View metadata, citation and similar papers at core.ac.uk brought to you by CORE

I. LEŠŠO, P. FLEGNER, B. PANDULA, P. HOROVČÁK

ISSN 0543-5846
METABK 46 (3) 165-168 (2007)
UDC - UDK 550.8:622.2:534.8=111

NEW PRINCIPLES OF PROCESS CONTROL IN GEOTECHNICS BY ACOUSTIC METHODS

Received - Primljeno: 2005-06-09
Accepted - Prihvaćeno: 2007-01-10
Preliminary Note - Prethodno priopćenje

The contribution describes the new solution of the control of rotary drilling process as some elementary process in geotechnics. The article presents the first results of research on the utilization of acoustic methods in identification process by optimal control of rotary drilling.

Key words: *geotechnics, process control, acoustic method, rotary drilling, rock massiv*

Nova načela procesne kontrole u geotehnici akustičnim metodama. Članak opisuje nova rješenja u kontroli rotacionog bušenja kao poznat jednostavni postupak u geotehnici. Daje se početni rezultat rabljenja akustične metode u identifikaciji procesa opimalne kontrole rotacionog bušenja.

Ključne riječi: *geotehnika, procesna kontrola, akustična metoda, rotaciono bušenje, stijene*

INTRODUCTION

Technological process control assumes that enough information about static and dynamic properties of the process and also information about its current state during its control is available. To the amount and quality of available information then corresponds the structure and the principle of the control system. The design of the control system is preceded by process identification the result of which is a process model, comprising its static and most of the time also the dynamic properties.

ROTARY DRILLING OF ROCKS

The process of rock separation by rotary drilling, from the viewpoint of process control, is a dynamical one, with strong stochastic component. From the viewpoint of measurability of state quantities there is a problem since the essence of the rotary drilling process is cutting and cleaving of the material by using a separation tool [1, 2]. These elementary mechanical processes are very difficult to measure under production conditions and their mathematical modeling has more theoretical significance than practical use in the control [3]. Because of this, in practice we encounter drilling and tunneling devices, whose working mode is defined in advance by the device manufacturer, or at best it is set by the operating personnel on the basis of average geomechanical properties of the rock massif.

In the framework of grant research the possibilities were investigated of utilizing the concurrent acoustic signal as integrated information source about the state of separation process. The original idea was that periodic mechanical vibrations, and also stochastic mechanical shocks occur at the indenter - rock boundary during the process of drilling, which correspond to elementary mechanical processes of cutting and material cleaving. There is an assumption that the character of these processes corresponds to the geomechanical properties of particular rock formation. These vibrations and shocks subsequently create corresponding noise. On the basis of this idea an assumption was made that the signal of mechanical vibrations as well as the corresponding noise signal contain in them the information about the conditions and the rock separation process, which could be put to use in process control.

The above idea of vibration or noise utilization relied on the application of analysis of vibro-acoustic signals in the area of technical diagnostics (e.g. so-called condition monitoring).

The problem of optimum control of the rock separation process by rotary drilling was worked out in [4]. The control quantities in this case are the revolutions n of the drilling tool (rpm) and contact force F / N. The objective function J is the ratio of the drilling speed v / (mm/s) to the specific energy of separation w / (J/m^3). The criterion of optimum control of the drilling process during the time $t \to T$ is then given by the relation:

I. Leššo, P. Flegner, B. Pandula, P. Horovčák, Faculty of Mining, Ecology, Management and Geotechnology Technical University of Košice, Košice, Slovakia

$$\max J\left(n,F\right)=\max\ \frac{J_v}{J_w}=\max\ \frac{C_v\int_0^T v\left(t\right)dt}{C_w\int_0^T w\left(t\right)dt}, \qquad (1)$$

where C_v are C_w are constants of the ratio (weight coefficients).

At the same time, basic limitations given by the drilling technology itself must be satisfied.

In Figure 1. is shown the behavior of objective function $J(n, F)|_{n = \text{const.}}$, where there exists the optimum drilling mode in the sense of (1).

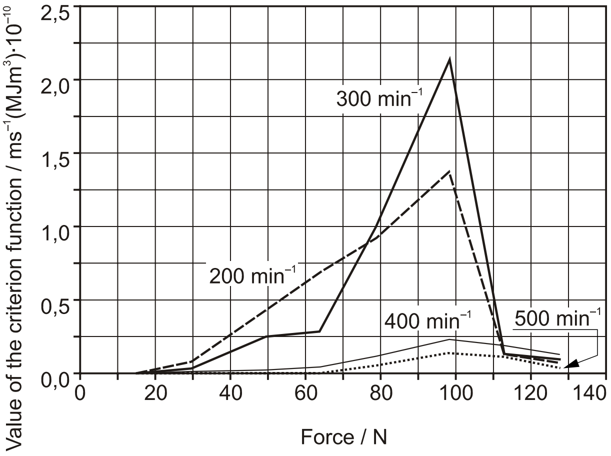

Figure 1. **Dependence of measured objective function value upon drilling mode**

Slika 1. **Ovisnost mjerenih objektivnih vrijednosti pri metodi bušenja**

A condition for the control of the rock massif drilling process in the above sense is the possibility to set the value of the objective function *J* for specific values of *n* and *F*. An analytical expression of this function is not realistic in view of the character of the process; therefore it is necessary to look for the possibility to measure this criterion function, directly or indirectly, under real production conditions. The finding of a suitable measurement method would enable the subsequent use of some known numerical gradient method for the purposes of optimum control of the drilling process. The aim of the objective research is to analyze the possibilities of indirect measurement of objective function *J* on the basis of the concurrent acoustic signal processing.

ACOUSTIC SIGNAL AS INTEGRATED INFORMATION SOURCE OF DRILLING PROCESS

The experiments were conducted at the drilling stand of ÚGT SAV in Košice which is equipped with a digital regulation system enabling to stabilize the revolutions and pressure at the required level. Moreover, it is equipped with a measurement and monitoring system providing the collection and preprocessing of basic process data [1]. There the behavior of the objective function was measured and is shown in Figure 1. The noise created in rock drilling is picked up by an electret microphone and subsequently digitized with the aid of an AD converter with 24 bit resolution at sampling frequency of 44 kHz.

The acoustic signal read-in (Figure 2.) has the character of a periodic signal mixed with stochastic signal. The periodic component of the signal corresponds to an excitation through the periodic activity of the drilling stand; the stochastic component corresponds to the random character of the rock separation process itself.

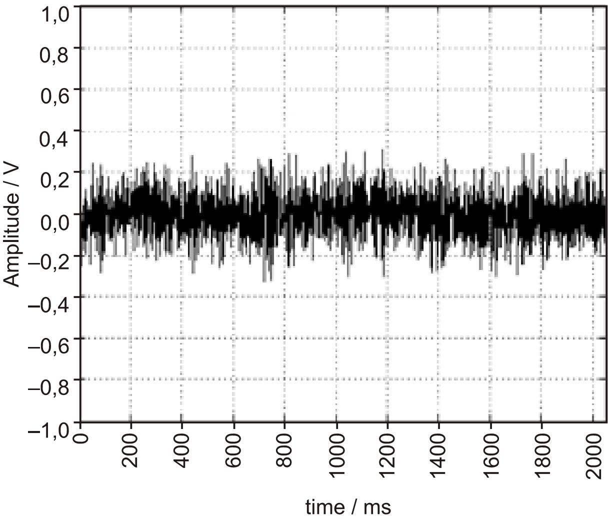

Figure 2. **Oscillogram of the concurrent acoustic signal at rock drilling**

Slika 2. **Oscilogram istodobnog akustičkog signala pri bušenju stijena**

This concurrent acoustic signal was analyzed in the time and frequency domain. The influence was proved of the drilling mode (revolutions *n*, contact force *F*) and the influence of separated rock type from the viewpoint

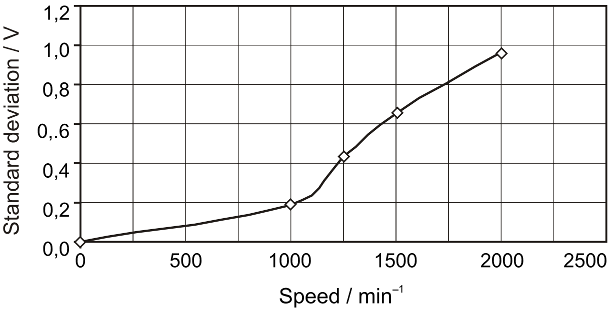

Figure 3. **Standard deviation of the concurrent acoustic signal as function of revolutions of drilling tool (chamotte)**

Slika 3. **Standardna devijacija istodobnog akustičkog signala kao funkcija okreta pri bušenju (šamot)** of geomechanics on the character of this signal (Figure 3., Figure 4.).

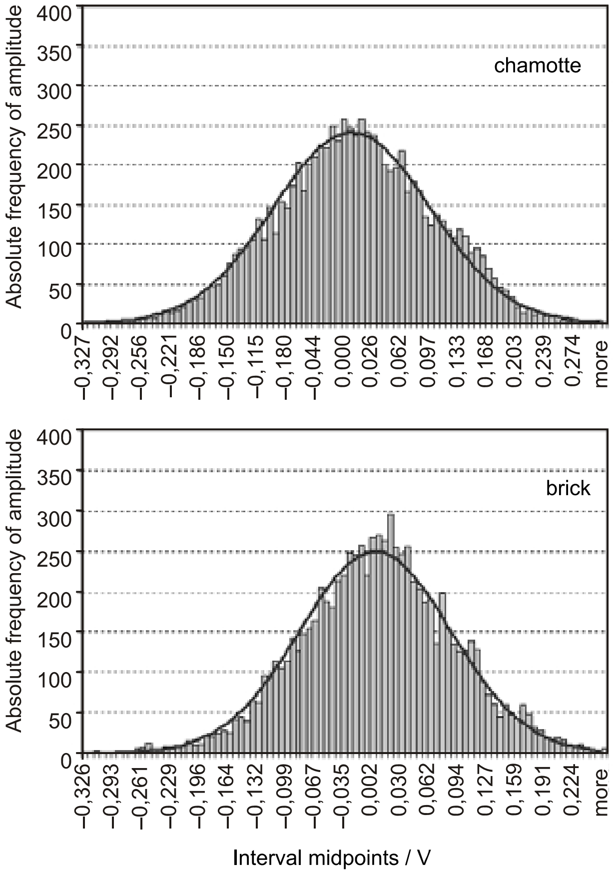

Figure 4. **Distribution of the probability density of the concurrent acoustic signal for different rocks (chamotte, brick)**

Slika 4. **Raspodjela možebitne gustoće istodobnog akustičkog signala za različite stijene (šamot, opeka)**

The basis of the acoustic signal evaluation in the frequency domain is the Fourier harmonic analysis or other suitable transformations [5, 6]. The result of this analysis is the frequency spectrum of the signal. During the research frequency evaluations were made of concurrent acoustic signals from the drilling of five types of rocks (the brick as artificial rock, chamotte, marble, limestone, quartz). From the signal of each rock, realizations were processed with the length of $N = 512$ samples at sampling frequency $f_{vz} =$ 44 kHz by using the DFT algorithm. The resolution of the AD converter used was 24 bits. In such a way, bright-line RMS spectrum was obtained with the limit frequency of 22 kHz and frequency resolution of $\Delta f = \dfrac{f_{vz}/2}{N/2} = 86$ Hz. For comparison, in Figure 5. are shown linear spectra (RMS) of the concurrent acoustic signal of brick and chamotte separation by rotary drilling in the same mode. There is an apparent difference in amplitudes and frequency representatives in these spectra.

The upper spectrum amplitude axis is linear; the lower spectrum amplitude axis is logarithmic. The spectrum is symmetric along the frequency line for $N = 256$.

For better documentation of the differences in spectra of the concurrent acoustic signal in the separation of rocks with different geomechanical properties the realizations of the signal of five types of rocks were grouped together into one common record and subsequently this record was subjected to time-frequency analysis.

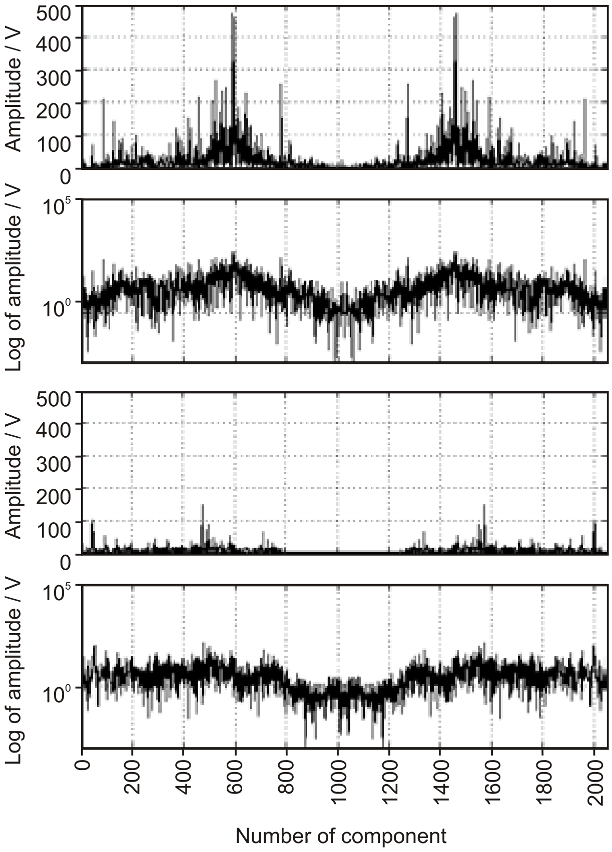

Figure 5. **Spectrum of concurrent acoustic signal of chamotte drilling (up) and brick (down)**

Slika 5. **Spektar istodobnog akustičkog signala bušenog šamota (gore) i opeke (dolje)**

Denote by symbol r the number of signal realization of the h th rock, let k be the serial number of the sample in given realization. Then the r-th realization of the rock signal h can be symbolically written as a sequence:

$$\{x_{r,k}\}_h = \{x_r(kT_{vz})\}_h . \tag{2}$$

For each of the five rocks 15 realizations with 1024 samples were used. Thus we have: $r = 1, 2, ..., 15$, $k = 0, 1, 2, ..., 1023$, $h = 1, 2, ..., 5$. Then the record which was formed artificially by grouping together these signal realizations can be expressed with the sequence

$$\{x_{k'}\}. \tag{3}$$

where $k' = k + (h-1)1024 \times 15$.

The record (3) created this way has a non-stationary character (Figure 6. above), since its individual parts correspond to different geomechanical properties of the rock being separated. By its time-frequency analysis a spectrogram was made (Figure 6. below). It can be seen from this spectrogram there is a marked difference in the properties of the concurrent acoustic signal spectra depending on the type of the rock being separated. This fact makes it probable that the concurrent acoustic signal will be a sufficient source of information for the analysis of current conditions of rock massif separation by rotary drilling with the aim of using this information in the drilling process.

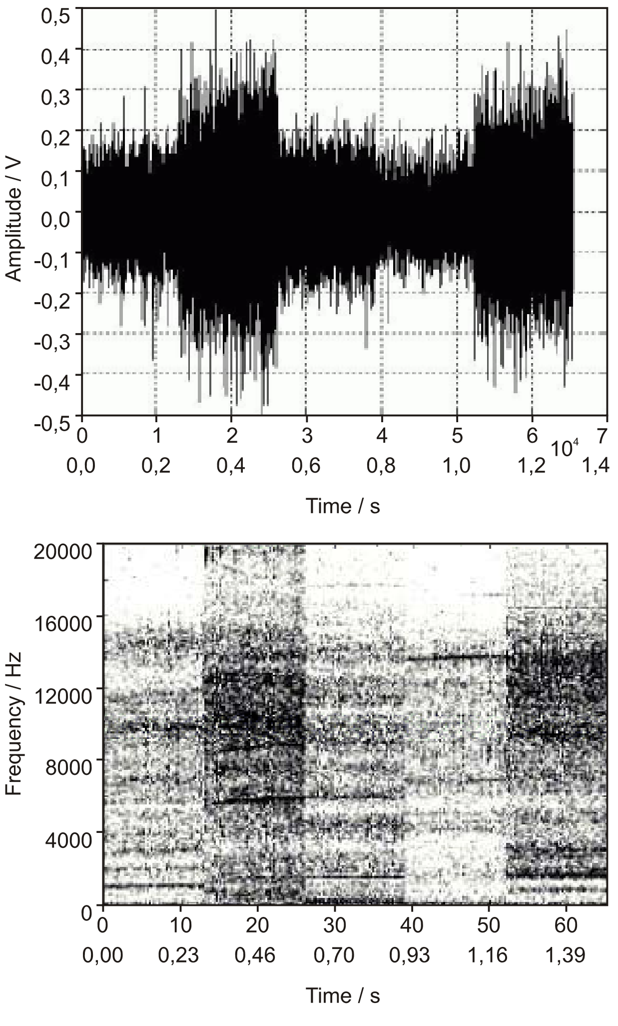

Figure 6. **Mutual comparison of oscillograms (top) of the concurrent acoustic signal in the separation of five types of rock by rotary drilling (from left, brick, chamotte, marble, limestone, quartz)**

Slika 6. **Međusobna usporedba oscilograma (vršak) istodobnog akustičkog signala u odjeljivanju pet vrsta stijena rotacionim bušenjem (s lijeva: opeka, šamot, mramor, vapnenac, kvarc)**

CONCLUSION

Experiments on the drilling stand have shown that the concurrent acoustic signal read in during rock separation by rotary drilling has some different characteristics depending on geomechanical properties of the rock being separated. An important finding is that the signal dispersion is sensitive to the working mode and its value is largest in the mode close to the optimum mode [4]. The distinctness of characteristic spectra in the five selected rocks was proved by the spectrogram in Figure 6.

The present research is oriented toward deepening the knowledge about the properties of concurrent acoustic signal and toward the area of classification of drilled rock massif form the viewpoint of its geomechanical properties and corresponding rational mode of separation. The final goal of the research is to find the method of indirect measurement of the objective function (1) by reading in the concurrent acoustic signal [7] and the modern methods of control [8, 9].

REFERENCES

[1] V. Krúpa, J. Pinka: Rozpojovanie hornín Stroffek, Košice 1998, 109.

[2] P. Horovčák: The Influence of Network Factors on Process Monitoring, Acta Tehnica Napocensis, Electronics and Telecommunications 41 (2001) 2, 36 - 45.

[3] D. Malindžák, a kol.: Modely pre automatizáciu rozvrhovania výroby ÚaE Oceľ s.r.o. VSŽ a.s. Košice, Záverečná správa projektu, Košice, 1994.

[4] I. Leššo, J. Futó, F. Krepelka, B. Pandula, A. Mockovčiaková: Control with acoustic method of disintegration of rocks by rotary drilling, Metalurgija 43 (2004) 2, 119 - 121.

[5] V. Janotka, J. Viskup, D. Bukov: Rock environment geological models for accelerogram and seismic response spectra computation. Proceedings of the 3rd International Conference “Soil-Structure Interaction”. Slovak Technical University, Department of Geotechnics, 1997, 27 - 32.

[6] N. Častová, Z. Kaláb: Waveletový rozklad seizmologických signálu: Sborník vědeckých prací VŠB-TU Ostrava, Řada stavební VŠB -TU Ostrava, 2/2003.

[7] I. Koštial, P. Rybár, P. Podlubný: Informatization of raw materials extraction and processing-looking forward to the XXI century, Metalurgija 42 (2002) 4, 231-234.

[8] Ľ. Dorčák: Numerical Models for Simulation the Fractional-Order Control Systems. UEF SAV, The Academy of Sciences, Inst. of Exp. Ph., Košice 1994, Slovak Rep.

[9] Ľ. Dorčák, I. Petráš, I. Koštial, J. Terpák: State-Space Controller Design for the FO Regulated Systems. In ICCC2001, Krynica 2000, Poland, 15-20.