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Acoustic signal – new feature in monitoring of rock disintegration process

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Abstract: A model apparatus adjusted for the imitation of rock disintegration by rotary drilling is used for laboratory experimental research. The device provides rotary drilling of rock samples by small-diameter drilling tools. The experimental drilling stand is equipped with monitoring system providing the scanning, recording and/or computation of input and output variables of disintegration process, such as thrust, revolutions, advance rate, specific disintegration energy, etc. Recently, the system has been enhanced by a microphone placed in defined point in acoustic space, which registers acoustic signal arising during the drilling.

The acoustic signal changes depending on the drilling regime and the task is formed as tracing the patterns of changes, dependencies on other variables characterizing the disintegration process and dependencies on tool and rock parameters. The signal is processed with the Fourier transformation decomposing general inharmonic periodical action into harmonic compounds. The analyses of noise as acoustic behaviour of rock drilling process is presented further in the paper. Acoustic signal possesses the potential to be used for control of rock disintegration process.

Key words: acoustic signal, monitoring, disintegration process, rock

1. Introduction

The Institute of Geotechnics SAS in Košice deals with the research of rock disintegration, apart from other scientific tasks. The research is focused on one of the most used technology in rock disintegration represented by rotary drilling, especially in mineral exploitation and underground construction engineering. The experimental research runs in both laboratory and in-situ conditions. A model apparatus adjusted for the imitation of rock disintegration by rotary drilling is used for laboratory experimental

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research. The device provides rotary drilling of rock samples shapes as cylinder and block stones by small-diameter drilling tools. The dimensions of rock samples are limited, but sufficient, according to the dimensions of used drilling tool.

2. Monitoring of rock disintegration process

The disintegration process runs at certain levels of tool thrust and revolutions, where both thrust and revolutions are regulated continuously. The experimental drilling stand is equipped with monitoring system providing the scanning and recording of thrust and revolutions values, as well as the input variables of disintegration process and the advance rate as output variable. The scanned variables are recorded by computer and further processed and valuated. The data are a source for computation of further variables, such as specific disintegration energy and working ability of tool (as a ratio of advance rate and specific disintegration energy).

The system has been recently upgraded by acoustic signal scanning. The acoustic signal represents the audible behaviour of oscillations arising at the disintegration process. Therefore, a classic monitoring system has been enhanced by a microphone placed in defined point in acoustic space, which registers acoustic oscillations coming through air to microphone. The experimental drilling stand and all its features, including drilling tool and rock comprise the source of acoustic oscillations in rock disintegration process. All parts impart a motion to the surrounding air and are sources of noise.

3. Goals and methods of research

The rock disintegration process can be controlled and affected by changing its input variables according to the demands for the output. There may be a demand for maximal advance rate or for minimal specific disintegration energy, or even some other demand for the process optimization as those output variables depend of the input ones. The goal of research task solved at the Institute of Geotechnics has been formulated as finding the possibility to engage the acoustic signal to the control of disintegration process. The acoustic signal changes depending on the drilling regime *(Miklúšová et al., 2004)*.

It is necessary to trace the patterns of changes, dependencies on other variables characterizing the disintegration process and dependencies on tool and rock parameters. The acoustic signal is evaluated and studied. Hence the signal is processed with the Fourier transformation, which decomposes general inharmonic periodical action into harmonic compounds. There are several possibilities and methods of processing and evaluation of acoustic signal *(Krepelka et al., 2002)*.

The microphone registers a complex surrounding noise spreading through the environment, thus it is necessary to eliminate the noise not related to the disintegration process. The conditions of laboratory stand research show two main stages of noise: the noise at idle operation (no rock drilled) and the noise at full load operation, i.e. at rock disintegration. The evaluation thus includes also the signal not caused by disintegration process directly.

The idle operation noise includes the noise of driving aggregate; flush water noise; whirling water noise, etc. The full load operation includes the noise generated directly by the tool bit penetration into the rock; the noise of oscillation of toll and rock generated by short impulses of cutting force at drilling. The second one shows the behaviour stronger the more elastic the rock is (i.e. more prone to oscillations). Another effect is the noise of the tool bit blunting, which is significant at higher stages of bluntness. The noise is thus affected not only by rock properties, but also by the drilling tool type and the way of its action.

The ideal state would be to eliminate the noise at idle run completely, which is unreal. To assure the noise to mirror the real state is is necessary to eliminate the noise caused by idle run and further to keep it at constant level. The above presented can be provided by a constant amount of the flushing water, which was secured during the experiments.

The evaluation of the scanned acoustic signal requires its further digital processing. The monitoring system is equipped with the standard IBM PC, supplied with accessory input-output card PCL 818L (Advantech Co.) transforming the sensor signals to digital form. The microphone signal is evaluated in frequency domain requiring high sampling frequency. The microphone signal scanning uses the “Direct Memory Access” method (DMA) using the special integrated circuit Intel DMA 8237 *(Leššo et al., 1997)*.

To achieve the plausible results from the research task goals, a large number of experimental data on disintegration process is required. Several rock types and tool types may enter the disintegration process. The process may be controlled with a view to be optimal at certain criteria. The criteria may contain the maximal instant advance rate, minimal specific disintegration energy or maximal drilling tool lifetime and other criteria. Every such requirement represents a significant increase (multiplication) of experiments number.

The experiments were realized at the regimes with constant revolutions and constant thrust; and constant revolutions and increasing thrust. The drilling tool was chosen to be an impregnated diamond core-drilling bit. The rocks represented the granite from Hnilec, andesite from Ruskov and a limestone from Včeláre.

4. Experimental results and analysis

The noise analysis requires determining the cause of its formation, i.e. the source and the propagation route. This is usually done by setting such feature of noise that uniquely characterizes the noise source or the ground of its change *(Ušalová, 2004)* .

Such a noise feature appears to be a sound power spectral density – PSD. It shows its maximum values in the frequency band 250-1000 Hz and has proven to respond to the change of disintegration process regime. A picture of such characteristic for discrete frequency bands is shown in Fig. 1. This frequency domain exhibits the largest difference of PSD for particular rock samples, which led us to include the values of PSD from this frequency domain and to relate them with the revolutions and thrust of drilling process. The experimental results are processed into many dependencies and several selected are presented in Figs 2, 3, 4, 5 and 6. The Figs 2, 3 and 4 present the dependencies of PSD from regime parameters of drilling process (revolutions and thrust), the Figs 5 and 6 show the behaviour of PSD related to rock strength characteristic (reduced indentation strength - σ_{red} that was also determined on rock samples). Single points were joined with lines for better understanding. The values of PSD were read at the frequency 1000 Hz. The dimension of PSD variable are not presented, as its is a stress

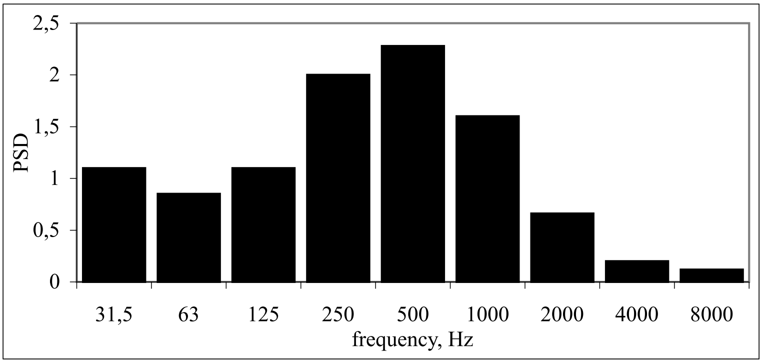

Fig. 1. Sound power spectral density for octave frequency bands.

variable with unessential dimensions in this case and shall play role later in selection and quantification of a particular physical characteristic of acoustic signal.

The Fig. 2 shows that sound power spectral density increases with the increase of revolutions. The dependence on thrust, however, is not so distinct and in presented range of regime variables in the case of granite even exhibits a local minimum. The Figs 2 and 3 point that the effect of revo-

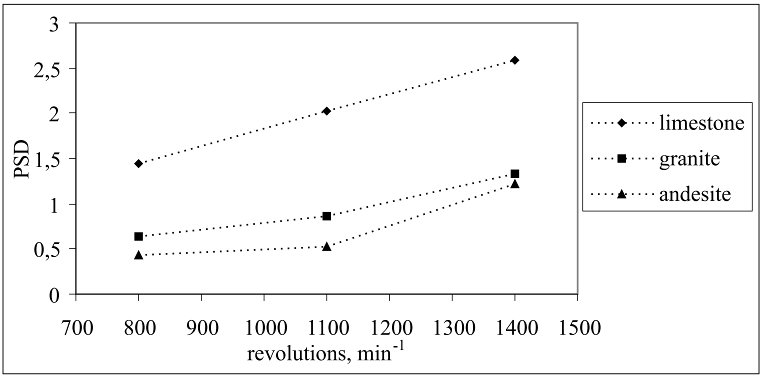

Fig. 2. Dependence of sound power spectral density on revolutions at thrust level 9000 N.

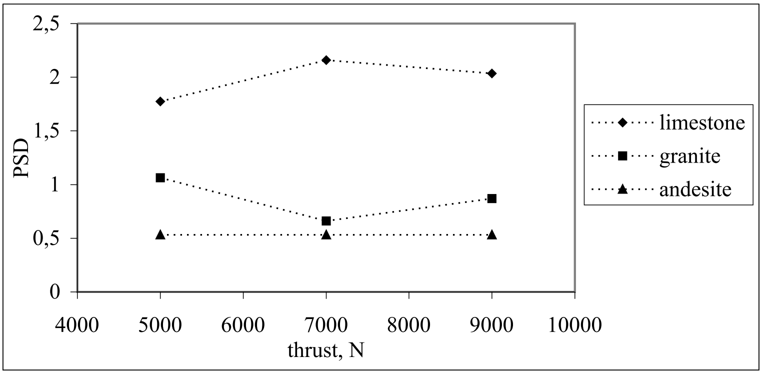

Fig. 3. Dependence of sound power spectral density on thrust at revolutions level 1100 min^{-1}.

lutions to the change of selected characteristic of acoustic signal – PSD is more significant than the effect of thrust.

The dependencies in the Figs 2 and 3 represent only selected dependencies for particular levels of thrust and revolutions. As they are two-dimensional it is necessary to take into account the dependencies for all experimental data. More light to this area is brought by three-dimensional dependencies PSD to revolutions and thrust, as shown in the Fig. 4, which is an example from the granite drilling in the area of measured variables. The three-dimensional picture shows that the PSD behaviour depending on thrust and revolutions is not planar. The plane inclines to higher PSD values with increasing revolutions and there is a notable area with minimum PSD value depending on thrust. 3D dependencies for andesite and limestone show similar behaviour as well, but are not presented in this paper. Their comparison is shown in Figs 5 and 6 at selected regime parameters. The dependencies PSD to reduced indentation strength decrease obviously for all presented measured levels of revolutions and trust. This means that the effect of rock on PSD is significant enough to presume the PSD distinguishing depending on changing the rock type.

The PSD values also contain the noise of the core drilling bit. The same drilling bit was used during the experiments, its influence on the noise share was constant, but it can not be separated, which means that the noise from

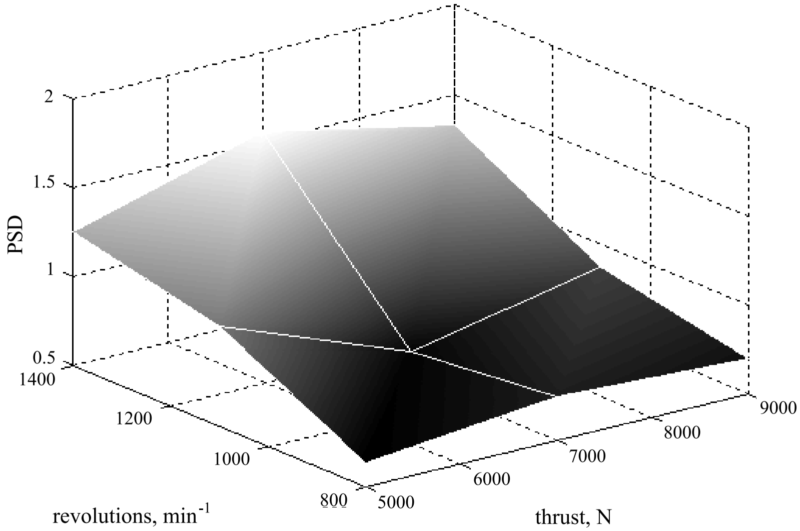

Fig. 4. Dependence of sound power spectral density on thrust and revolutions for granite.

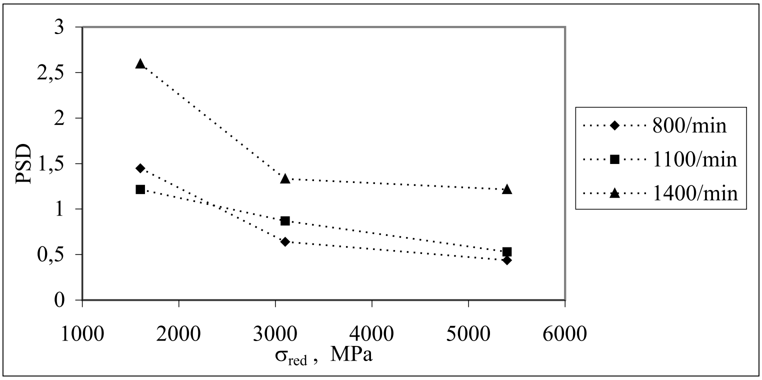

Fig. 5. Dependence of sound power spectral density on reduced indentation strength at thrust level 9000 N, limestone $\sigma_{\rm red}$ = 1 600 MPa, granite $\sigma_{\rm red}$ = 3 400 MPa, andesite $\sigma_{\rm red}$ = 5 400 MPa.

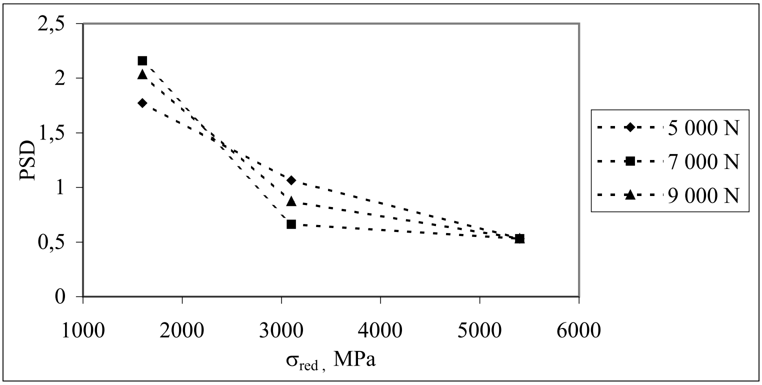

Fig. 6. Dependence of sound power spectral density on reduced indentation strength at revolutions 1100 min^{-1}. Limestone $\sigma_{\text{red}} = 1\ 600$ MPa, granite $\sigma_{\text{red}} = 3\ 400$ MPa, andesite $\sigma_{\text{red}} = 5\ 400$ MPa.

the bit is not assessable. Similarly, the flushing water noise is the same problem.

5. Conclusions

The research task followed the inclusion of acoustic signal accompanying the signal with no further need to monitor the thrust and revolutions.

Presented results show that selected characteristic of acoustic signal considerably responds to the change of disintegration process regime parameters as well as to the change of rock type.

Many verifying experiments are necessary for particular specification of rock disintegration process by acoustic signal characteristic. Range of input regime parameters, both thrust and revolutions, has to be wide enough, various rock types and drilling tool types have to be tested, and the effect on acoustic signal shall be traced.

The method for connection of acoustic signal and regime parameters with other variables of disintegration process will be searched for. The evaluation will contain such regime parameters, where the acoustic signal characteristic changes will be assigned to the certain particular influences.

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