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OPTIMIZATION OF ROCK DISINTEGRATION BASED ON ACOUSTIC BACKGROUND OF DRILLING MACHINE

SUMMARY

The rotary drilling of rock is widespread technology in mining and in tunnelling. The paper describes the results of research by aim to find relationships between optimal drilling and sound signal of drilling machine. The optimisation criterion has been formulated as the minimisation of specific energy with maximal effective speed of drilling in process of the rock disintegration. The research in this field has been made on experimental drilling stand. Our monitoring system has measured following variables: pressing force of core drill, revolutions of drilling head, length of drilling, time, power, acoustic signals. For measurement of acoustic signals have been used very sensitively sound meter Mediator 2238. From this measurement have been processed acoustic spectrums. Then we are found relationships between optimal control of drilling and composition of acoustic spectrum. On base of experimental results, we can formulate the optimal control following: "To achieve the minimum difference between the equivalent sound level at the load and idle modes only at the representative frequency. The representative frequency dependences on type of the rock". New method based on these relationships enables the optimal control of drilling machine by using measured acoustic signals only.

Keywords*: rotary drilling, acoustic fields, optimal drilling*

OPTYMALIZACJA ROZDRABNIANIA SKAŁ
NA PODSTAWIE ANALIZY SYGNAŁU AKUSTYCZNEGO MASZYNY DRĄŻĄCEJ

Obrotowe rozdrabnianie skał jest bardzo rozpowszechnioną technologią w górnictwie i drążeniu tuneli. Artykuł opisuje wyniki badania zależności pomiędzy optymalnym rozdrabnianiem skał a sygnałem akustycznym narzędzia rozdrabniającego. Kryterium optymalizacji jest minimalizacja dostarczonej energii podczas rozdrabniania przy prędkości rozdrabniania z maksymalną efektywnością. Badania przeprowadzono na eksperymentalnym stanowisku badawczym. Opracowany system monitorowania rejestruje następujące parametry: siłę docisku wiertła, obroty narzędzia rozdrabniającego, długość odwiertu, czas, moc, sygnał akustyczny. Podczas eksperymentów użyto czujnika poziomu sygnału akustycznego Mediator 2238. Pomiary te posłużyły do wyznaczenia widm akustycznych procesu rozdrabniania. Przy poszukiwaniu zależności pomiędzy optymalnym sterowaniem prędkością obrotową narzędzia a zestawem widm akustycznych założono minimalną różnicę pomiędzy widmem akustycznym samego wiertła przy jego ruchu jałowym i podczas procesu rozdrabniania, przy jednakowych parametrach eksploatacyjnych. Widmo akustyczne zależy nie tylko od parametrów eksploatacyjnych wiertła, ale także rodzaju rozdrabnianej skały. Ta nowa metoda oparta na opisanej zależności pozwala na sterowanie optymalne maszyną rozdrabiającą wyłącznie na podstawie sygnału akustycznego.

Słowa kluczowe*: wiercenie skał, sygnał akustyczny, wiercenie optymalne*

1. INTRODUCTION

The processes of mineral mining and underground drilling belong to energetically demanding processes. In these processes, the method of rock separation by rotary drilling is widely used. Therefore it is necessary to investigate these processes from the viewpoint of the energy costs reduction.

One of the ways to cut energy costs of rock disintegration is to create a know-how. The common use of optimization requires the measurement of several quantities since we are dealing with multi-parameter optimisation [1]. The aim of the research running from 1999 to 2002 was to reduce the multi-parameter optimization into single-parameter one.

A phenomenon accompanying the process of rock separation through drilling is the creation of noise. And this noise can be the ideal parameter for optimization. Put in other words, based on the measurement of sounds emitted in this process an optimum control of rotary drilling should be achieved. The results of research hinted at the possibility of using the sound emission analysis for rock identification. Rock identification is of double significance. The first one consists in the choice of suitable drilling tool (indentor) for the particular rock. The second one is in improving the geological knowledge (geological map) of rocks.

2. OPTIMIZATION CRITERIA

The aim of analysis was the investigation of objective function on independent variables (force, revolutions) and dependent variable (the acoustic signal).

The optimization criteria are various:

- the maximal lifetime of drilling tool,
- the minimization of specific energy,
- the maximal drilling rate.

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The optimization criteria were formulated as follows:

- the minimization of specific energy

$$w=\int_{\tau}\frac{P(\tau)}{V(\tau)}\cdot d\tau \quad \left[\mathrm{J\cdot m^{-3}}\right] \tag{1}$$

- the maximization of ratio

$$\varphi=\frac{v(\tau)}{w(\tau)} \tag{2}$$

where:

P – performance [W],
V – drilled rock volume [$\mathrm{m^3}$],
w – deformation work [$\mathrm{J\cdot m^{-3}}$],
τ – time [s],
v – average drilling rate [$\mathrm{m\cdot s^{-1}}$].

The optimization criterion (2) is is a complex criterion. From measurements of the thrust, the drilling volume, the drilling rate and performance, the values (1) and (2) can be computed in some time.

Further in the paper we deal only with optimization of rock disintegration from the viewpoint of energy cost minimization.

3. LABORATORY ENVIRONMENT CHARACTERIZATION

The goal of the experiment carried out at the Slovak Academy of Sciences (SAV) laboratory at the trial stand was to determine the effects of changes in the mode of disintegration and of the acoustical behavior of the environment and evaluate these changes in dependence on the optimal mode of disintegration. For these experiments, the Mediator 2238 sound meter of the Brüel Kjaer company has been used.

The research in this field has been made on experimental drilling stand (see Fig. 1).

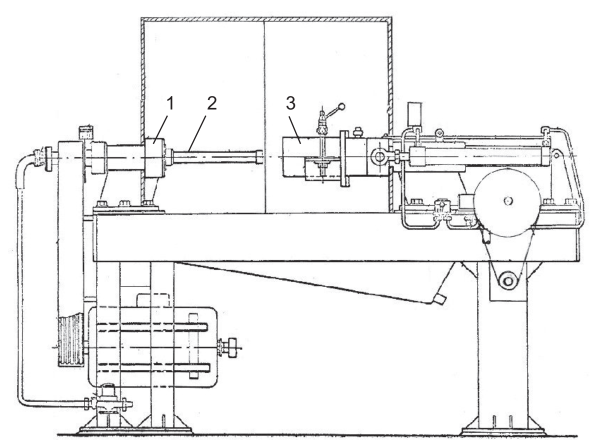

Fig. 1. The scheme experimental drilling stand

The stand is situated in horizontal level. The rock is fixed in the head 3. The drilling tool 2 is fixed in the drilling head 1. The aim of research was to investigate the influences of thrust and revolutions changes at drilling regime.

Our monitoring system has measured following variables:

- thrust of core drill,
- revolutions of drilling head,
- length of drilling,
- time,
- performance,
- acoustic signals.

The monitoring system has been realized by PLC cards and standard PC.

In ordinary cases of closed space it can be assumed that the sound field is a diffusion field. If the sound source is located in the closed space then the waves emitted from the source reflect from the enclosing surfaces. In the enclosed space there is a large difference in acoustic pressure depending on the location the sound meter in part of the remote field, i.e. the region where mutual interaction of the waves propagating directly from source and reflected waves occurs.

Sound meters are widely used in the technology of sound measurement. During the measurement sound levels (A) or acoustic pressure levels are determined at individual measurement points, distributed uniformly along the hypothetical, simply definable surface completely enclosing the measured instrument for which the measurement is taken. A suitable surface can consist of five faces of an imaginary rectangular prism whose dimensions are chosen so that the faces in which the measurement takes place are at most 1 m away from the outline of the machine.

The sound level (A) at the reference distance is a frequent piece of data on the noise level of machines or devices. It can be determined exactly with one of the measurement methods of acoustic output with the weight filter "A" switched on.

In our case the sound meter of the type Mediator 2238 by the Brüel Kjaer company was used.

Based on the measured values of the equivalent sound level A (also average sound level A) it is defined as follows

$$L_{Aeq,T}=10\log\left\{\left(\frac{1}{T}\int_{t1}^{t2}p_A^2(t)\;p_0^{-2}\,dt\right)\right\} \quad [\mathrm{dB}] \tag{3}$$

where:

$L_{Aeq,T}$ – equivalent sound level A, at the reference value 20 μPa, determined in the time interval of measurement;
T = $t2$–$t1$;
p_A – current acoustic pressure of the sound signal, which is frequency-weighted with weight filter A;
p_0 – frequency acoustic pressure 20 μPa.

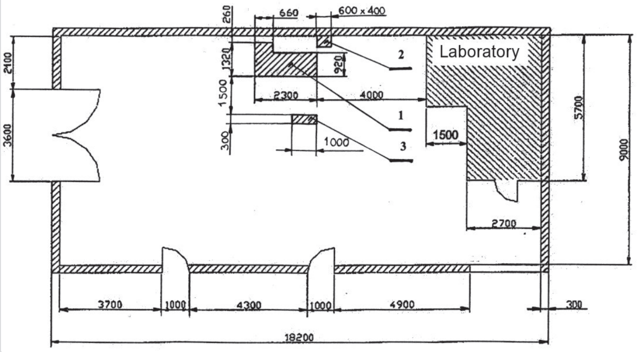

Fig. 2. Ground plan of SAV labs with trial stand:
1 – trial stand, 2 – hydrogenerator, 3 – pump

The measurement was evaluated in octave bands while

$$f=\sqrt{f_d \cdot f_u} \quad \text{[Hz]} \tag{4}$$

where:

f_d – down limit of band frequency,
f_u – upper limit of band frequency.

As seen in the ground plan of the laboratory in Figure 2 the source of noise is not only the trial stand with the driving aggregate and noise generated during interaction of the indentor with rock, but also the hydrogenerator and the pump.

4. ENERGY ASPECTS OF DISINTEGRATION

In the sequel the energy aspects of erosion and disintegration will be considered the starting point for the process of disintegration. From this viewpoint disintegration is a process in which the action of forces overcomes the bonding forces of the building blocks of the material and gives rise to new surfaces. This is the simplest definition of disintegration. Before the disintegration is accomplished, however, the forces acting on the material cause its deformation up to the breaking strength and perform deformation work.

$$W=k_2 \cdot V \quad [\text{J}\cdot\text{m}^{-3}] \tag{5}$$

where:

V – volume of disintegrated rock,
k_2 – constant.

Relation (5) has become the foundation of the so-called energetic strength theory which has a broad applicability in practice in evaluation of the energy costs of the process of rock disintegration.

The larger part of the isintegration energy, according to the current interpretations of this theory, is consumed in the formation of new surfaces of the generated products during disintegration or in plastic deformations. The main part of thed isintegration energy goes into the processes of erosion in the neighboure zone of creation of tension and deformations, i.e. in the contact zone.

Dependence of the instantaneous speed of progress and depth of rock cleaving, on the pressure are identical in character, because of the formula

$$h=\frac{v}{n} \tag{6}$$

where:

n – revolutions [s^{-1}],
h – depth of drilling per one revolution [m],
v – speed [$\text{m}\cdot\text{s}^{-1}$].

The above discussion of separation output and instantaneous speed of separation element movement suggests generally valid properties of specific volume work of rock separation. Its general behaviour in relation to the behavior of instantaneous rate is shown in Figure 3 [2]. Then the working capacity of the separation tool can be defined as

$$\varphi=\frac{v}{w} \tag{7}$$

From the viewpoint of optimization φ should be maximized all along the drilling period.

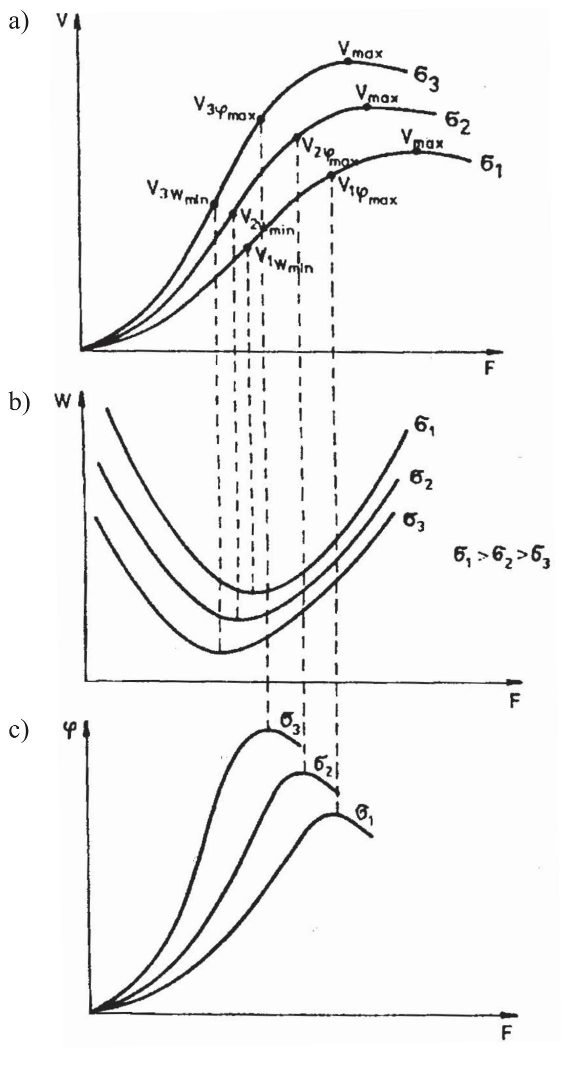

Fig. 3. Dependence of instantaneous drilling rate v (a), the specific volume disintegrated energy w (b) and ratio of these quantities φ (c), on the thrust F

5. THE ANALYSIS OF RESULTS FROM STANDPOINT OF OPTIMIZATION

In Figures 4 and 5 are plots showing the dependence of the working capability of separation tool on the pressure at various modes of separation of andesite and granite and its dependence on thrust. Based on these plots we can determine the value of φ and mutually compare individual working modes of the trial stand at equivalent revolutions and various pressures.

In the plot of Figures 6 and 7 are shown the measured equivalent levels of sound at the drilling of andesite on the frequency at various revolutions (the order of column diagrams in individual octave bands represents the mounting pressure and the dark colour represents improvement in the value of φ). In both cases in the plot of Figures 6 and 7 there is an evident increase in equivalent sound level in the 1000 Hz band. Let us denote this octave band as frequency $f = 1000$ Hz, as representative in andesite separation. Then it follows from both plots that the optimum mode of rock separation (maximum φ) will be at such a pressure and revolutions when the equivalent sound level reaches the maximum value.

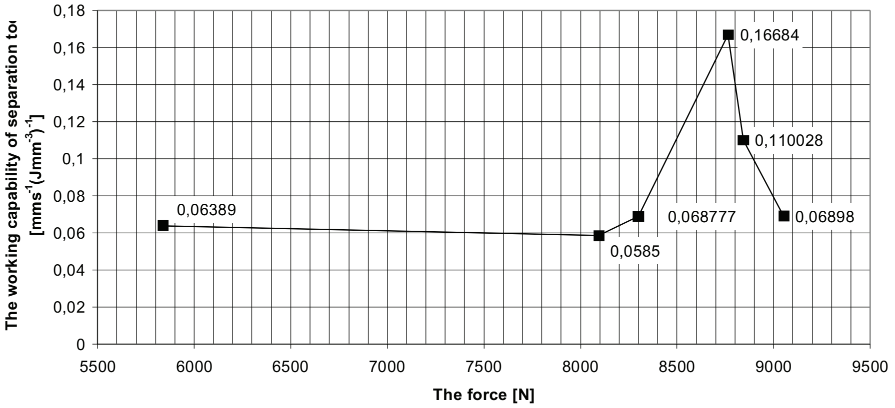

Fig. 4. The dependence of the working capability of separation tool on the thrust at various drilling modes of andesite

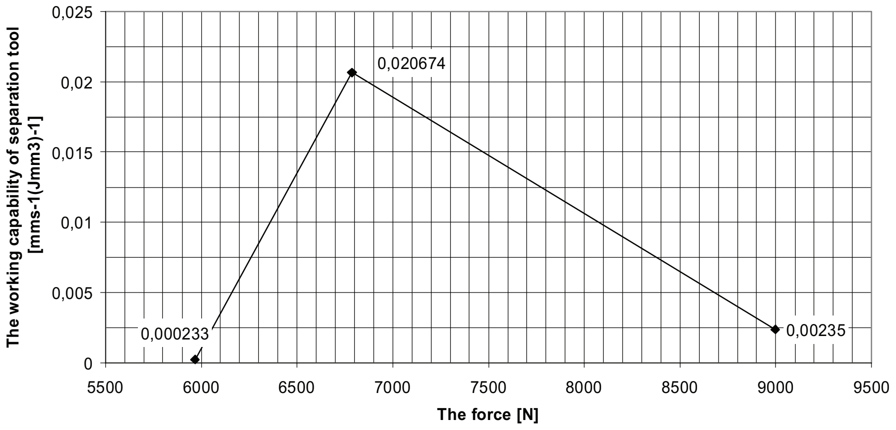

Fig. 5. The dependence of the working capability of separation tool on the thrust at various drilling modes of granite

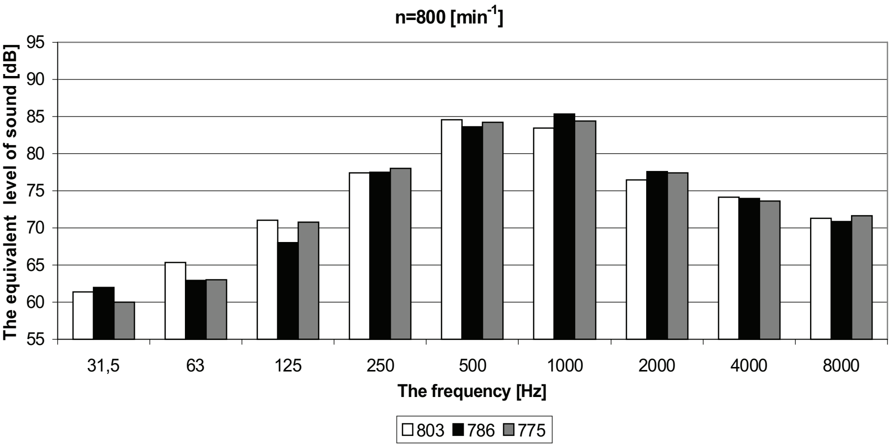

Fig. 6. The dependence of equivalent levels of sound on frequency for disintegration of andesite

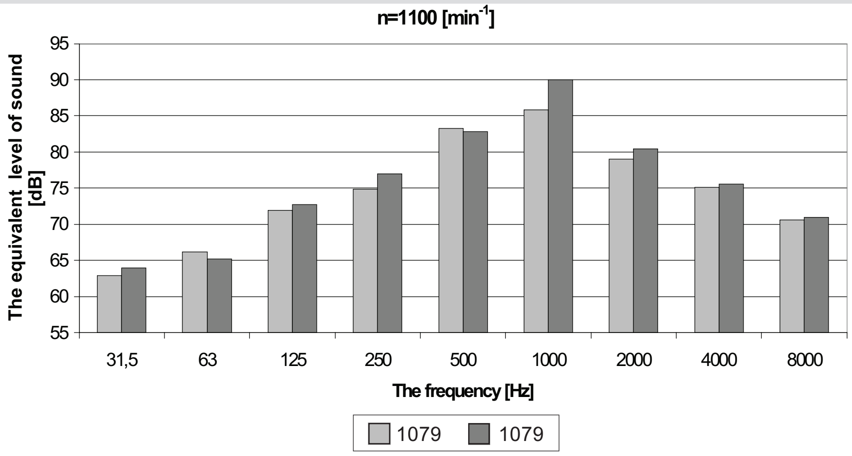

Fig. 7. The dependence of equivalent levels of sound on frequency for disintegration of andesite

Then, for the purpose of optimization, we could extend the representative frequency to the frequency band

$$f \in \langle f_{d1}, f_{u1} \rangle \tag{8}$$

which in our case will be f_{d1}=1000 Hz and f_{u1}=4000 Hz. Considerable increase in equivalent sound level can be observed in Figure 6 also for the bands 31.5 and 63 Hz.

In Figures 8 through 10 are the plots showing the change of equivalent sound level at idle mode and equivalent revolutions in andesite drilling. Their common characteristic is the steady increase of the equivalent sound level in the 1000 Hz band. Dramatic increase of the equivalent sound level for all modes occurs in the 2000 through 4000 Hz bands.

In plots (Figs. 8–10) are compared L_{Aeq} for different pressure forces, revolutions of the stand and various values of the optimization criterion φ corresponding to them. Let us emphasize that the darker the colour of the column the higher is the criterion value φ. The darkest colour of the columns is in plot (Fig. 8). This means that this mode has the maximum value of φ (see Fig. 4), i.e. it is optimal. If we compare Figures 8 and 9 and 10 then the characteristic of the optimum control is as follows: *To achieve the minimum difference between the equivalent sound level at the load and idle modes only at the representative frequency (f = 1000 Hz).*

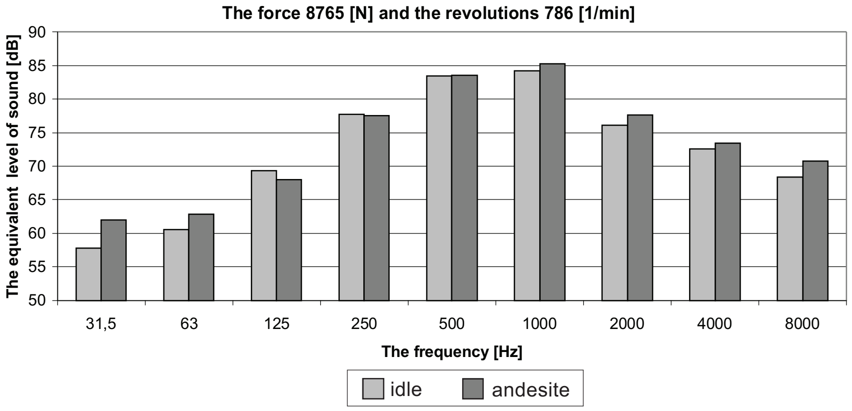

Fig. 8. The comparing of equivalent levels of sound at various frequencies in idle mode and during andesite disintegration

Fig. 9. The comparing of equivalent levels of sound at various frequencies in idle mode and during andesite disintegration

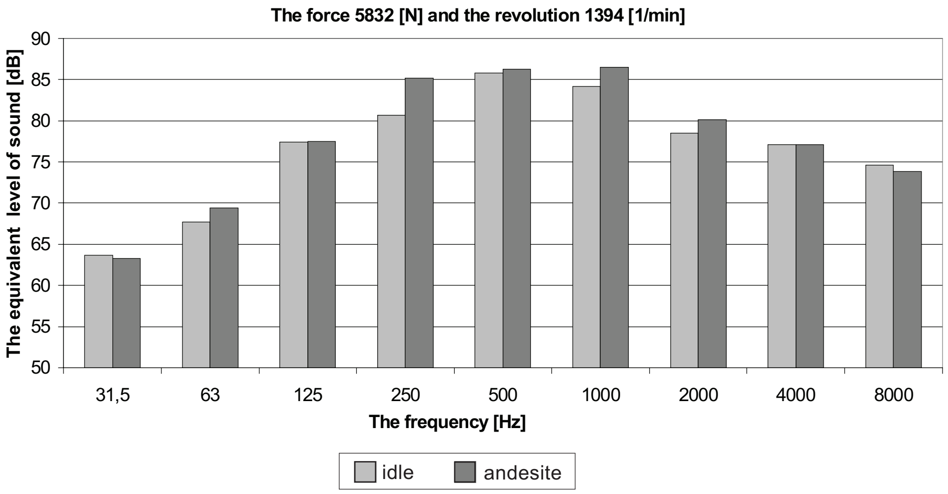

Fig. 10. The comparing of equivalent levels of sound at various frequencies in idle mode and during andesite disintegration

In Figures 11 through 13 are the plots showing the change in equivalent sound level at idle mode and equivalent revolutions in granite drilling. Their common characteristic is a steady increase of equivalent sound level in the 500 Hz band and increase in equivalent sound level for almost all modes in the 2000 through 8000 Hz bands.

From the more detailed analysis of the results analogous qualitative conclusions were drawn as with andesite. The fundamental difference consists in the definition of representative frequency ($f = 500$ Hz), at which (thrust, revolutions) the optimum mode of drilling will be sought, which means finding again the minimum difference L_{Aeq} between the idle and load modes of the drilling machine.

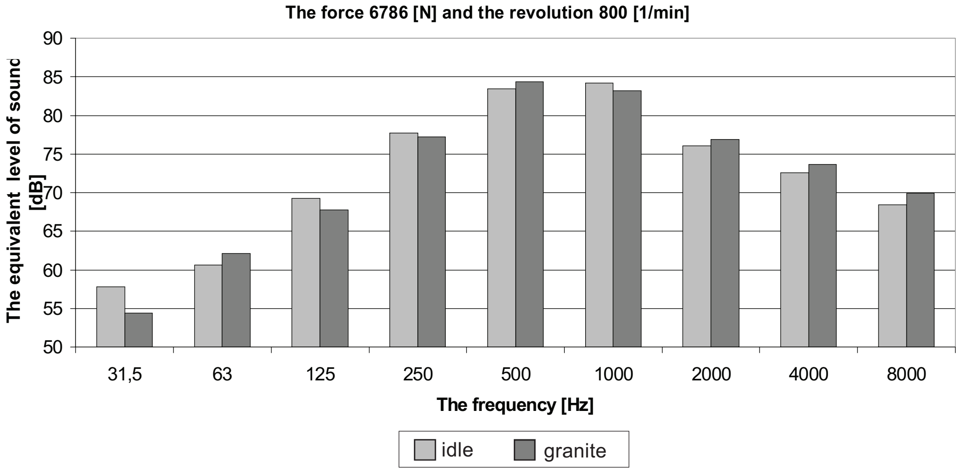

Fig. 11. The comparing of equivalent levels of sound at various frequencies in idle mode and during granite disintegration

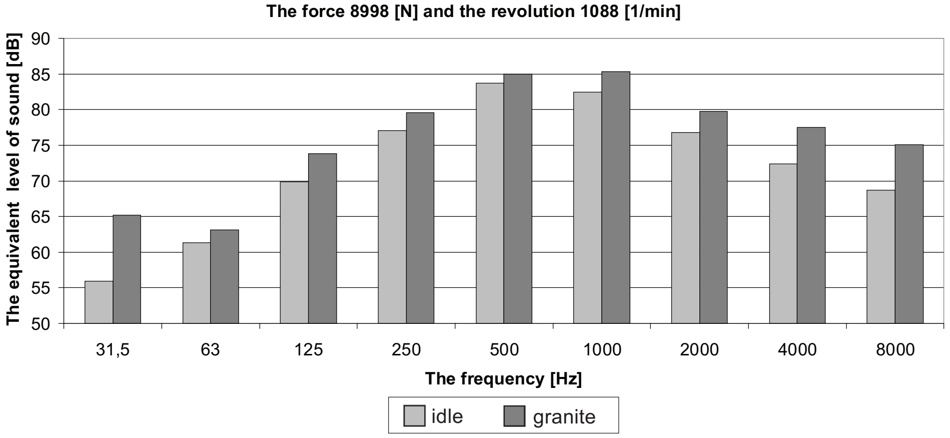

Fig. 12. The comparing of equivalent levels of sound at various frequencies in idle mode and during granite disintegration

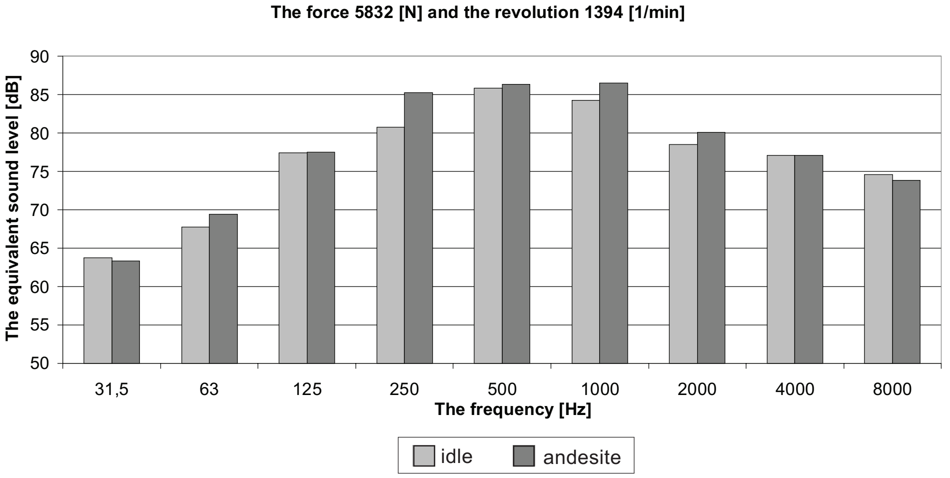

Fig. 13. The comparing of equivalent levels of sound at various frequencies in idle mode and during granite disintegration

The optimal regime can to be determined by following algorithm.

1. To determine the equivalent sound level at idle mode of drilling machine.
2. To determine the equivalent sound level during rock disintegration.
3. The finding of the equivalent sound level $L_{A,eq}$ by changing of drilling regime.
   a) If the difference of $L_{A,eq}$ between first and second step is increasing then the input drilling conditions need to be changed.
   b) If the difference of $L_{A,eq}$ between first and second step is decreasing then continue according the second step.
4. The third step will be repeated until the required accuracy is achieved.

6. CONCLUSIONS

Experimental measurements show the possibilities of utilizing acoustic signals for optimal control drilling machine. Results of research in this field were used for creating of algorithm of optimal control. This algorithm was verified in laboratory. The equivalent level for representative frequency depends also on types rock (see Figs. 8 to 10 and 11 to 13). Therefore $L_{A,eq}$ can be used for identification of rock type.

Acknowledgement

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