Acoustic and physiological effects of the surroundings in rock cutting process

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A noise effect arising in the rock cutting process is gaining a large attention as to the identification and optimization of the cutting process. The sense experience acquired during the experiments in the process of rotary rock drilling related to the determination of rock type or to the optimal drilling regime determination is formed due to sense perception, mainly hearing, and its further evaluation by the human brain from the information exempted from the environment.

Key words: *rock cutting process, processing of acoustic signal, loudness*

Introduction

Noise as an effect arising in the rock cutting process which gains a large attention concerning the identification and optimization of the cutting process. One of basic aspects, i.e. the effect on the human organism, has been, however, omitted in the past. The perception and evaluation of the noise is related to the processing of acoustic signal acting as the information carrier of the interaction between the cutting tool and the rock [2]. The noise affects the human organism: the noise information is perceived and evaluated by human senses, mainly by hearing. Regarding the physiological evaluation of noise, the human evaluation is mostly similar to the noise processing and evaluation using the loudness, or loudness level, derived from the Fechner-Weber law. The law expresses the fact that the total loudness of several tones perceived concurrently equals to the addition of partial loudnessses, which would be caused by partial tones individually. This fact is considered in the calculations [10].

Grounds for the acoustic evaluation

Issues of identification of real process not always appear as an easily feasible task. It is complicated by the conditions and the environment, in which the identification experiment is performed [4, 6]. Such limitations have to be considered in the identification unconditionally and the method and realization of experiment has to be adjusted in order to reach the defined goal and not to spoil the long-term effort and the financial costs spent in the research. The examination of the rock cutting process, or to be more precise - of the indentor-rock system, issued from the measurements performed by the sound level meter Mediator 2238 by Brüel&Kjaer company.

Figures 1 to 3 illustrate the behaviour of equivalent sound pressure level measured by the sound level meter Mediator 2238 during the small-diameter rotary core-drilling of three different rock types, namely andesite, limestone and granite, in various working regimes (points). The graphs show the behaviour of equivalent sound pressure level during the changes of input variables thrust force F and revolutions n entering the indentor-rock system.

The Figure 1 shows 16 working regimes during andesite drilling. The behaviour of the equivalent sound pressure level depending on the increasing thrust force may be described as a linear dependence in the whole working range. The equivalent sound pressure level ranges from 87 to 93,5 dB. The separation of sound pressure levels depending on the level of revolutions applied in the individual experiments is approximately 1,5 dB.

The Figure 2 shows 16 working regimes during the limestone drilling. The behaviour of the equivalent sound pressure level depending on the increasing thrust force may be described again as a linear dependence in the whole working range. The equivalent sound pressure level ranges from 87 to 91,5 dB. The separation of sound pressure levels depending on the level of revolutions applied in the individual experiments is approximately 1 dB.

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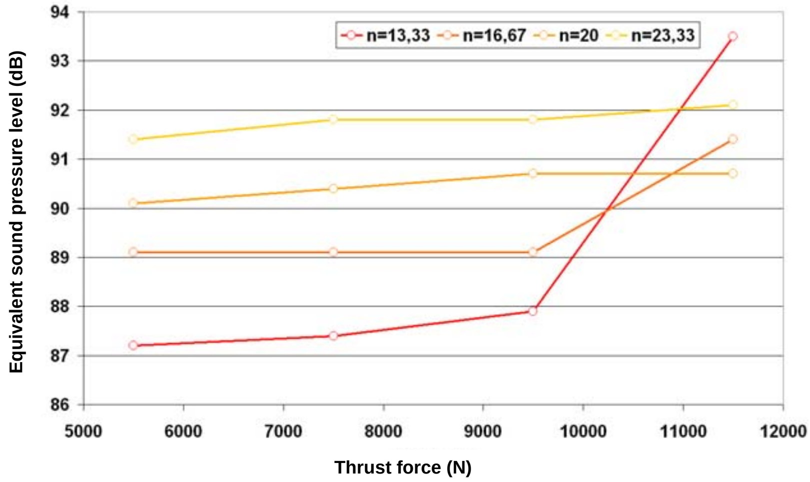

Fig. 1. Behaviour of equivalent sound pressure level in various regimes of andesite drilling.

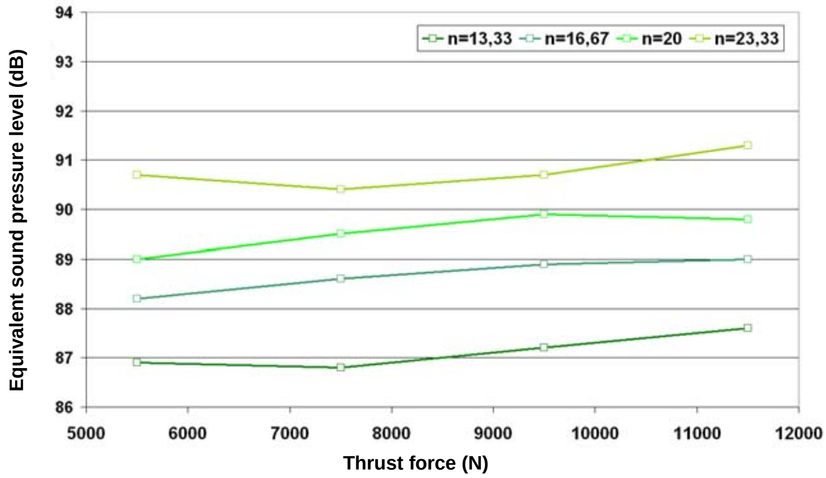

Fig. 2. Behaviour of equivalent sound pressure level in various regimes of limestone drilling.

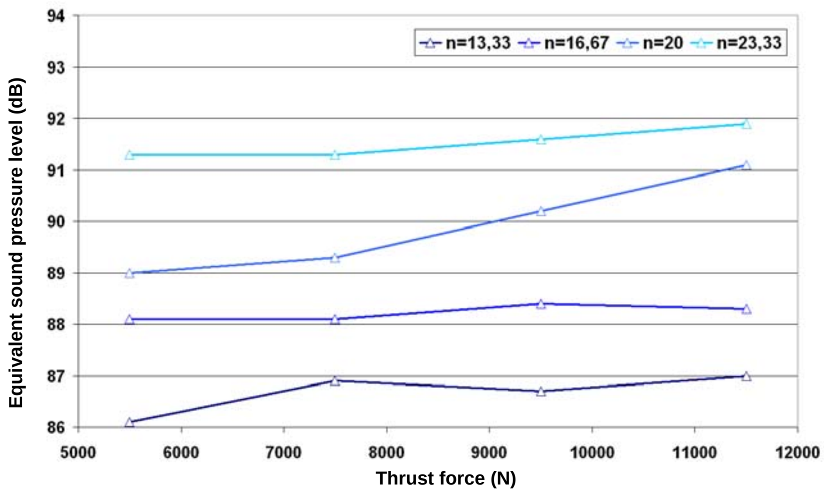

Fig. 3. Behaviour of equivalent sound pressure level in various regimes of granite drilling.

The Figure 3 shows 16 working regimes during the granite drilling. The behaviour of the equivalent sound pressure level depending on the increasing thrust force may be described again as a linear dependence in the whole working range. The equivalent sound pressure level ranges from 86 to 92 dB. The separation of sound pressure levels depending on the level of revolutions applied in the individual experiments ranges from 1,5 to 2 dB.

A summary assessment of the experiments with three different rock types, as presented in Figures 1-3 showed that the equivalent sound pressure level arising in the rock drilling process ranges from 86 to 93,5 dB depending on the thrust force and revolutions; it shows a linear dependence and the separation of individual sound pressure levels depending on the revolutions ranges form 1 to 2 dB.

The acoustic assessment of the measured values proved that the differences between the individuals measuring points (defined by the rock type, thrust force and revolutions) are too small for determining the working regime and the rock type distinction. However, the experience obtained during the experiments [1] outlines that human senses, mainly hearing, is able to provide an information on the system condition in such a range that an experienced researcher is able to determine the type of drilled rock and/or the optimal drilling regime. This proved again that the method of loudness calculation approaches the physiological concept of the cognitive process of hearing.

Method of loudness calculation and evaluation

The loudness is determined on the base of sound pressure levels measured by the sound level meter in octave or one-third octave bands. The selection of bandwidth is derived from the nature of measurement. Calculated value represents a statistical assumption and contains less information than calculated or measured spectrum. Sounds that do not exhibit the frequency discontinuities may be displayed in octave bands; however the sounds containing the discontinuities might require one-third octave analysis in order to be described properly.

Stevens' method was used for the calculations in the first case, Zwicker's method in the second case. Stevens' method is considered as a proper one for the evaluation, as the observed acoustic behaviour of rotary drilling is not exhibiting any major effects of impulse character during the rock drilling process.

The norm STN ISO 532 01 1602 provides the calculation of complex sound using the relevant methods [9]. The procedure was derived based on three assumptions:

1. Function of loudness in sones related to the loudness level in phons.
2. Existence of the system of empirically determined curves of equal loudness for noise bands in the diffuse acoustic field.
3. Rule for determination of total loudness derived from the loudness index in frequency bands.

Presented method determines the total loudness with sufficient accuracy for technical purposes, assuming that the calculation holds for a diffuse acoustic field. The method is designed for the types of wide-band spectrum, more for stable than for varying noise.

Definition of STN ISO 532:

- the sound pressure level (L) is 20log10(p/p_0) dB when p is measured air pressure and p_0 is a reference sound pressure of value $2x10^{-5}Nm^{-2}$,
- sound pressure level in the band correspond to the part of measured spectrum (octave),
- loudness in sones, i.e. numerical value of the sound source abundance proportional to its subjective volume assessed by human listeners. One sone is a sound loudness with loudness level of 40 phons, defined as the loudness level of a 1 kHz tone at 40 dB of sound pressure level,
- loudness index is a number determined from geometric mean frequency and sound pressure level in octave band using the curves constructed according to STN ISO 532 [9],
- calculation of loudness is defined by the equation (1) by following procedure:

1. Loudness index of each octave band is determined after definition of geometric mean frequency of each octave band according to the table or graph defined in the norm STN ISO 532.
2. Total loudness is then calculated using the formula:

$$S_t = S_m + F\left(\sum S - S_m\right) \tag{1}$$

where S is total loudness in sones, S_m is the highest loudness index, $\sum S$ is sum of loudness indexes from all octave bands, F=0,3 for octave bands.

Loudness for several working regimes presented in the Fig. 1 – 3 was calculated using the presented procedure and the results are shown in the Fig. 4.

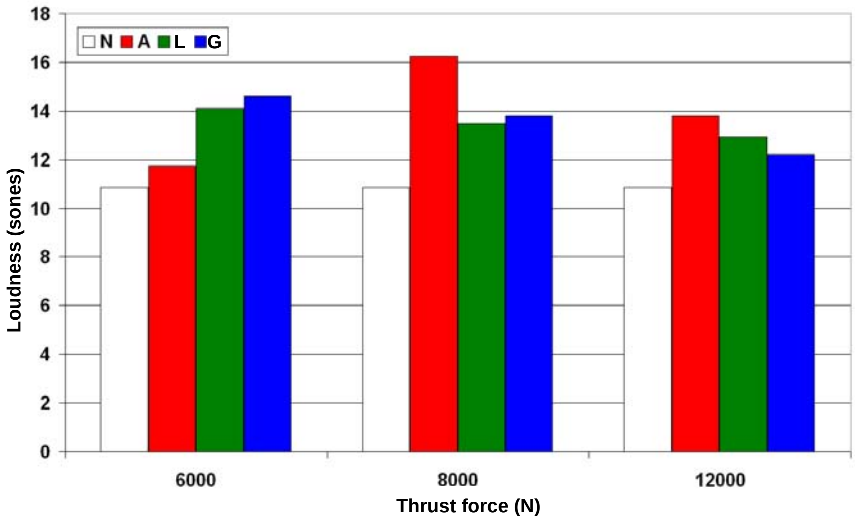

Fig. 4. Loudness of rotary drilling of andesite A, limestone L and granite G in nominal thrust force and revolutions n=16 s^{-1} and in idle run N n=15 s^{-1}.

Figure 4 illustrates also the idle run N of drilling device in order to provide the comparison of other regimes with the reference loudness level. Graphs show that loudness ranges from 10 to 17 sones and the differences in loudness between the individual regimes are only minor ones. The graphs show also the change of loudness depending on the thrust force while keeping the revolutions constant. This evaluation method of considers the composition of measured octave spectrum shown in the behaviour of loudness in individual working regimes. Evaluated results however show contradictory trends. While in rotary drilling of limestone and granite the loudness decreases with the increasing thrust force, the andesite drilling caused an increase in the area of lower thrust force and the decrease in higher applied thrust force. We do not assume an explicit behaviour of loudness in rock drilling win individual regimes due to used algorithm of its calculation.

Similarly, the Figure 5 shows loudness behaviour depending on the thrust force, compared to the specific drilling energy [3], [5], [7], [8].

Analysis of the behaviour did not show an explicit relation of the values of independent variable thrust force and dependent variable loudness. The use of sound pressure level in octave bands represented by loudness is not suitable for identification of the system indentor-rock. Due to small number of experiments in the one-third octave band analysis, the loudness was not calculated and evaluated using the Zwicker's method [9].

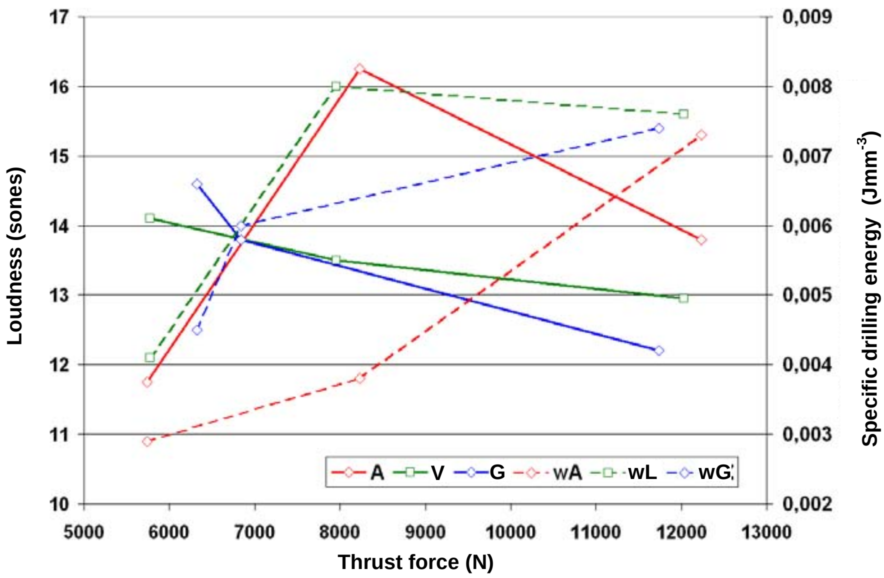

Fig. 5. Behaviour of loudness and specific drilling energy in rotary drilling of andesite A,wA, limestole L, wL and granite G, wG during various regimes.

Conclusion

The noise approaching or crossing the sound pressure level $L_{eq} = 85\,\mathrm{dB}(\mathrm{A})$ is considered as harmful for humans. Regarding this fact, the noise arising in the rock drilling process at the experimental drilling stand of Institute of Geotechnics SAS in Košice is above the limits in the observed technological area (Fig. 1-3). The sense experience acquired during the experiments in the rock drilling process related to the inverse determination of rock type or to the optimal drilling regime determination is formed due to the sense perception (mainly hearing) and its further evaluation by human brain from the information exempted from the environment. This fact is outlined in the results (Fig. 4) where different rock types show antagonistic behaviour, while the evaluation of measurement using the loudness considers the subjectivity of perception related to the physical variable.

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