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Geometrization of Physical-Mechanical Properties of Rocks Based on the Solution of the Inverse Problem of Diagnostics of a Condition of Geophysical Parameters

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Abstract: The study considers the problem of geometrization of physical-mechanical properties of rocks of the coal strata. The solution of the inverse problem of diagnostics of a condition of the geophysical parameters of the geological space is considered. The approach is proposed for determining the parameters of the regression equation of physical and mechanical properties on the geophysical parameters defined in the exploratory wells. Optimization of parameters of mathematical models is based on the solution of the inverse problem of diagnostics of a condition of the geophysical parameters by the method of full-scale modeling of the experiment. The regularization criterion takes into account the principles of self-organization of mathematical models of complex systems. Identification of the parameters of the regression equation carried out on the basis of algorithm with successive selection of trends (the method of group accounting of arguments).

Key words: Full-scale modeling experiment, inverse problem, diagnostics, simulation, regression, forecasting

INTRODUCTION

Subject of research are mathematical models, used for the geometrization of the parameters of the coal strata. It is necessary to use probabilistic and statistical methods in the simulation because of the complexity of geological processes involved in forming geological conditions of occurrence of mineral deposits. Recent research Auzin appeared in which the method of group accounting of arguments is used to identify statistical relationships. This method is a development of the method of least squares. It allows you to determine the optimal parameters of the regression equation linking the physical-mechanical properties of rocks and geophysical parameters.

The rating of roof in coal mines (Coal Mine Roof Rating-CMRR) was developed in the United States on the basis of regression analysis of the collapse of the roof in 37 mines. It is calculated taking into account the strength of rocks composing the roof, the nature of the contacts between the layers, fracture and the water content of rocks. The regression model proposed to predict the degree of collapsing of the roof based on fuzzy logic (Ghasemi and Ataei, 2013).

The allocation of the coal in the thicker sections with various mining and geological conditions often found in practice geometrization is a task of pattern recognition. Comparison (diagnosis) of predictive conditions testing of the new extraction area is carried out with known geological situations identified during the previous mining operations at the coal mine. Discriminant analysis was the most common. The equation of the separating hyperplane can be represented in terms of regression analysis.

These problems are also widespread in the areas of science as geophysics, medical imaging (Aleksanyan *et al*., 2014, 2015a, b; Lankin *et al*., 2015a, b), computed tomography (Shaykhutdinov *et al*., 2015a; Grayr *et al*., 2014), tasks of non-destructive testing (Bulgakov *et al*., 2015; Shaikhutdinov *et al*., 2015; Shaykhutdinov *et al*., 2015b-h), tasks of diagnostic of complex technical systems (Dubrov *et al*., 2015; Lankin *et al*., 2015b; Shaykhutdinov *et al*., 2013), etc.

Discriminant analysis applied to separate rock masses into four types. Parameters are the depth of coal seam, the power of rock mass to the power of the coal seam, the strength of rocks in compression, the area of fractured rock. Classification of rocks the sedimentary and igneous was carried out on the basis of discriminant analysis. Zoning of a soil types of coal seams is made. Region with high seismic activity detected. A nonparametric modification of the method of discriminant analysis are

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presented, taking into account errors in the source data. Consistent application of the hierarchical cluster analysis and discriminant analysis are described in (Zhou *et al*., 2007).

MATERIALS AND METHODS

The process of geometrization and forecasting parameters of the coal strata in the geological space can be represented in terms of a full-scale model experiment. It combines the results of geological exploration and modeling. The interaction of the exploration process (field testing) with mathematical modeling allows to continuously adjust and refine the model embed different parameters of the mineral deposit as the emergence of new surveying and geological information in the course of detailed and field prospecting.

Structural diagram of full-scale modeling of the experiment is given with the goal of geometrization of coal strata parameters according to the geological sampling and surveying measurements (Fig. 1). The required information about the properties of the coal strata for mine planning is formed according to the vector of the control signals Q. It is generated by the automated control system, given the vector of measurement data U (exploration results) and simulation results F. Experimental (measured) and estimated (simulation) methods are usually not applied in the complex despite the widespread introduction of coal mining enterprises of computers and software tools to solve various problems in mining production. The use of computer technology in exploration limited to the decision of problems of automation and statistical processing of the data mostly.

The measurement of coal thickness and modeling of their location in geological space are equal parts in the procedure of full-scale-model experiment. Their effective interaction as a single process allows, on the one hand, to develop reasonable mathematical models of placement options, adequate natural features of the coal accumulation and on the other to clarify the requirements for metrological support of measurements (errors).

The construction of multidimensional mathematical models is based on two principles of heuristic self-organization of complex systems. The first principle is to use external add-ons in the form of a set of control data not used in the determination of model parameters (e.g., unknown coefficients of the regression equation). It is based on the incompleteness theorem which for the regression analysis establishes the impossibility of finding a single optimal model for determining the equation coefficients by OLS (using all experimental data). External criterion (acceptance of regularization) is required to obtain the best possible dependencies describing the geological feature.

The principle of inconclusive solutions is the second feature. The optimum model is carried out by successive approximation to its final form and not just one technique as is done in classical methods of regression analysis. Thus reducing the computing time, the selection of the optimal model proposed to be achieved through the use of information about the parameters of mathematical models obtained in the previous step (the algorithm with successive selection of trends). The forecast equation is:

$$P = a_0 + a_1 f_1(x_1) + a_2 f_2(x_2) + ... + +a_m f_m(x_m) \qquad (1)$$

where, f_i (x_i), $f_2(x_2)$, f_m (x_m) the regression equation according to the arguments $x_1, x_2, ..., x_m$. The trend $f_1(x_1)$ is highlighted in the first stage. The balance (the difference between known values p and trend $f_1(x_1)$ is computed. The residue is approximated by a second trend $f_2(x_2)$. The rest is on the second stage. This process continues until the minimum of the differences between the known and the model values. The share of natural component in the residual sum of squares is reduced to a minimum as the complexity of the equation. Reception regularization allows to separate the natural component from accidental.

Determination of the model parameters on full-scale observations is the process of solving the inverse problem of diagnostics of a condition of parameters of the coal strata. The inverse problem are not correct, however, the principle of external additions to the theory of self-organization of mathematical models of complex systems can be considered as a variant of the criterion of regularization. This approach allows you to choose a single decision at a choice of optimum coefficients of the regression equation between the parameters of the coal strata as shown above. On the other hand, the principle of inconclusive decisions (in particular, the algorithm with successive selection of trends) allows to increase the stability of the solution with respect to small disturbances (errors) of observations by separating the logical component placement parameter from the random component.

The principles of heuristic self-organization of mathematical models of complex systems used in the method of group accounting of arguments for the solution of inverse problems of diagnostics of a condition of the geophysical parameters measured in the exploration workings. The regression equation predicted physical-mechanical properties of rocks p_i in geophysical parameters $p_1, \dots, p_{i-1}, p_{i+1}, \dots, p_m$ represents a special case of Eq. 1:

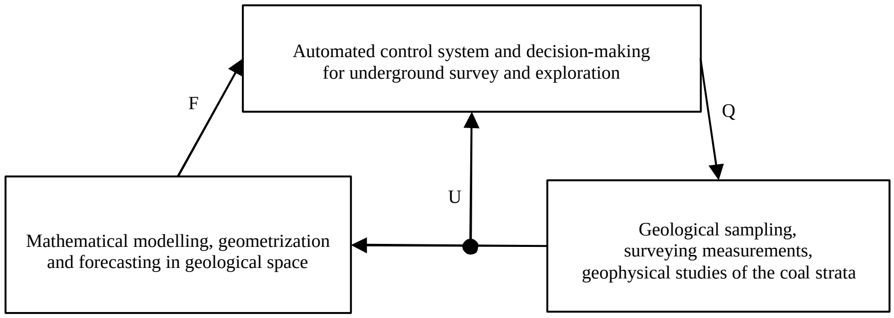

Fig. 1: Structural diagram of full-scale-model experiment

$$P_i = \lambda_1 P_1 + ... + \lambda_{i-1} P_{i-1} + \lambda_{i+1} P_{i+1} + ... + \lambda_m P_m \quad (2)$$

The data are divided into two sets-training (n_1 points) and control (n_2 points) for receiving external additions (regularization criterion for finding optimal parameters of the regression equation). The values of coefficients of regression equations are estimated using the least squares method on the points of training together, consisting of all pairs of geophysical parameters $p_1, ..., p_{i-1}$ $p_{i-1}, ..., p_m$:

$$P_i^{(1)} = a_1 P_1 + a_2 P_2, P_i^{(2)} = b_1 P_1 + b_2 P_3, ...,. \\ P_i^{(s)} = c_1 P_{m-1} + c_2 P_m \quad (3)$$

Where:

$p_i^{(1)}, p_i^{(2)}, ..., p_i^{(s)}$ = The regression equation for parameter on the first row of selection
p_i = The number of pairs of parameters
a_i, b_i, c_i = Coefficients determined by the method of least squares. The simulation error for the models
$p_i^{(k)}$ = Checked by the criterion on the data of the control population

$$\delta_k^{(1)} = \sqrt{\frac{1}{n_2} \sum_{j=1}^{n_2} \left(P_{ji} - P_{ji}^{(k)}\right)^2} \quad (4)$$

Where:

$\delta_k^{(1)}$ = The standard deviation of the estimated vialues calculated from the regression model
$p_i^{(k)}$ = From known values of the parameter
$p_i^{(k)}$ = In the row number selection
p_{ji} = Known value of the parameter
p_i = In the control sample
$p_{ji}^{(k)}$ = Estimation of parameter values in the control sample, calculated according to the regression model $P_i^{(k)}$

The best regression (Eq. 3) are selected by the values of criterion (Eq. 4) with the smallest errors of the simulations for criterion. The source data is generated for the second row selection models. The coefficients of regression equations are estimated on the training data set. The arguments are the responses of regression (Eq. 3) first number of selection $p_i^{(u)}$ and $p_j^{(t)}$:

$$Q_i^{(1)} = d_1 P_i^{(1)} + d_2 P_i^{(2)}, Q_i^{(2)} = e_1 P_i^{(1)} + \\ e_2 P_i^{(3)}, ..., Q_i^{(s)} = f_1 P_i^{(m-1)} + f_2 P_i^{(m)} \quad (5)$$

Where:

$Q_{i(}^{(1)}, Q_i^{(2)}, ..., Q_i^{(s)}$ = The regression equation for parameter p_i on the second row of selection
s = The number of pairs of parameters
d_i, e_i, f_i = Coefficients determined by the method of least squares

This criterion is calculated according to the Eq. 4 at the control points together for each regression equation $Q_i^{(k)}$. If $\min_k \delta_k^{(1)} > \min_k \delta_k^{(2)}$, then go to the third row selection. Calculations continue until the condition is $\min_k \delta_k^{(v-1)} < \min_k \delta_k^{(v)}$ met. The optimal model (regression equation) has a minimum simulation error.

RESULTS AND DISCUSSION

Comparison of the results given for the method of Least Squares (OLS) and the method of group accounting of arguments (GMDH). The simulation error is estimated. Estimate coefficients of the regression equation obtained by the method of least squares:

$$\sigma = a_0 + a_1 \frac{\Delta d}{\rho} + a_2 \frac{J_Y}{\rho} + a_3 \rho H + a_4 \rho + a_5 \Delta d + a_6 J_Y + a_7 J \\ + a_8 H = \underset{49.771}{65.548} - \underset{14.733}{2.042} \frac{\Delta d}{\rho} + \underset{0.007}{0.002} \frac{J_Y}{\rho} - \underset{0.001}{0.001} \rho H \\ + \underset{0.420}{0.808} \rho + \underset{0.928}{1.102} \Delta d - \underset{0.001}{0.001} J_Y + \underset{1.422}{1.581} J + \underset{0.026}{0.018} H, \quad (6)$$

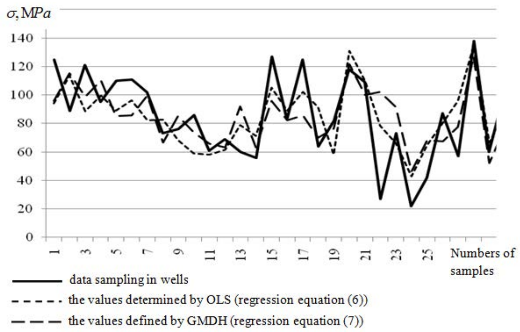

Fig. 2: Graphs of the strength of rocks in compression

Where:

- σ = The most probable value of the strength of rocks in compression (MPa)
- Δd = The difference between the borehole diameter and drill string diameter (mm)
- p = The apparent electrical resistance (the method of potential probe) (Ohm·m)
- JΥ = The value of gamma-gamma logging, pulse/min
- H = The depth of sampling (m)
- J = The value of gamma logging (μr/h)

Standard symbols are used in the regression (Eq. 6), adopted in statistics. The magnitude of the standard error is written under the corresponding regression coefficient. The coefficient of determination is 0.52. Standard error for estimate is 25.2 Mpa. The following expression obtained as the result of calculations by the method of group accounting of arguments (GMDH):

$$\sigma_{сж} = \underset{0.411}{1.188}\rho_{пз} + \underset{15307.577}{110916.215}\frac{J}{J\gamma} + \underset{0.402}{1.023}\Delta d - \underset{0.024}{0.043}\rho_{пз} J \quad (7)$$

All the coefficients of this equation were statistically significant. The coefficient of determination is 0.95. Standard error for estimate is 23.0 MPa. Graphs of values of strength of rock in compression defined in the wells and their most probable values according to the Eq. 6-7 are given in Fig. 2.

Using the method of group accounting of arguments (GMDH) has achieved the reduction of the standard error compared to OLS when modeling regression equations. Information basis for the modeling are geological data of geological reports including counts of the values of the geophysical parameters and the value of tensile strength of rocks in compression in borehole sections detailed exploration. Application of the method of group accounting of arguments (GMDH) to estimate the coefficients of the optimal regression equations allowed to reduce the standard error in absolute terms of 2.7 MPa (relative 10.5 %) for development of a coal seam of mine "Rostovskaya". Likewise, the dependence of compressive strength from geophysical parameters for breeds of roof and soil of coal seams and within the field of mine 'Gukovskaya" and mine "Vostochnaya" (Table 1).

Table 1: Accuracy evaluation of modeling of geophysical dependencies

Rock	Standard error σ (MPa) OLS	GMDH	Absolute improve the accuracy of modeling (Mpa)	The relative increase of accuracy of model σ (%)
Roof and Soili$^{lH}_3$	25.7	23.0	2.7	10.5
Roof k_2	44.5	43.7	0.8	1.8
Soil k_2	45.6	38.2	7.4	16.2
Roof k^{iB}_5	30.4	28.7	1.7	5.6
Soil k^{iB}_5	31.9	30.2	1.7	5.3
Roof l_2	18.2	15.6	2.6	14.3
Soil l_2	24.3	20.7	3.6	14.8
Mean			2.9	9.8

CONCLUSION

Optimal regression equation for modeling (geometrization) of physical-mechanical properties of rocks is determined on the basis of solving the inverse problem of diagnostics of a condition of the geophysical parameters. Algorithm with successive selection of trends enables identification of the optimal parameters of the mathematical model through the use of information about the parameters of mathematical models obtained in the previous step. Improving the accuracy of determining most probable values of the limit compression strength of rocks by geophysical parameters is achieved based on the methods of group accounting of arguments and full-scale modeling of the experiment. It was in absolute terms of 2.9 MPa, a relative by 9.8% in mean for all mines.

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REFERENCES

Aleksanyan, G.K., N.I. Gorbatenko and A.I. Kucher, 2015a. Development and production of multi-layered electrode system for electrical impedance tomography devices. Int. J. Appl. Eng. Res., 19: 40580-40584.

Aleksanyan, G.K., N.I. Gorbatenko, A.I. Kucher, K.M. Shirokov and C.N. Phong, 2015b. Developing principles and functioning algorithms of the hardware-software complex for electrical impedance tomography of biological objects. Biosci. Biotechnol. Res. Asia, 12: 709-718.

Aleksanyan, G.K., N.I. Gorbatenko, D.A. Tarasov, 2014. Modern trends in development of electrical impedance tomography in medicine. Biosci. Biotechnol. Rese., 11: 85-91.

Bulgakov, A., D. Shaykhutdinov, N. Gorbatenko and S. Akhmedov, 2015. Application of full-scale experiments for structural study of high-rise buildings. Procedia Eng., 123: 94-100.

Dubrov, V.I., D.V. Shaykhutdinov, K.M. Shirokov, S.V. Akhmedov and N.I. Gorbatenko, 2015. Information-measurement system for stend for testing hydraulic products. Proceedings of the 2015 International Siberian Conference on Control and Communications (SIBCON), May 21-23, 2015, IEEE, Omsk, Russia, ISBN: 978-1-4799-7102-2, pp: 1-3.

Ghasemi, E. and M. Ataei, 2013. Application of fuzzy logic for predicting roof fall rate in coal mines. Neural Comput. Applic., 22: 311-321.

Grayr, K.A., G. Nikolay and D.T. Alexander, 2014. Development of hardware-software complex for electrical impedance tomography of biological objects. Res. J. Applied Sci., 9: 1030-1033.

Lankin, A.M., M.V. Lankin, N.I. Gorbatenko and D.V. Shayhutdinov, 2015a. Determination of weber-ampere characteristic for electrical devices based on the solution of har-monic balance inverse problem. Int. J. Appl. Eng. Res., 10: 6509-6519.

Lankin, A.M., M.V. Lankin, V.V. Grechikhin and D.V. Shaikhutdinov, 2015b. Determination of magnetic characteristics of alternative current electrotechnical devices using the method of full-scale-model tests. Res. J. Appl. Sci., 10: 690-695.

Shaikhutdinov, D.V., N.I. Gorbatenko and K.M. Shirokov, 2015. Facility for measuring magnetic parameters of articles from sheet electrical steel on the basis of national instruments technologies. Met. Sci. Heat Treat., 56: 618-620.

Shayhutdinov, D., N. Gorbatenko, V. Grechikhin, K. Shirokov and V. Dubrov, 2015a. Development of the computer-based stand for research of the voltage generation effect of the magnetic shape memory material. Res. J. Appl. Sci., 10: 170-172.

Shayhutdinov, D., N. Gorbatenko, G. Aleksanyan, V. Grechikhin and K. Shirokov *et al*., 2015b. Development of a computer-based stand for testing algorithms of electrical impedance tomography. Res. J. Appl. Sci., 10: 173-175.

Shaykhutdinov, D., A. Lankin, S. Janvarev, N. Gorbatenko and D. Schuchkin, 2015c. Application of tensor methodologies for the description of non-linear processes in electromagnetic drive. Res. J. Appl. Sci., 10: 798-800.

Shaykhutdinov, D., A. Lankin, S. Janvarev, N. Narakidze and R. Leukhin *et al*., 2015d. Development multiprocessing mathematical model of electromagnetic AC drive. Res. J. Appl. Sci., 10: 812-814.

Shaykhutdinov, D., N. Gorbatenko, R. Leukhin, 2015e. Development of a computer-based stand for research of the methods of sensorless control of electromagnets DC. Res. J. Appl. Sci., 10: 845-847.

Shaykhutdinov, D.V., N.I. Gorbatenko, S.V. Akhmedov and R.I. Leukhin, 2015f. Device for control of magnetic properties of electrical steel for industrial production management system. International Siberian Conference on Control and Communications, May 21-23, 2015, Omsk, Russia, pp: 1-2.

Shaykhutdinov, D.V., R.I. Leukhin and K.M. Shirokov, 2015g. Automated stand for intelligent actuators regulators setup parameters. Procedia Eng., 129: 749-753.

Shayhutdinov, D., A. Lankin, N. Narakidze, V. Grechikhin, K. Shirokov and N. Gorbatenko, 2015h. Complex predict fault diagnostics of electromagnetic actuators based on the principle component analyses. Res. J. Appl. Sci., 10: 555-557.

Shaykhutdinov, D.V., N.I. Gorbatentko, V. Akhmedov, M.V. Shaykhutdinova and K.M. Shirokov, 2013. Experimental and simulation tests of magnetic characteristics of electrical sheet steel. Life Sci. J., 10: 2698-2702.

Zhou, F., H.C. Guo, Y.S. Ho and C.Z. Wu, 2007. Scientometric analysis of geostatistics using multivariate methods. Scientometrics, 73: 265-279.