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RESEARCH OF THE POSSIBILITY OF APPLICATION OF VECTOR QUANTISATION METHOD FOR EFFECTIVE PROCESS CONTROL OF ROCKS DISINTEGRATION BY ROTARY DRILLING

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Preliminary Note – Prethodno pripoćenje

The subject of the paper is investigation of the properties of concurrent vibro-acoustic signal in the process of rock massif separation with the method of rotary drilling. The aim is to investigate the possibilities of using this signal as an integrating information source for the purposes of identification of the process of separation from the viewpoint of efficiency of the set mode (pressure, revolutions, indentor) under current geotechnical conditions. Investigated is the possibility of recognition of the state of the process based on the method of vector quantisation.

Key words: vibro-acoustic signal, rotary drilling, identification, vector quantization, process control

Istraživanje mogućnosti primjene metode vektorske kvantitacije za učinkovito upravljanje procesom rotacijskog bušenja stijena. U radu je provedeno vrednovanje atributa simultanog vibro-akustičnog signala u procesu rotacijskog bušenja stijena. Cilj je istražiti mogućnosti korištenja vibro-akustičnog signala kao integriranog izvora informacija za identifikaciju procesa i određivanje optimalnih parametara (tlak, broj okretaja, indentor) za određene geotehničke uvjete. Istražena je mogućnost primjene metode vektorske kvantizacije za identificiranje stanja procesa rotacijskog bušenja stijena.

Ključne riječi: vibro-akustični signal, rotacijsko bušenje, identifikacija, vektorska kvantizacija, upravljanje procesom.

INTRODUCTION

Rotary drilling belongs to the key methods of rock separation not only in mining, but also in wider areas of geotechnologies [1, 2]. The most efficient separation of rocks is in so-called volume area which can be achieved with the correct choice of work tool and work mode while taking into account the geomechanical properties of rock separation. Theoretical research of rock separation by rotary drilling and subsequent experiments on a drilling stand [1, 3, 4] showed that there exists an optimum – efficient mode of drilling from the viewpoint of specific energy consumption w (J/m^3), from the viewpoint of the wear of the separation tool, but also from the viewpoint of the speed of drilling v (m/s).

These facts led to the idea of efficient control of the process of drilling. Further research showed that in the neighborhood of efficient mode of the process of drilling the accompanying vibro-acoustic signal has identifiable properties [3, 4].

In the contribution are given first partial results in the area of design of control system for the process of rock drilling, based on recognition of geomechanical class of rock with the method of vector quantization. At the same time, the necessary information about the character of the process are obtained from the signal of the accompanying vibro-acoustic emissions.

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DEFINITION OF THE PROBLEM

The problem of control of the rock separation process has its specifics. The main problem is the fact that this process is intrinsically involved and its state quantities are non-measurable with standard methods in real-life conditions. The key question is the sufficiency of information about the effect of the drilling mode on the very behavior of separation of particular rock. Under the term „mode of separation“ we understand the synergic effect of main technological components of the process of drilling which are the following action quantities: pressure of the drilling tool on the front of the drill F (N), revolutions of the drilling tool n (rev/s), flow capacity of the lavage during time unit Q (m^3/s) and the quality of the lavage, given by its physicochemical parameters. All these components are independent of each other, it is possible to control them individually during drilling. The knowledge of the drilling modes is the foundation of the knowledge of the process of rock separation by rotary drilling.

From the system point of view the process of rock drilling can be understood in simplified form as the system characterized by the set of quantities some of which we can affect, but some not Figure 1.

The parameters w and φ are state quantities of the process, which are not measurable directly under real-life conditions. More state quantities affect the process of separation: properties of the indentor (drilling tool) and the geomechanical properties of the rock massif being separated.

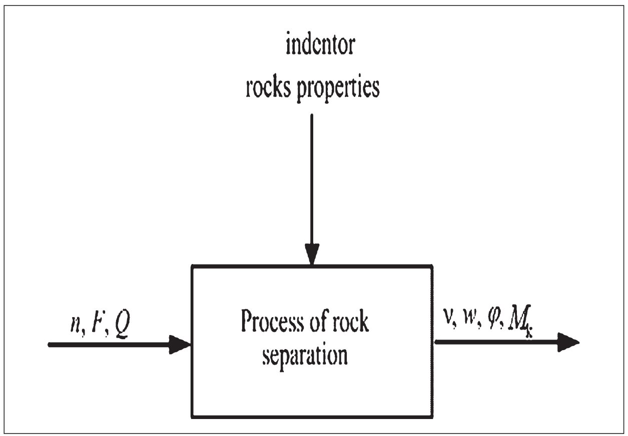

Figure 1. Process of rock separation as the object of control, controlled system
n – revolutions of the drilling tool (rpm), F – pressure force (N), Q – volume of lavage of the drill with water (m^3/s), v – speed of drilling (mm/s), M_k - torque (N×m), w – specific work of separation (J/m), φ - work capability of the tool ($m^4/J\times s$).

The task of synthesis of control of the process of drilling the rock massif, defined in this way, with the requirement to maintain efficient mode under the condition of maximization of the objective function, encounters the problem that it is unrealistic to create adequate analytical mathematical model of the process of rock separation by rotary drilling. This is because this process is too involved from the viewpoint of fundamental modeling and empirically obtained models are only valid under specific conditions. However, the monitored process of separation is strongly stochastic and non-stationary under the influence of changing geomechanical conditions and also under the influence of the indentor wear. Added to this problem are problems with measurability of the objective function under real conditions.

The solution is to avoid the classical system of control using a model of the process and to solve the system of control based on some of the modern methods of control of complex processes where the source of complexity can be nonlinearity, nonstationarity, difficult to describe stochasticities, nonmeasurability of parameters, multicriteriality etc. Among such modern methods of control belong also the methods based on so-called artificial intelligence.

In research of the question of efficient control of the process of rock separation by rotary drilling the basis was the intuitive idea that the accompanying vibro-acoustic signal contains information about the character of the process of separation from the viewpoint of geomechanical properties of the rock and from the viewpoint of efficiency of the process of drilling itself. This idea was verified experimentally [5, 6]. In the following, two versions of solution have been considered.

a) parametric control with classification of rocks being separated

This alternative assumes that the rocks being separated are divided into classes on the basis of similar geomechanical properties and the corresponding optimal mode of drilling. For each class of rocks the parameters of efficient mode of drilling (indentor type F, n, Q) are determined experimentally or with expert method. The system performs a running identification of the class of the rock being separated in the process of drilling under real conditions based on special analysis of the concurrent vibro-acoustic signal [7, 8, 9]. On the basis of the class of rock recognized in this way the associated efficient mode of drilling is set. The classification of rocks itself is based on utilization of neural network as classifier and on the method of vector quantization [7, 9].

b) control with feedback with indirect measurement of the criterion of efficiency of the process

With this alternative of control of the drilling process we use the results of previous research which confirmed that the efficient mode of drilling the rock has specific attributes in the concurrent vibro-acoustic signal [4, 10]. During the process of drilling the concurrent vibro-acoustic signal is being evaluated and at the same time the mode of the process (n, F) is stabilized so that the attributes in the signal correspond to the efficient mode of the process with maximum value of the objective function $\varphi = v / w$.

This contribution further deals with the first alternative of control of the process of rock separation by rotary drilling. It is a parametric control where the key role is played by the classification of rocks and the method of vector quantization of the flag space of the concurrent vibro-acoustic signal.

In the case when the classifier recognizes the new class (there is no sufficiently close template), it assigns the class to the set of templates A^L.

THE RESULTS AND DISCUSSIONS

A series of measurements were performed at the experimental drilling stand of the Institute of Geotechnologies SAV directed toward the application of the above-described method of vector quantization for the purpose of parametric control of the process of rock separation by rotary drilling. Drilled were rocks such as an-

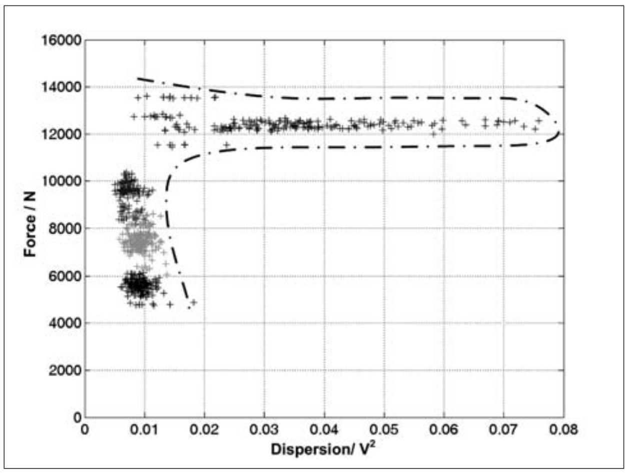

Figure 2. Andesite - $\sigma^2 = f(F)$

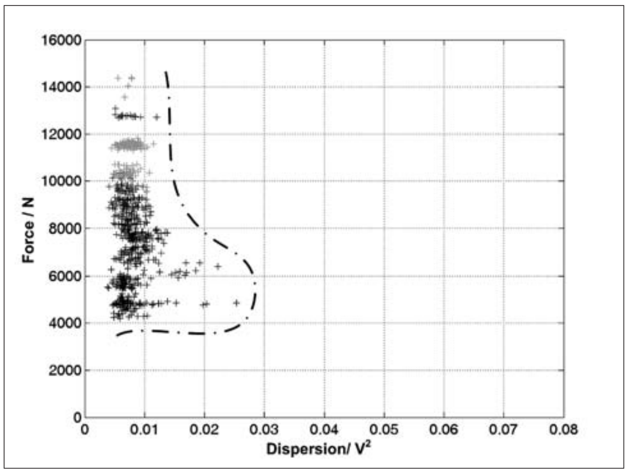

Figure 3. Limestone - $\sigma^2 = f(F)$

desite, limestone, granite, silica and brick as an artificial rock.

As possible components of the symptom vector were investigated:

– time behavior and dispersion of the vibro-acoustic signal,
– Fourier coefficients of the power spectrum of concurrent acoustic emissions in the frequency range 0 to 22 kHz,
– coefficients of the Wiener filter as a parametric model of the process of drilling [8].

In Figure 2 through 4 are shown dispersions σ^2 of the sequence of 200 realizations of the concurrent acoustic signal (f_{vz} = 44 kHz, length of each realization 1500 samples) at different pressures. On the basis of the formed aggregates of points it can be seen that the maximum dispersion of the signal is achieved at certain pressure depending on the type of rock and characterized by its geomechanical properties. According to [3] it is at the same time the pressure corresponding to the efficient mode of drilling. On the basis of these findings one can consider the parameteras σ^2 the only symptom for the classification of rocks. In Figure 5 is shown the behavior of the parameter σ^2 during 200 s of drilling into andesite

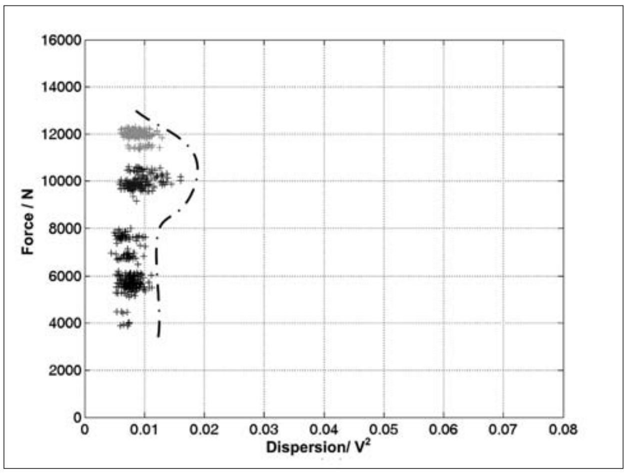

Figure 4. Granite - $\sigma^2 = f(F)$

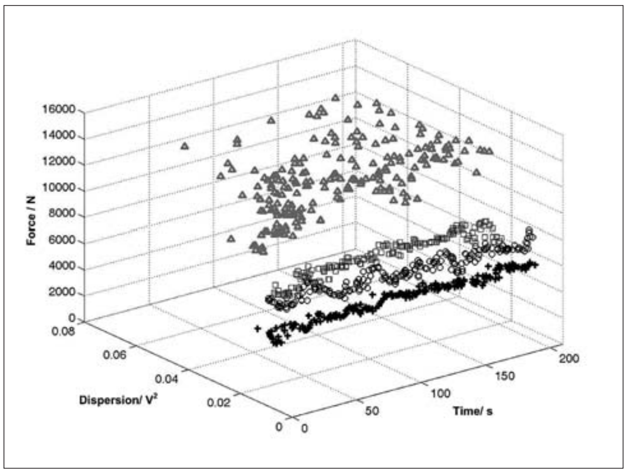

Figure 5. Andesite - $\sigma^2 = f(F)$

at various pressures. The behaviors are in correspondence with Figure 2.

Figure 5 shows the dependence between the pressure in the drilling of andesite and the diffusion of the concurrent acoustic signal for the time period of 200 s. The figure suggests the stationary character of this dependence with given mode of drilling.

In Figure 6 is shown the value of the length (L_2 norm) of the symptom vector x, calculated according to relation.

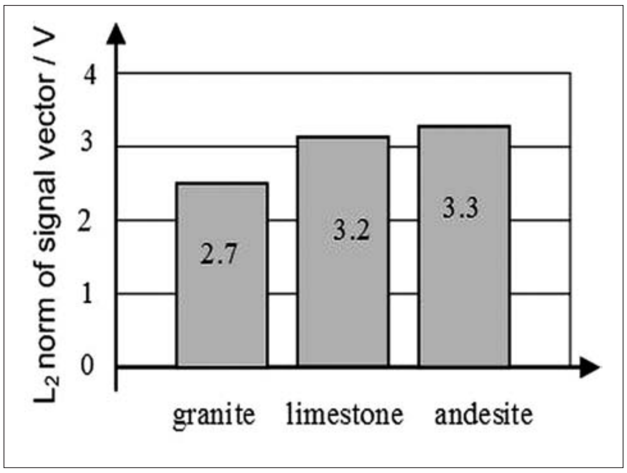

Figure 6. L_2 norm of signal vector

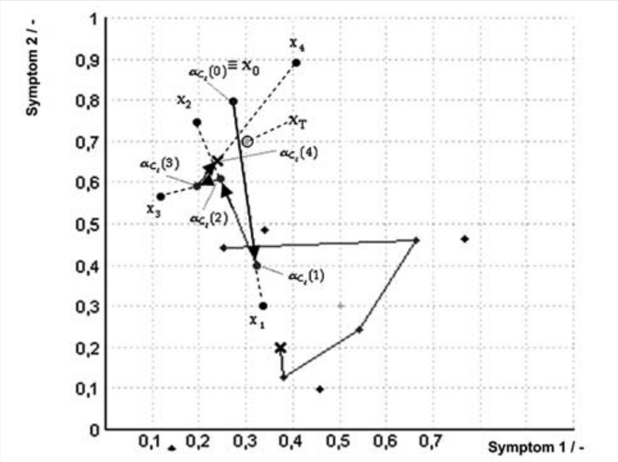

Figure 7. First four steps of the process of learning (gradual creation of the template of the class defined in two-dimensional symptom space); Rem.: points in lower part of the space correspond to different class

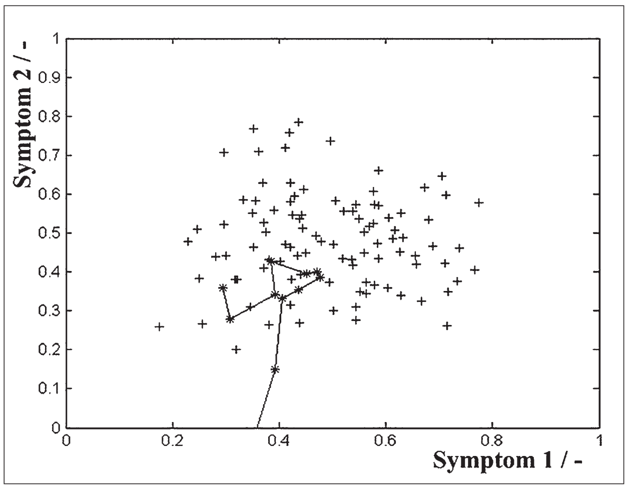

Figure 8. Prejudication „damping" proces of learning then by 11 step weight wrong elective first parameter $\mu(0)$ a $\Delta\mu$ (+ -appearence, * -template)

The components of the vector were the samples of the acoustic signal numbered 1024. Andesite and limestone have the values very close to each other, however, sufficiently differentiable from granite. This knowledge corresponds to the findings regarding the dispersion (Figure 2 through 4). Also, this fact makes it possible to utilize the norm of time behavior of the vibro-diagnostic signal as a suitable symptom in the classification of rocks.

Within the framework of the research was verified the algorithm itself for the process of creation of code book A^L as the set of templates of individual classes of rocks $\{C_i\}_{i=1}^{L}$.

The essence of this algorithm is the iteration calculation which provides the mechanism of shifting the template always toward the new training symptom vector, however, with gradually decreasing extent of the shift μ. The goal of learning is for the resulting location of the template to be as close as possible to the centroid of the set of symptom vectors of the training data. From this viewpoint, the success

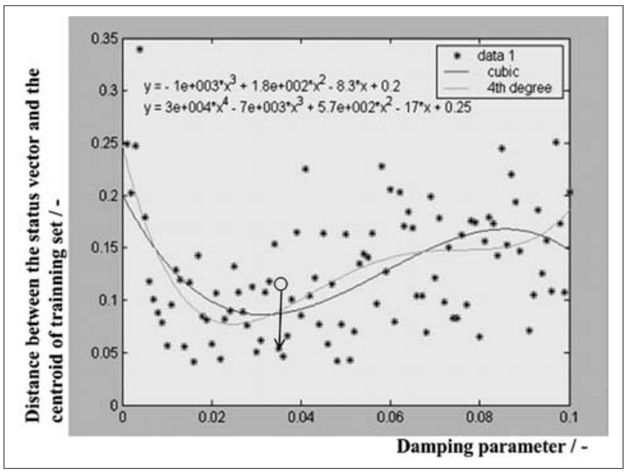

Figure 9. Fitted dependence of the distance between the resulting template of the class of rocks and the centroid of the training set of vectors upon the choice of damping parameter $\Delta\mu$ in interval 0,001 when 0,1

of this algorithm strongly depends on the correct choice of the initial value of the extent of shift $\mu(0)$ and on the choice of the damping parameter $\Delta\mu$.

In Figure 7 are shown the first four steps of learning of the classifier on the training set of symptom vectors of class C_i in two-dimensional symptom space. By processing the symptom vectors x_0 through x_4 with the aid of the calculation scheme template of the class gradually gets to the position $\alpha_{C_i}(4)$, while the following parameter values were defined: $\mu(0) = 1$, $\Delta\mu = 0{,}1$.

It can be seen that with these parameter values the template gradually approaches the centroid x_T of the training data. However, with unsuitably chosen parameter values this learning method can diverge Figure 8. The centroid of the training set of symptom vectors was calculated with the formula

$$x_i^T = \frac{\sum_{j=1}^{D} p(x_{ij}) \cdot x_{ij}}{\sum_{j=1}^{D} p(x_{ij})}, \quad i = 1,2,\ldots,n \qquad (1)$$

where x_{ij} represents the value of the i-th symptom in the j-th symptom vector of the training set of data, $p(x_{ij})$ is the estimate of the probability of this value according to the Gauss distribution.

In Figure 9 is shown fitted dependence of the distance between the resulting template of the class of rocks and the centroid of the training set of vectors upon the choice of damping parameter $\Delta\mu$ of the extent of shift $\mu(k)$. The training set consists of 200 six-component symptom vectors. It can be seen that there exists an optimum damping at which is achieved the maximum approximation of the template to the centroid of the training set, whereby at end condition is satisfied. This finding is important for the utilization of the calculation scheme in the process of self-learning (learning without teacher), when a template is sought for a new as yet unknown class of rocks.

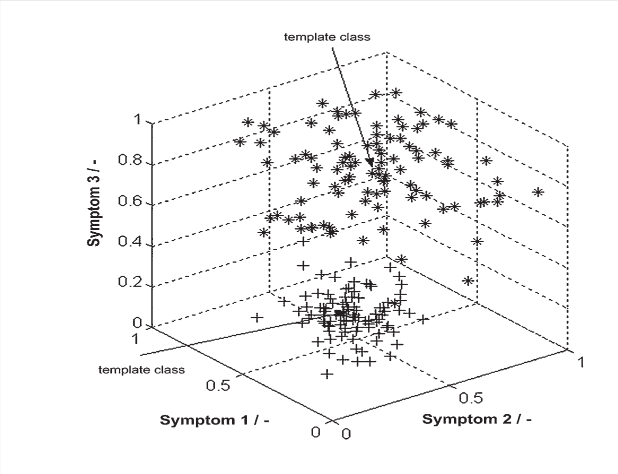

Figure 10. Templates of two classes were created characterized by 3-dimensional symptom space

Figure 10 shows a successful process of learning when templates of two classes were created characterized by 3-dimensional symptom space.

CONCLUSION

In this contribution are published the first partial results of application of the method of vector quantization at efficient control of the process of separation of rocks by rotary drilling. It concerns a parametric control of the process by using the neural network as a classifier of separated rocks into classes from the viewpoint of their geomechanical properties. Investigated was the possibility of utilization of the concurrent vibro-acoustic signal for the calculation of symptoms that would sufficiently differentiate rocks according to their geomechanical properties. Positive results were achieved in utilization of some methods of signal processing in the time domain. For further research in this direction are very important the findings about suitable strategy of the process of creation of the code book of templates of rock classes [5, 10, 11].

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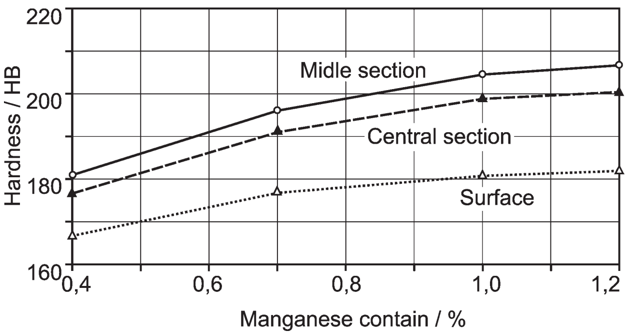

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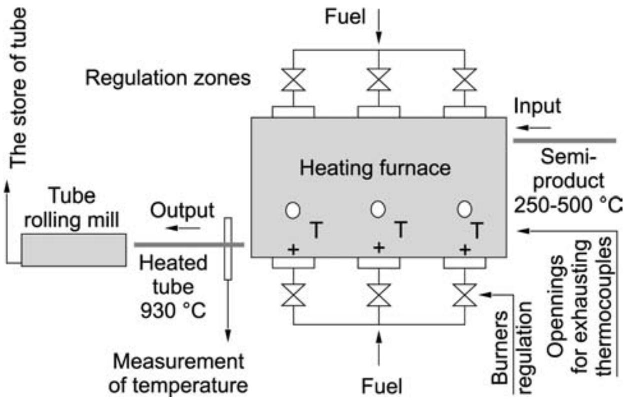

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