Standard Specific Drilling Energy of the Acoustic Signal for Identification of Indentor-Rock System

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Summary

Current computer techniques provide new modern utilization and approaches in processes that have not been used. One of such possibilities is a design of models for optimization of rock excavation process. The qualities of the model derived from conventional energy theory of rock drilling are compared to the qualities of non-standard model obtained by scanning of the acoustic signal as an accompanying effect of environment in the rock drilling process. The paper focuses on the signal energy, as one of type energy transformed by rock drilling process. The acoustic signal was registered on the laboratory drilling stand at the Institute of Geotechnics SAS in Košice.

Keywords: rock drilling process, acoustic signal, specific energy, working ability of cutting tool, standard specific drilling energy of the acoustic signal

Introduction

The mechanism of rock disintegration process and the cutting tool wear was studied using the laboratory experimental stand at the Institute of Geotechnics SAS in Košice. For the last few years, the changes in various fields of science and technology have been made with the response in these fields of science and technology. Current computer techniques provide the new modern possibilities and approaches of the data recording, monitoring and archiving. New non-standard methods for the identification of the indentor-rock system denoted significant assignment in research in previous years and decades. The results of the experiments exhibit that the acoustic signal represents approximately only 3% of the total value of the recorded signal. New models can be used for the optimization of the drilling regime in addition to standard models which are based on the evaluation of the specific drilling energy from measured signal of torque, advance rate of the drilling tool and revolutions, respectively on the evaluation of the working ability of the drilling tool. The models are based on the processing of the accompanying acoustic signal as an acoustic effect of environment in the rock drilling process.

Material and methods

Description of the laboratory experimental stand

Experimental equipment – rotary stand is used for the study of the rock drilling process by drilling tools with diameter to 80 mm, which are commonly used in practise. Stand is located at the framework. It is buried in concrete to the floor area. The experimental laboratory has in terms of acoustic space complex geometric-physical configuration. The sound propagation is not possible to describe by using a simple relation, however it can be considered as a diffusion space as any enclosed space.

Mathematical model used for system optimization.

The system is generally described by q inputs and v outputs which are defined by the equations in the area close to the working point

$$\mathbf{x}^{(1)}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t), \tag{1}$$

$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t), \tag{2}$$

where x(t), u(t), y(t) represent the state variables, input and output and A, B, C are the matrixes with relevant dimensions. System identification outcomes from measured variables, i.e. from inputs and outputs, which after well-defined conditions of „ideal“ experiments, provided testing of the assumption and comparison of various methods.

Figure 2 illustrates a simple scheme of a dynamic system indentor-rock, which is affected by two decisive input variables, thrust force and revolutions. Measurable outputs of the system are represented by two variables, power and drilled length, which both can be recorded as a time order, and an accompanying acoustic signal produced by the rock drilling process. Disturbances, represented by the controllable inputs (indentor, rock type) or uncontrollable inputs (rock properties, drilling tool condition, properties of environment, etc.) enter the system and effect it.

Application of the energy theory of the rock disintegration belongs to the conventional methods for determination of the optimal drilling regime for indentor-rock system. The method is based on the calculation of the extreme (minimum) specific energy w or extreme (maximum) working ability of the drilling tool φ [1,2,6]. It is necessary to emphasize, the value of the specific energy w is proportional to the intensity of the indentor wear and value of the working ability of the drilling tool φ effects efficiency of the drilling process. Non-standard methods, such as measurement acoustic effect of environment in rock drilling process should be available for determination of the optimum presented technological process [8,9,10].

The investigation is based on a presumption that acoustic effect of environment in rock drilling process is characteristic for any individual rock type and drilling regime, and that it is possible to determine the system parameters, for which the drilling process reaches its minimal energy consumption. Presented issues are very complex as it is necessary to apply a whole range of factors acting in the system. At first, it has to be decided, which disintegration theory is appropriate to examination the process. Depending on this decision, the conditions of acoustic signal measurement have to keep regarding the complex acoustic field, which is usually a closed-diffused field.

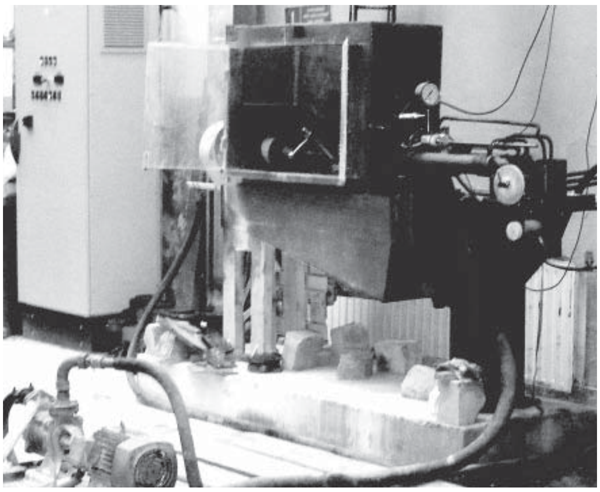

Fig. 1.tory experimental stand at the Institute IGt SAS Košice

Rys. 1. Laboratoryjny eksperymentalny stojak do wiercenia w Instytucie Geotechniki SAS w Koszycach

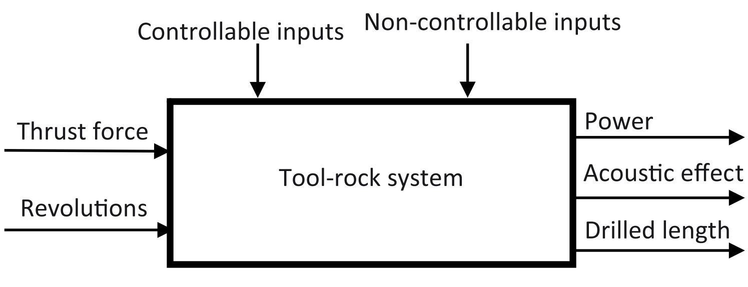

Fig. 2. Scheme of the indentor-rock system

Rys. 2. Schemat systemu Indentor-Rock

Variables characterizing the rock disintegration process by determination of optimal drilling regime

Application of the energy theory of the rock disintegration by search of the optimal drilling regime outcomes from instantaneous advance rate *v*, specific drilling energy *w* depending on thrust *F* and revolutions *n* or working ability φ. Examples of their behaviours and relations are presented in Fig. 3 [4].

Specific cutting energy *w* is defined by the formula [7]

$$w = \frac{P_1}{V}, \qquad (\mathrm{W/m^3,\ W,m^3}). \qquad (3)$$

where P_1 is power input [J], *V* – volume of fragmented rock [mm^3]

Working ability of the drilling tool φ is determined as ratio instantaneous drilling rate *v* [ms^{-1}] and specific drilling energy *w* [Jmm^{-3}]

$$\varphi = \frac{V}{W}, \qquad (\mathrm{W/m^3,\ W,m^3}), \qquad (4)$$

φ is depending on thrust force *F* [N] and revolutions *n* [min^{-1}] applied in the drilling process.

The optimal rock drilling regime of the selected working point and its close area is determined by minimum specific drilling energy w or maximum working ability of the drilling tool φ [3,5]. It is necessary to emphasize, that the model of minimum specific drilling energy w is preferable from physical matter of the process, whereas model of the working ability reflects technological process parameters.

Signal is parameter determining the state of the system. Global characteristic describe the digital signal in more details and provide additional information [11,12]. It is necessary to work with all the samples for the calculation of the characteristics, some of them have an integral character, i.e. they determine the signal properties as a whole in a certain time interval or in interval of an independent variable. Following characteristics describe the presented model: volume, mean value, standard deviation, median, instantaneous power, effective power, effective value, signal energy.

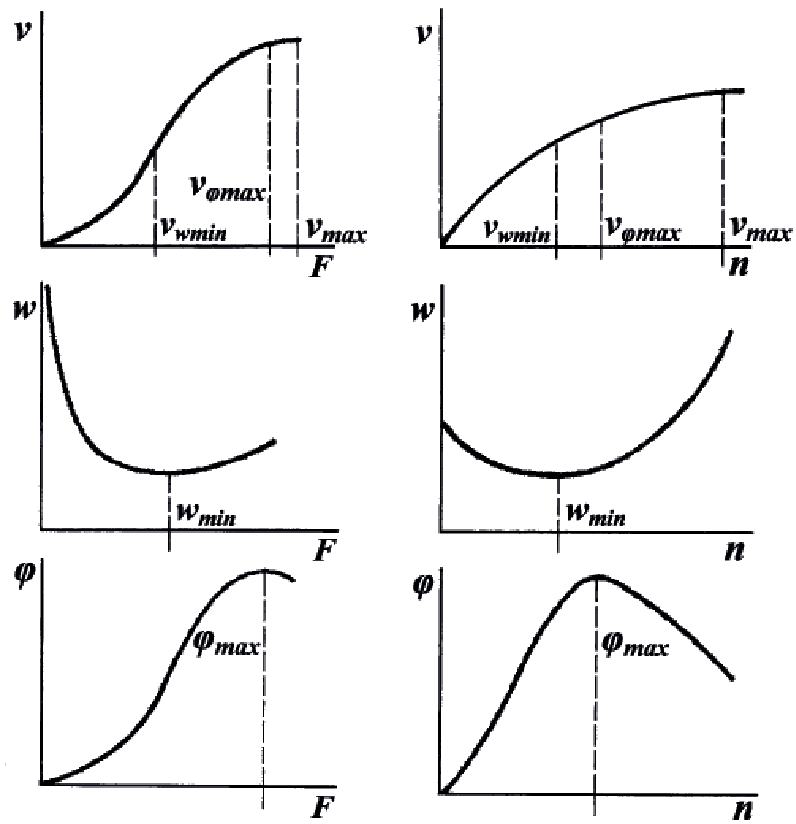

Fig. 3. Behaviour of instantaneous drilling rate *v*, specific cutting energy *w* and the ratio of both variables φ depending on thrust force *F* or revolutions *n*

Rys. 3. Zachowanie chwilowej prędkości wiercenia *v*, rozporządzalnej energii tnącej *w* oraz stosunek dwóch zmiennych φ w zależności od siły odporu *F* oraz ilości obrotów *n*

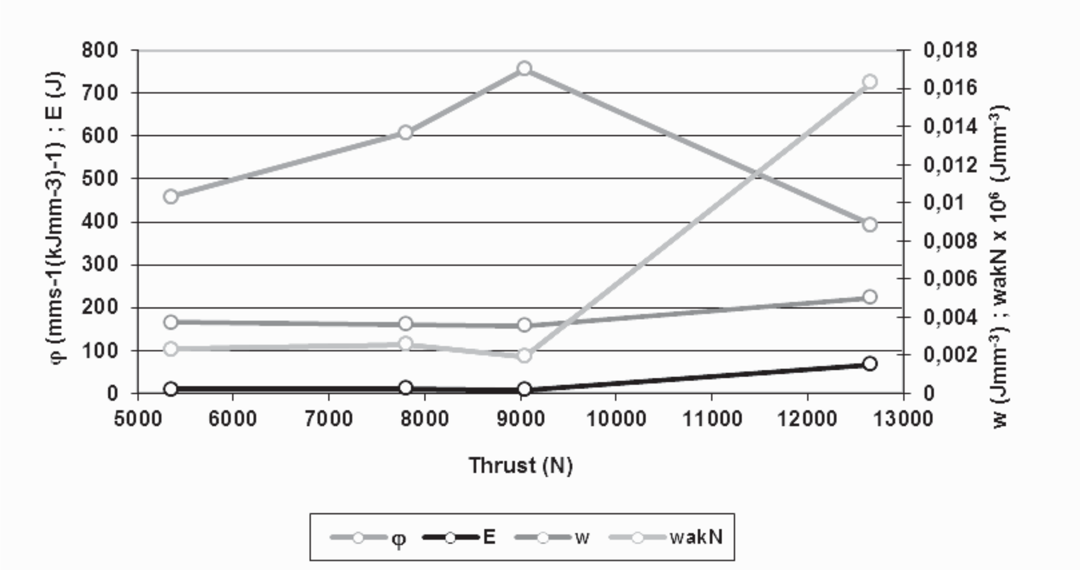

Fig. 4. Working ability of drilling tool φ, specific drilling energy *w*, energy of signal *E* and standard specific drilling energy of the acoustic signal $_{(wakN)}$ depending on the thrust *F* in andesite drilling

Rys. 4. Zdolność do pracy narzędzia drążącego φ, rozporządzalna energia drążąca w, moc sygnału *E* i standardowa rozporządzalna energia drążąca sygnału akustycznego $_{(wakN)}$ w zależności od siły odporu *F* drążenia w andezycie

The main goal of the presented paper is to focus on the signal energy, as one of types energy transformed by rock cutting process. Energy of signal is calculated as power multiplied by a time period. In case of digital data, following formula is used

$$E = P.N = \sum_{k=0}^{N-1} p(k) = \sum_{k=0}^{N-1} s^2(k), \qquad \text{(W, W, -)} \qquad (5)$$

where:
E – energy of signal; *P* – mean power; *p(k)* – instantaneous power of signal; *s* – original value of digital signal.

Conventional energy values of rock drilling process, i.e. working ability of the drilling tool φ, specific cutting energy *w*, add energy of signal *E* are presented in the graph at the same working point (regime) for comparison values obtained from different models. The specific drilling energy strictly determines from the physical point of view energy consumption for disintegration of unit volume of rock. Values are assessed with small differences. The working ability of the drilling tool enhances small differences in values, but the optimum can be shifted to the area of the high contact pressure. Due to its universality, the value is often used to determine the optimum.

Relation (5) is sufficient for optimization of the rock drilling process, however, it is desirable to express by formula (6) from a physical matter by comparison with other evaluation parameters

$$E = P.\frac{N}{F_{vz}}, \qquad \text{(J, W, s}^{-1}\text{)} \qquad (6)$$

where $F_{(vz)}$ is the sampling frequency of the signal.

Relationship to the calculation of acoustic energy modified to formula (7) estimates of standard specific drilling energy of the acoustic signal $W_{(akN)}$, that is appropriate parameter for comparison of models:

$$w_{akN} = \frac{E}{V_{ak}}, \qquad \text{(J/m}^3\text{, J, m}^3\text{)} \qquad (7)$$

where $V_{(ak)}$ is the volum of the acoustic area in the close of sensor, for which the comparison is performed.

From the physical point of view, a standard specific drilling energy of the acoustic signal is comparable to energy density of wave *w*.

Figure 4 illustrates behaviour of the working ability of drilling tool φ, specific drilling energy *w*, energy of signal *E* and standard specific drilling energy of the acoustic signal $_{wakN}$ depending on the thrust *F* in andesite drilling. The graph presents 4 points measured by various applied values of thrust force ranging from 500 to 1300 N and revolution of drilling bit n=12 s^{-1}. The plotted regime denotes the minimum level of revolution in andesite drilling.

As the graph shows, the minimum of the specific drilling energy is identified by thrust F=9000 N and estimated working ability of drilling tool is maximum in that measured point. Energy of signal as a standard specific drilling energy of the acoustic signal are minimum at that point, thus the optimums determined by conventional energy approach correspond with transformed energy of signal. The most unfavourable energy regime is by thrust F=12500 N. This regime is established by both conventional methods supplemented with equally energy demand acoustic effect. Based on performed examination, it is possible to claim that the applied optimization method is satisfying for all the observed technological range and working regimes with their energy consumption is properly determined.

Conclusion

Follow is possible to describe obtained results:

1. Two types of models were used for assessment of accordance of observed system: conventional approach derived from specific cutting energy w and working ability of cutting tool φ and model of accompanying acoustic signal $_{wakN}$. Specific cutting energy has been derived and verified by a long–term research at the Institute of Geotechnics SAS for rotary drilling and full-face tunnel excavation. Presented acoustic method is based on the examination of the acoustic signal characteristics – energy, respectively standard specific drilling energy of the acoustic signal.
2. Analysis of results evaluated from the measured values confirms accordance in search of optimum in most of the conventional models compared with results from model of accompanying acoustic signal. The accuracy is 60% by comparison of the evaluated value of optimum by parameter of working ability of drilling tool φ and energy of signal (standard specific drilling energy of the acoustic signal $_{Wak}$) for all defined drilling regime. The accuracy 75% is by comparison of the evaluated value of optimum by parameter specific drilling energy w and energy of signal (standard specific drilling energy of the acoustic signal $_{Wak}$).
3. Relations (6) and (7) are advisable to use in terms of physical dimension and correct graphic presentation.

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Standardowa Rozporządzalna Energia Wiercenia Sygnału Akustycznego dla Identyfikacji za pomocą Systemu Identor-Rock

Obecne możliwości technologiczne zapewniają nowe, nowoczesne sposoby wykorzystania i opracowywania nieużytych jeszcze procesów. Jedną z takich możliwości jest projekt modelu do optymalizacji procesu drążenia skały. Wartości modelu powstałego z konwencjonalnych teorii na temat energii w drążeniu skały zostały porównane z niestandardowym modelem wykorzystującym skan sygnału akustycznego odnoszącego podobny efekt w procesie drążenia skały. Sygnał akustyczny został zarejestrowany w laboratoryjnym stojaku do wiercenia w Instytucie Geotechniki SAS w Koszycach.

Słowa kluczowe: procesy drążenia skały, sygnał akustyczny, energia rozporządzalna, zdolność do pracy narzędzia tnącego, rozporządzalna energia drążąca sygnału akustycznego