholes for blasting are important for underground technologies. The degree of breakage is dependent on the mutual position and deviation of these boreholes.

2. Principle of the magnetic pulse method

One way of mapping the position of boreholes by magnetic methods is based on measuring the component of magnetic induction B of a generated magnetic field. Using the measured values of the field of a rod magnet, it is possible to determine the distance (length l) between the source of this field and the sensor of the magnetometer, i.e. B=f(l) [SEDLÁK 1991, 1992, 1993].

The mutual position of the boreholes is determined in the mapping plane as a network of triangles based on lengths l (distances between boreholes). It is then possible to evaluate the suitability of borehole course and position for applying freezing and grouting technologies or the technology of driving underground mining or engineering workings by blasting.

The advantages of this magnetic probe method include the fact that the cost of devices and materials is low, the accuracy of the method is relatively high, measurements are rapid, and the results can be calculated directly in-situ.

The advantages of the pulse regime are low power input but, at the same time, it is possible to gain an increase in the time change of the measured magnetic field intensity. Electromagnet feeding is illustrated by the diagram of *Fig. 3,* where contact *SP* in the preparatory phase to the measurement is in the given position and condenser C_1 is charged at the initial voltage $U_{C1(0)}$. At the moment of a measurement, the contact *SP* disconnects condenser C_1 from the feeding source and switches it in series with the electromagnet winding,

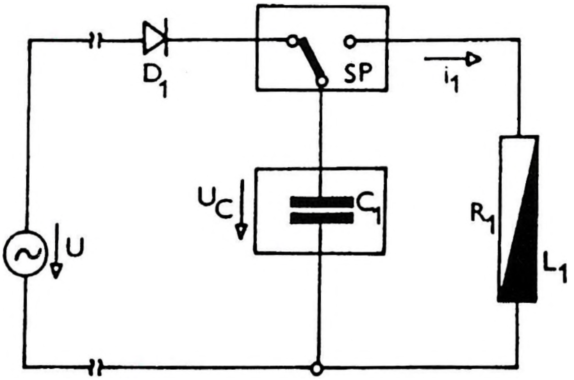

Fig. 3. Diagram of electromagnet electric circuit. *SP*— contact; C_1 —condenser; L_1— inductance; R_1—resistance

3. ábra. Az elektromágnes áramkörének vázlata. *SP*—érintkezés; C_1—kondenzátor; L_1—önindukció; R_1—ellenállás characterized by the active resistance R_1 and in inductance L_1. The transition phenomena occurs, inducing the defined magnetic field intensity time change [BLAŽEK 1985].

In the electric part of the circuit this phenomena is expressed by the equation

$$R_1\, i_1 + l_1 \frac{\mathrm{d}i_1}{\mathrm{d}t} + \frac{1}{C_1}\int_0^t i_1 \mathrm{d}t + U_{C1(0)} = 0 \qquad (1)$$

By modifying the differential equation of the second order, one obtains the roots

$$k_{1,2} = -\beta \pm (\beta^2 - \Phi_r^2)^{(1/2)} \qquad (2)$$

where

$$\beta = \frac{R_1}{2L_1}; \qquad \Phi_r^2 = \frac{1}{L_1 C_1} \qquad (3)$$

and where β represents the damping coefficient and Φ_r the resonance frequency.

It is suggested that the parameters of the electromagnet are such that the condition of low circuit damping will be fulfilled, so $R_1 < 2\,(L_1 C_1)^{1/2}$. The transition phenomenon of the electromagnet current is then a periodic harmonic function

$$i_1 = \frac{U_{C1(0)}}{\Phi_r\, L_1} = e^{-\beta t} \sin \Phi_r\, t \qquad (4)$$

In first approach it is possible to consider the ideal case of undamped oscillations, when the amplitude reaches the value

$$i_{1(max)} = \frac{U_{C1(0)}}{\Phi_r L_1} = I_0 \qquad (5)$$

and this current value will be reached at moment

$$t_{1(max)} = \frac{\pi}{2}\,(L_1 C_1)^{1/2} \qquad (6)$$

The electromagnet current maximum time change can then be expressed by

$$\lim_{\mathrm{d}t \to 0} \frac{\mathrm{d}i_1}{\mathrm{d}t} = I_0 \Phi_r \qquad (7)$$

To this state corresponds the maximum time change of the magnetic field intensity *H* and maximum time change of the electromagnet magnetic induction *B*

$$\left[\frac{\mathrm{d}h}{\mathrm{d}t}\right]_{\max} = \frac{N}{2^{1/2}} I_0 \Phi_r; \qquad \left[\frac{\mathrm{d}B}{\mathrm{d}t}\right]_{\max} = \mu_0 \left[\frac{\mathrm{d}H}{\mathrm{d}t}\right]_{\max} \tag{8}$$

where *N* gives the number of windings of the electromagnet and μ_0 is core permeability.

In pulse magnetization of materials this is magnetized in internal small (minority) loops, and it is the result of current or voltage impacts in one direction [REINBOTH 1970]. In order to obtain the maximum change of induction d*B*, the shortest time pulses must be selected.

The magnetic field is generated by an electromagnet with a corresponding number of turns wound round the cylindrical core of a special, magnetically-soft material. The electromagnet is inserted into the casing of the source probe. During measurements the probe is placed in the appropriate measurement area in a single borehole. The measuring element is in the form of an induction coil inserted into the casing of the measuring probe which is placed, during measurements, in the appropriate measurement area in the second borehole (*Fig. 4*). It is necessary to determine the distance between the probe of the source and the measuring probe in the mapping plane, i.e., the length *l* between both boreholes in this plane. This is based on the knowledge that the vector of magnetic induction *B*, parallel to the axis of the given electromagnet, is situated at the points of the plane perpendicular to this axis and passing through the centre of the electromagnet (equatorial plane). The value of magnetic induction *B* depends on the distance *l* between the probe of the source and the measuring probe.

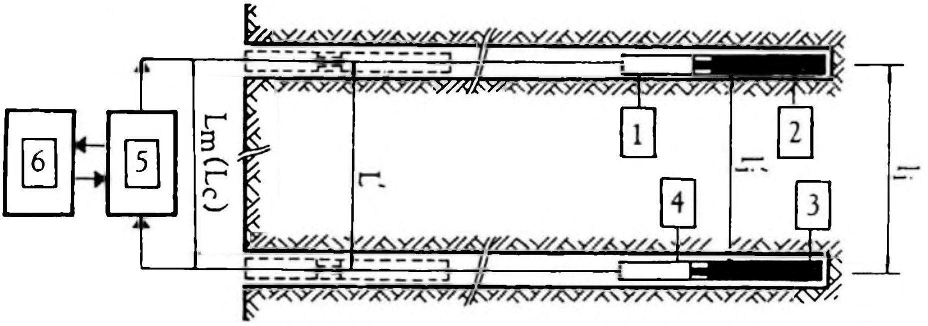

Fig. 4. Principle of the magnetic pulse method. 1—pulse feeder; 2— electromagnet; 3— sensor; 4— circuit for signal regulation; 5— control and evaluation system; 6— operator

4. ábra. A mágneses impulzus módszer alapelve. 1—impulzus töltő; 2—elektromágnes; 3—érzékelő; 4—jelszabályozó áramkör; 5—ellenőrző és értékelő rendszer; 6—operátor

Fig. 4 shows the measuring principle with computer adjustment of the measured magnetic induction values. The main part of the power system is the pulse feeder which is connected to the electromagnet. Direct current in the range from 1 to 10 amperes [A] is sufficient to saturate the electromagnet and generate a magnetic field with the required induction. The measuring element is the sensor with the circuit for signal regulation. Theoretically, if it is taken into account that the measuring circuit operates in the pulse regime, interference by external stationary magnetic fields can be ignored.

The mutual position of boreholes can then be determined from the distribution of their openings and the distribution plan of the bottoms of these boreholes, this plan being constructed on the basis of the distances between the individual boreholes in the plane perpendicular to their direction.

3. Magnetic measurements in boreholes

Measurements taken in holes are based on calibration curves. The elements of a calibration base and the conditions of calibration measurements (distances between the probes, intensities of current pulses) are selected in accordance with the need to obtain the required number of calibration curves. These curves are then plotted as a graphic function of the measured induced current I_i on the logarithmic scale against length (distance) l between the probes (*Fig. 5*).

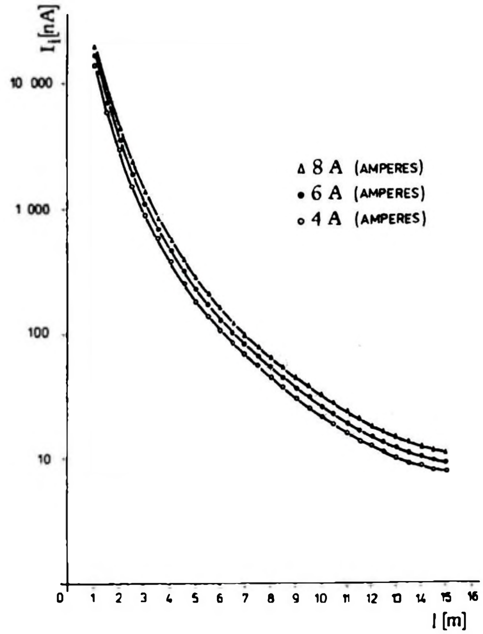

Fig. 5. Calibration curves; measured induced current I_i, length (distance) l between probes

5. ábra. Kalibrációs görbék, I_i a mért indukált áram, l a hosszúság (távolság) a minták között

When determining the distance between the boreholes it is necessary to eliminate the influence of the magnetic properties of the surrounding rock on the magnetic induction measured value. This problem is solved by introducing the correction coefficient *k*, which is determined in-situ by the source and measuring probes inserted in the openings of two boreholes where we want to determine the distance of their bottoms (Fig. 4). The probes are inserted in the borehole openings so that both probes are situated in the full-space of a rock material. From the measured data of magnetic induction we can estimate the correction coefficient *k* as the ratio of the measured or calculated distance L_m (L_c), (L_m is equal to L_c), to distance $L^{\cdot}$,

$$K = \frac{L_m}{L'}, = \frac{L_C}{L'}, \tag{9}$$

which can then be used to correct the individual distances l_i in the mapping area

$$l_i = kl_i' \tag{10}$$

where $L^{\cdot}$ and l_i' are the distances determined from the appropriate calibration graph.

Determination of the correction coefficient *k* in this way assumes invariable magnetic permeability of a rock mass.

The magnitude of magnetic induction *B* depends directly on the magnetic permeability μ and the magnetic intensity *H* of a medium in which the electromagnet is found. This follows from the known relation for a power activity of the generated magnetic field

$$B = \mu H \tag{11}$$

4. Verification of magnetic measurements under mining conditions

The proposed magnetic pulse method of determining the mutual position of the boreholes arranged in a group was successfully verified directly under mining conditions, in a protective pillar F-8 in the fourth mining horizon of the underground, Bankov mine — Slovak Magnesite Mines in Košice [SEDLÁK 1991].

Magnetic measurements were taken in a group of six quasi-parallel and quasi-horizontal boreholes drilled through the protective pillar. The coordinates of the points 1, 2, 3, ... 6 of their openings and the points 1', 2',3', ... 6' of their bottoms as well as the coordinates of the points 1_m, 2_m, 3_m, ... 6_m; 1_m', 2_m',3_m', ... 6_m', of magnetic measurements were calculated from the positional and levelling surveys in the geodetic coordinate system (*Fig. 6*). Because the differences of magnetic measurements at points 1, 2, 3, ... 6 and 1_m, 2_m, 3_m, ... 6_m (analogically 1', 2', 3', ... 6' and 1_m', 2_m', 3_m', ... 6_m') were neglected, all

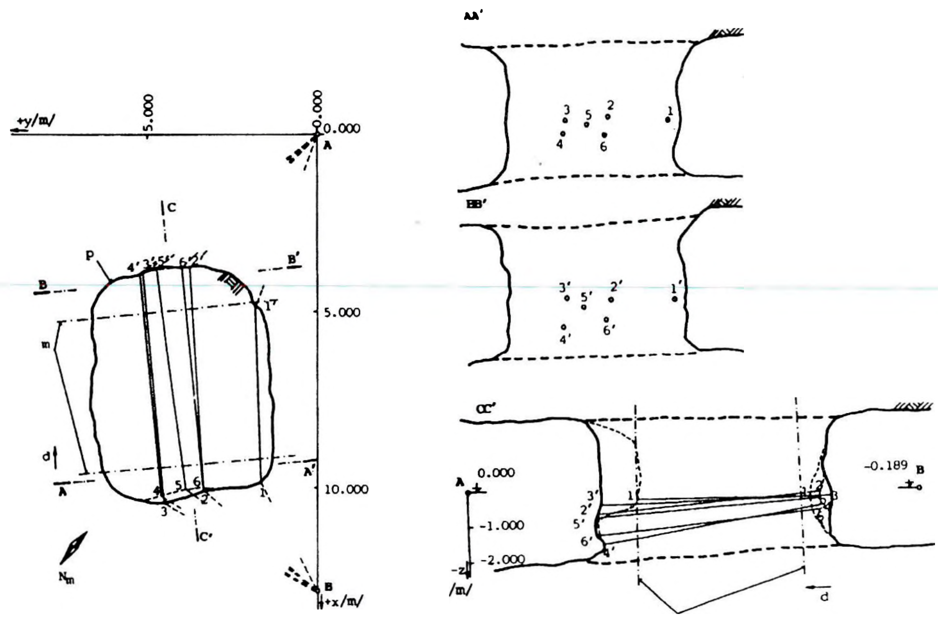

Fig. 6. Block scheme of the magnetic measurements in boreholes in the Slovak Magnesite Mines -Košice. d—drilling direction; m— plans of magnetic mapping; p— protective pillar

6. ábra. A Szlovák Magnetit Bányák (Kassa) fúrólyukaiban mért mágneses mérések blokkvázlata. d—fúrásirány; m—a mágneses térképezés tervei; p—védőpillér

accuracy analyses are applied to the points 1, 2, 3, ... 6 of the borehole openings and 1', 2', 3', ... 6' of the borehole bottoms.

The pulsed magnetic method was applied at saturating currents of 3 and 4 A without commutation. The resultant lengths in the average values of the lengths l_{mag} obtained from the individual magnetic measurements using three electromagnets in all boreholes are presented in *Table I.* The lengths l_{calc} were calculated on the basis of the positional and levelling surveys. All calculations are supplemented by analysis of the estimated distance accuracy.

On the basis of comparison of the correction coefficient k=0.931 and the magnetic permeability values μ of rock in the protective pillar, formed by a mixture of carbonates of the magnesite series with $MgCO_3$ prevailing (based on laboratory measurements, the magnetic permeability of this material is μ=0.9282667, i.e., approximately 1), it can be concluded that the correction coefficient value k of magnetic measurements is represented by the magnetic permeability μ of the surrounding rock; k *is* just satisfied in respect of the accuracy of 1 when working in homogeneous rocks. The accuracy will drop significantly in mineralized rocks, where the magnetic susceptibility varies in a wide range even within a few meters [SEDLÁK 1992].

Points in boreholes	LENGTHS l_{calc}	 l_{mag} [m]	 $l_i = kl_{mag}$	Real errors $E = l_{calc}-l_i$ [mm]	Square EE [mm^2]
1_1-2_1	1.716	1.792	1.668	48	2304
1_1-3_1	2.960	2.968	2.763	197	38809
1_1-4_1	3.031	3.190	2.970	61	3721
1_1-5_1	2.348	2.470	2.300	48	2304
1_1-6_1	1.870	1.918	1.786	84	7059
2_1-3_1	1.269	1.337	1.245	24	576
2_1-4_1	1.378	1.435	1.336	42	1764
2_1-5_1	0.671	0.677	0.630	41	1681
2_1-6_1	0.556	0.575	0.535	21	441
3_1-4_1	0.454	0.592	0.551	-97	9409
3_1-5_1	0.722	0.795	0.740	-18	324
3_1-6_1	1.276	1.448	1.348	-72	5184
4_1-5_1	0.726	0.770	0.717	9	81
4_1-6_1	1.203	1.220	1.136	67	4489
5_1-6_1	0.622	0.640	0.596	26	676
$1_2'$-$2_2'$	1.849	1.958	1.823	26	676
$1_2'$-$3_2'$	3.172	—	—	—	—
$1_2'$-$4_2'$	3.359	3.523	3.280	79	6241
$1_2'$-$5_2'$	2.695	—	—	—	—
$1_2'$-$6_2'$	2.100	2.208	2.056	44	1936
$2_2'$-$3_2'$	1.325	1.425	1.327	-2	4
$2_2'$-$4_2'$	1.606	1.708	1.590	16	256
$2_2'$-$5_2'$	0.860	0.898	0.836	24	576
$2_2'$-$6_2'$	0.600	0.672	0.626	-26	676
$3_2'$-$4_2'$	0.830	0.890	0.829	1	1
$3_2'$-$5_2'$	0.565	—	—	—	—
$3_2'$-$6_2'$	1.332	1.497	1.394	-62	3841
$4_2'$-$5_2'$	0.821	0.843	0.785	36	1296
$4_2'$-$6_2'$	1.270	1.400	1.303	-33	1089
$5_2'$-$6_2'$	0.782	0.875	0.815	-33	1089

Mean square error: $m = \pm\,([EE]/n)^{1/2}$
Openings: $m_{LM(0)} = \pm 72.5$ mm; Bottoms: $m_{LM(B)} = \pm 38.4$ mm
Average: $m_M = \pm 55.4$ mm

Table I. Resultant distances between boreholes from magnetic measurements

I. táblázat. A fúrólyukak közötti távolságok a mágneses mérések alapján

5. Analysis of distance accuracy

The accuracy of the magnetic method under investigation is determined by comparing distances between borehole openings and borehole bottoms determined geodetically with the same distances determined magnetically.

N. B. To simplify the symbols used, the following are introduced:

— borehole openings:

$$l_{calc} = L_{12G}, L_{13G}, \dots L_{56G} = L_{ijG} = L_G$$
$$l_{mag} = L_{12M}, L_{13M}, \dots L_{56M} = L_{ijM} = L_M \qquad (12)$$

— borehole bottoms:

$$l_{calc}' = L_{12G}', L_{13G}', \dots L_{56G}' = L_{ijG}' = L_G'$$
$$l_{mag}' = L_{12M}', L_{13M}', \dots L_{56M}' = L_{ijM}' = L_M' \qquad (13)$$

Accuracy of distances determined geodetically

Every space distance L_{ij}; $i, j < 1,n>$ is defined by two points B_i, B_j whose coordinates X, Y, Z are determined geodetically in a cartesian three-dimensional rectangular system.

For these distances the following hold:

$$\begin{aligned} L_{12} &= (X_2-X_1)^2+(Y_2-Y_1)^2+(Z_2-Z_1)^2 \\ &\vdots \\ L_{ij} &= (X_j-X_i)^2+(Y_j-Y_i)^2+(Z_j-Z_i)^2 \\ &\vdots \end{aligned} \qquad (14)$$

$$L = f(C_1, \dots C_i, C_j, \dots) \qquad (15)$$

where

$$C_i = \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} \qquad (16)$$

is the 3x1 vector of coordinates of a point B_i and

$$\Sigma_{Ci} = \begin{bmatrix} {m_{Xi}}^2 & & \\ & {m_{Yi}}^2 & \\ & & {m_{Zi}}^2 \end{bmatrix} \tag{17}$$

is its covariance matrix (with zero covariance components).

In order to express the variances of $\boldsymbol{L}$, the known law of propagation of variances can be applied to (15) in the form

$$\Sigma_L = \boldsymbol{F} \,.\, \Sigma_C \,.\, \boldsymbol{F}^T \tag{18}$$

where

$$\Sigma_C = \begin{bmatrix} {m_{X1}}^2 & & & & & & & & & \\ & {m_{Y1}}^2 & & & & & & & & \\ & & {m_{Z1}}^2 & & & & & & & \\ & & & {m_{X2}}^2 & & & & & & \\ & & & & {m_{Y2}}^2 & & & & & \\ & & & & & {m_{Z2}}^2 & & & & \\ & & & & & & \cdot & & & \\ & & & & & & \cdot & & & \\ & & & & & & & {m_{X6}}^2 & & \\ & & & & & & & & {m_{Y6}}^2 & \\ & & & & & & & & & {m_{Z6}}^2 \end{bmatrix} \tag{19}$$

is the covariance matrix of all coordinates of six points and

$$F = \begin{bmatrix} \frac{\partial L_{12}}{\partial X_1}, \frac{\partial L_{12}}{\partial Y_1}, \frac{\partial L_{12}}{\partial Z_1}, \ldots \frac{\partial L_{12}}{\partial X_i}, \frac{\partial L_{12}}{\partial Y_i}, \frac{\partial L_{12}}{\partial Z_i}, \ldots \frac{\partial L_{12}}{\partial X_6}, \frac{\partial L_{12}}{\partial Y_6}, \frac{\partial L_{12}}{\partial Z_6} \\ \cdot \\ \cdot \\ \frac{\partial L_{23}}{\partial X_1} \\ \cdot \\ \cdot \\ \frac{\partial L_{ij}}{\partial X_1}, \frac{\partial L_{ij}}{\partial Y_1}, \frac{\partial L_{ij}}{\partial Z_1}, \ldots \frac{\partial L_{ij}}{\partial X_i}, \frac{\partial L_{ij}}{\partial Y_i}, \frac{\partial L_{ij}}{\partial Z_i} \\ \cdot \\ \cdot \end{bmatrix} \qquad (20)$$

is the matrix of related coefficients (Jacobian matrix).

Because the plane of the borehole opening and bottom distributions is small (about 12 to 15 m^2), the standard errors m_X, m_Y, m_Z in (19) were taken as a 'middle point' determined by calculating the average measured values: horizontal angles, zenith distances *z*, and lengths *d* between point *B* and points 1, 2, 3, ... 6; and point *A* and 1', 2', 3', ... 6'. The variances and the standard errors obtained for this 'middle point'

$$\begin{aligned} m_X{}^2 &= 12.3 \text{ mm}^2 \\ m_Y{}^2 &= 12.3 \text{ mm}^2 \\ m_Z{}^2 &= 2.2 \text{ mm}^2 \end{aligned} \qquad (21)$$

have then been introduced into the matrix Σ_C (19).

The covariance matrix Σ_L indicates the variances of determined lengths L_{ij}. The variances $m_{Lij}2$ of these lengths are situated on the diagonal of this matrix and the covariances m_{Lij} off the diagonal.

$$\Sigma_L = \begin{bmatrix} m_{L12}{}^2, & m_{L12,13}, & \cdot & \cdot & \cdot \\ m_{L13,12}, & m_{L13}{}^2 & \cdot & & \\ \cdot & & \cdot & & \\ \cdot & & m_{Lij}{}^2 & & \\ \cdot & & & \cdot & \\ \cdot & & & & \cdot \end{bmatrix} \qquad (22)$$

Table II shows the mean square (standard) errors obtained.

Distance		Mean square error		
L_{ijG} [m]		m_{Lij}^2 [mm^2]	m_{Lij} [mm]	$m_{average}$
L_{12}	1.716	20.7	4.5	openings:
L_{13}	2.960	21.2	4.6	
L_{14}	3.031	20.6	4.5	$m_{LG(0)} = \pm 4.2$ mm
L_{15}	2.348	20.5	4.5	
L_{16}	1.870	19.8	4.4	
L_{23}	1.269	21.1	4.6	
L_{24}	1.378	19.3	4.4	bottoms:
L_{25}	0.673	18.7	4.3	
L_{26}	0.556	2.9	1.7	$m_{LG(B)} = \pm 4.0$ mm
L_{34}	0.454	15.6	3.9	
L_{35}	0.722	23.3	4.8	
L_{36}	1.276	20.0	4.5	
L_{45}	0.726	20.4	4.5	average:
L_{46}	1.203	20.7	4.5	
L_{56}	0.622	15.0	3.9	$m_G = \pm 4.1$ mm
L_{12}'	1.849	24.4	4.9	
L_{13}'	3.172	1.5	1.2	
L_{14}'	3.356	23.5	4.8	
L_{15}'	2.695	24.7	5.0	
L_{16}'	2.100	23.3	4.8	
L_{23}'	1.325	24.1	4.9	
L_{24}'	1.606	19.7	4.4	
L_{25}'	0.860	24.2	4.9	
L_{26}'	0.600	7.0	2.6	
L_{34}'	0.830	4.8	2.2	
L_{35}'	0.565	15.6	3.9	
L_{36}'	1.332	17.4	4.2	
L_{45}'	0.821	12.5	3.5	
L_{46}'	1.270	23.9	4.9	
L_{56}'	0.782	19.0	4.4	

Table II. Mean square errors of the distances (L_G, L_G')
II. táblázat. A távolságok (L_G, L_G') átlagnégyzetes hibái

Accuracy of distances determined magnetically

Whole accuracy analysis of distances l_{mag} $(L_M, L_M',)$ determined by the magnetic pulse method is included in Table I. The mean square error m_M was calculated on the basis of the calculated distances l_{calc} (L_G, L_G').

6. Comparing accuracy of distances determined geodetically with those determined magnetically

If it is taken into consideration that the distances L_G are determined with the standard error $m_G = \pm 4.1$mm, it means that these distances are not exact. Then the final standard error m_{MAG} of the magnetically determined distances will be given by

$$\begin{aligned} m_{MAG} &= \pm(m_M{}^2 - m_G{}^2)^{1/2} \\ m_{MAG} &= \pm 55.2 \text{ mm} \end{aligned} \tag{23}$$

For detailed accuracy analysis of the distances determined by the magnetic pulse method the following should be taken into account: the standard errors of the magnetic induction value deductions B (I_i) on the measuring device, of the rock magnetic permeability μ determination, of the calibration curve distance deduction, etc., too. However, in mining activities where a 10% length toleration of determined distances between boreholes is sufficient, a 5% accuracy in the magnetically determined distances is sufficiently accurate.

7. Conclusion

The possibilities of magnetically determining borehole deviations are presented. The proposed magnetic pulse method is utilized in determining the mutual positions of boreholes arranged in groups, e. g. blasting boreholes, freezing and grouting boreholes.

Borehole deviations whose convergence or divergence is not greater than 15 to 20° can be determined from these magnetic measurements. The measurement range, from 10 m to 12 m and more, with an accuracy about ±5%, is completely adequate for this purpose. However, the position of one borehole from a group of boreholes must be determined by an inclinometric method, because the distances between boreholes can be determined by the pulse magnetic method only. The magnetic method presented here can be applied only in straight boreholes, i. e. in boreholes whose axes are lines, not curves. In spite of these limits, the magnetic pulse method for determining borehole deviations can find a wide application in tunnelling, mining and structural engineering or boreholes used in other fields.

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MÁGNESES IMPULZUS MÓDSZER A FÚRÓLYUK ELHAJLÁSÁNAK MÉRÉSÉRE

Vladimír SEDLÁK

Fúrólyuk-elhajlást mérő mágneses módszert mutatnak be, amely bizonyos esetekben, alagút kihajtásban és más földalatti munkáknál alkalmazható. A mélyszinti bányákban illetőleg egyéb mérnöki munkálatoknál a víztároló rétegekben a fagyasztásos és a cement-injektálásos módszernél a fúrólyukak kölcsönös elhelyezését határozzák meg. A fúrólyukak közötti távolság meghatározásához az impulzusos mágneses módszert hibaelemzéssel egészítették ki.