Selected characteristics of vibration signal at a minimal energy consumption for the rock disintegration

Viera Miklúšová[1]

The rock disintegration process involves the action of disintegrating tool, resulting in the formation of forced mechanical oscillations of all components, i.e. the disintegration device, tool and the rock. The vibration signal scanned during the process depends on all of the presented components, on their properties and on the regime parameters. The paper presents relations of the vibration signal characteristics, effective values of the acceleration of vibration oscillations and dominant frequencies, and the energy consumption needed for the rock disintegration, which is characterized by a specific disintegration energy. Presented results were acquired as a part of laboratory experimental research on the rotary drilling of rocks.

Key words: *vibration signal, rock, rotary drilling, specific energy.*

Introduction

The Department of destructional and constructional geotechnics at the Institute of Geotechnics of Slovak Academy of Sciences in Košice focuses on the research of rock disintegration by rotary drilling, which is a technology widely used in the mineral exploitation and underground constructions.

The issues of affecting the rock drilling process by controlling the regime parameters and later by the use of the acoustic signal arising in the process, were investigated in recent years, (Miklúšová et al. 2004, Futó et al. 2008). Current research tasks focus on the implementation of the vibration signal into the control of the disintegration process.

Vibrations represent the forced vibrations arising in the rock disintegration process due to the action of the drilling tool on the rock, which induces the vibrations of all components acting in the disintegration, i.e. the disintegration device, tool and the rock. The vibration signal is thus the response of all the components of the disintegration process, their condition, properties and regime parameters, (Miklúšová 2009, Miklúšová et al. 2009, Miklúšová 2010).

Research goals and methods

The main goal of the research is the investigation of behaviour of the vibration signal in the rock disintegration by rotary drilling and the implementation of the vibration signal into the control of the disintegration process. It is essential to know what and how it affects the vibration signal in the rock disintegration, to assess the change of vibration signal characteristics depending on the variables defining the disintegration process or the characteristics of the drilling tool and characteristics of the rock, i.e. to specify the patterns of such relations. This requires scanning, processing and investigating the characteristics of the vibration signal and other variables entering the drilling process.

The experimental research of the rock disintegration process by rotary drilling focused on the vibration signal is performed in laboratory conditions.

There are several analytic methods for assessing the issues of rock disintegration, which explain the disintegration mechanisms of solids by a simplified model of the problem, or use the drilling devices that enable to acquire the information on disintegration patterns by imitating the drilling process Dvornikov, Dončenko, Alimov, Frolov, Sekula et al., (Sekula 1979).

A model device - laboratory stand, adjusted for the imitation of rock disintegration by rotary drilling is used in the experimental research. The laboratory stand enables rotary drilling of rock samples with small-diameter drilling bits used commercially, up to the 75 mm diameter.

The laboratory stand is equipped with a conventional monitoring system of drilling process as well as with piezoelectric transducers for the vibration signal acceleration. The outputs of conventional monitoring system (thrust p, performance P, tool revolutions n, penetration depth of tool h and drilling time t) together with other data provide the calculation of the thrust force F, drilling rate v and the specific disintegration energy w.

Piezoelectric transducers of acceleration AC102-1A by the CTC company measure the vibration signal in three orthogonal directions x, y, z in the range 0.5-15000 Hz with the resonance frequency of transducer

[1] *Mgr. Viera Miklúšová, PhD.*, Institute of Geotechnics of the Slovak Academy of Sciences, Watsonova 45, 043 53 Košice, Slovak Republic, tel.: (+421) 55 7922639, miklusv@saske.sk

23000 Hz. The x-direction is identical with the drilling direction; z-direction is orthogonal to x and lies in a horizontal plane. The transducers are fixed mechanically on the frame of the drilling stand. Recorded vibration signal from transducers is processed by an on-line monitoring system of vibrations ADASH 3900 II and subsequently evaluated by a computer in both time and frequency domains.

Evaluation of the vibration signal in time domain provides the acceleration of mechanical oscillations a depending on time, in all three scanned directions x, y, z. Effective values of acceleration evaluated from time outcomes of the signal in relevant directions x, y, z are denoted as ax, ay, az, respectively. Vibration signal processing in the frequency domain results in frequency spectra, which enables to determine the dominant frequencies f for individual directions x, y, z (denoted as fx, fy, fz).

Scanned acceleration of vibration signal a does not only reflect the rock disintegration process itself. The transducer measures the acceleration of oscillating motion of drilling device also in its idle run, i.e. with no contact between the drilling tool and the rock. Oscillating motion is induced by operating aggregates: direct current motor drive and hydrogenerator, which both provide thrust and revolutions required for the disintegration, and by the pump of flushing fluid securing the removal of crushed rock from under the tool. Elimination of the oscillating motion in the idle run is not feasible, but there is an effort to keep the vibrations at constant level, e.g. by the use of the constant volume of flushing fluid.

Rock disintegration process is affectable and controllable by changing its input regime variables according the requirements on the output, whether it is a demand for maximal advance rate or for minimal consumed energy, or another demand for process optimization, as these output variables depend on the input variables.

The main interest was focused on the optimization of rock disintegration process regarding the achieving minimal consumed energy for rock disintegration. The evaluation was concentrated on the specific disintegration energy w, which represents the amount of energy consumed for the disintegration of a unit volume of rock, (Miklúšová, 1989).

Specific disintegration energy w is determined from known data on tool geometry according to the formula

$$w = \frac{P}{S\,\frac{h}{t}}, \quad [\mathrm{J\ m^{-3}}] \tag{1}$$

where:

P – performance [J s^{-1}],
S – cross section of the borehole [m^2],
h – tool penetration depth in the rock [m],
t – drilling time [s].

Ratio h/t in the formula (1) represents the drilling rate v.

Three different rock types were used in the experiments on the laboratory stand: andesite samples from Ruskov, granite from Hnilec and limestone from Včeláre. A diamond-impregnated core-drilling bit with 6 flushing channels of 46 mm diameter was used as a disintegrating tool in the experiments. Rotary drilling was performed in constant regimes, keeping the constant levels of revolutions at n = 500 min^{-1}, 1000 min^{-1} and 2000 min^{-1}, and thrust force F = 4 500 N, 7 500 N, 9 500 N, 11 500 N a 13 000 N.

Experimental results and discussion

Analysis of a large number of results from rock drilling experiments in the previous research proved that the specific disintegration energy w shows a minimum in a certain range depending on the regime parameters thrust force F and revolutions n, (Sekula, 1979, Miklúšová et al. 2008).

Three areas are distinguished in the rock disintegration process in the whole range of regime parameters of thrust force F and revolutions n, representing three modes of disintegration:

- surface-abrasion disintegration mode – low thrust force F, low revolutions n, very high energy consumption,
- volume mode of disintegration – drilling rate v increases directly with the thrust force F, specific disintegration energy w reaches its lowest values,
- secondary disintegration – increasing of the values of regime parameters brings a certain attenuation in drilling rate v increase due to insufficient transport of disintegrated products from under the drilling bit, which causes secondary disintegration of the rock resulting in higher demands for energy.

The optimal disintegration regarding the energy consumption occurs in the volume mode of disintegration, where the specific disintegration energy *w* exhibits its minimum. The minimum of energy is related to certain values of thrust force *F* and revolutions *n* representing the most proper regime of disintegration for given rock type concerning the minimization of energy demands of the rock disintegration process by a given drilling tool. It is obvious that if the energy demands in disintegration process should be decreased, the regime parameters should be as close as possible to the parameters assuring the minimum of specific disintegration energy w_{min}. Thence the minimum of specific disintegration energy w_{min} serves as an optimization parameter in disintegration process.

Specific disintegration energy *w* is a response of the properties of disintegrated rock and of the drilling tool applied in the disintegration process. The same diamond-impregnated core-drilling bit was used in all experiments in order to eliminate its effect. Figure 1 shows the behaviour of specific disintegration energy *w* depending on the thrust force *F* in drilling of various rock types for three different levels of applied revolutions.

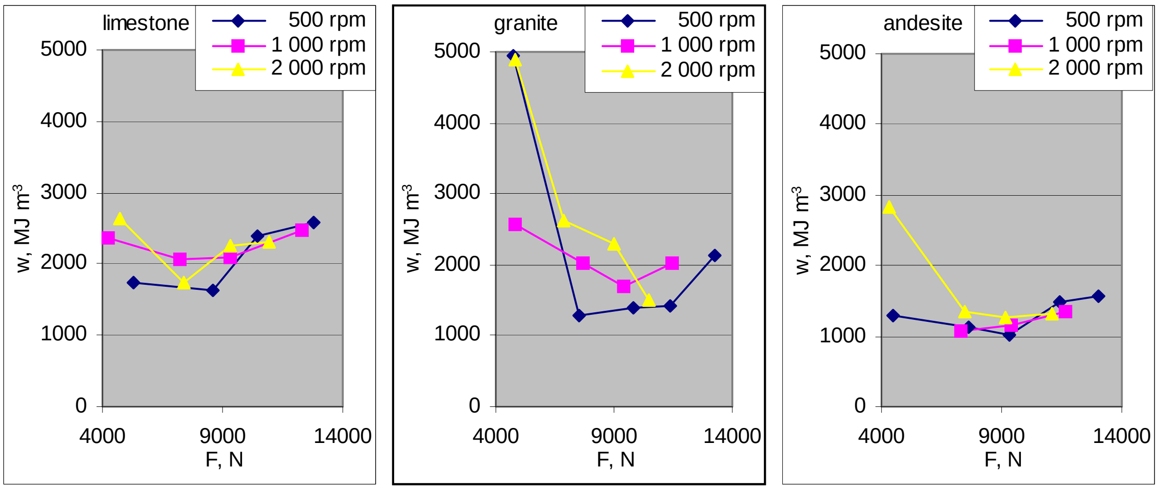

Fig. 1. Dependence of specific disintegration energy w on thrust force F.

The Figure 1 shows the mentioned area of volume disintegration, represented as an interval of values of thrust force *F*, where the specific disintegration energy *w* reaches its lowest values. It is obvious that reached minimal values of specific disintegration energy differ for individual rock types, which means that the minimum of specific disintegration energy w_{min} depends on the rock properties.

Figure 2 illustrates the minimum of specific disintegration energy w_{min} of individual rock types depending on the reduced indentation strength σ_{red} as one of the rock properties characterizing them in the disintegration.

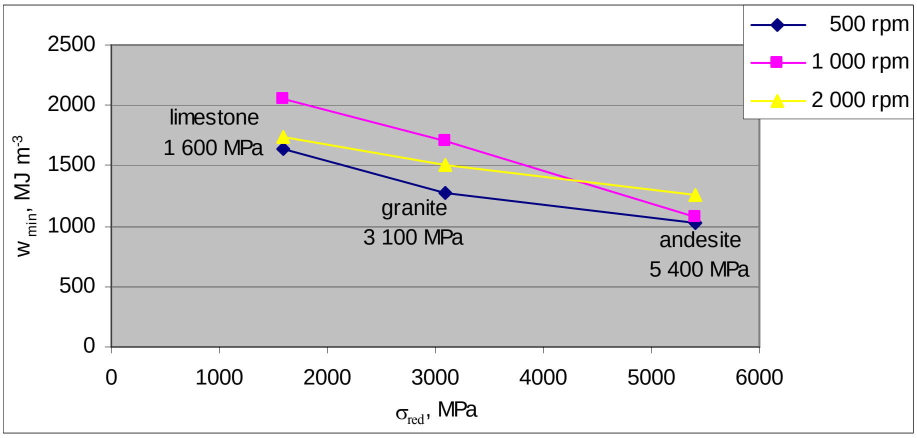

Fig. 2. Dependence of the minimum of specific disintegration energy w_{min} on the reduced indentation strength σ_{red} for three different levels of revolutions applied in the drilling process.

Dependencies in the figure 2 show a decreasing trend, which means that in rock drilling in the area of volume disintegration less energy is consumed for disintegration of rocks with higher values of reduced indentation strength σ_{red}.

Focusing on the research goal (implementation of vibration signal into the control of rock disintegration process), it is necessary to know the behaviour of vibration signal depending on the regime parameters concerning the observed optimization of rock disintegration process, when the minimum energy is required for rock disintegration.

Figures 3 and 4 illustrate the dependence of specific disintegration energy *w* with the vibration signal.

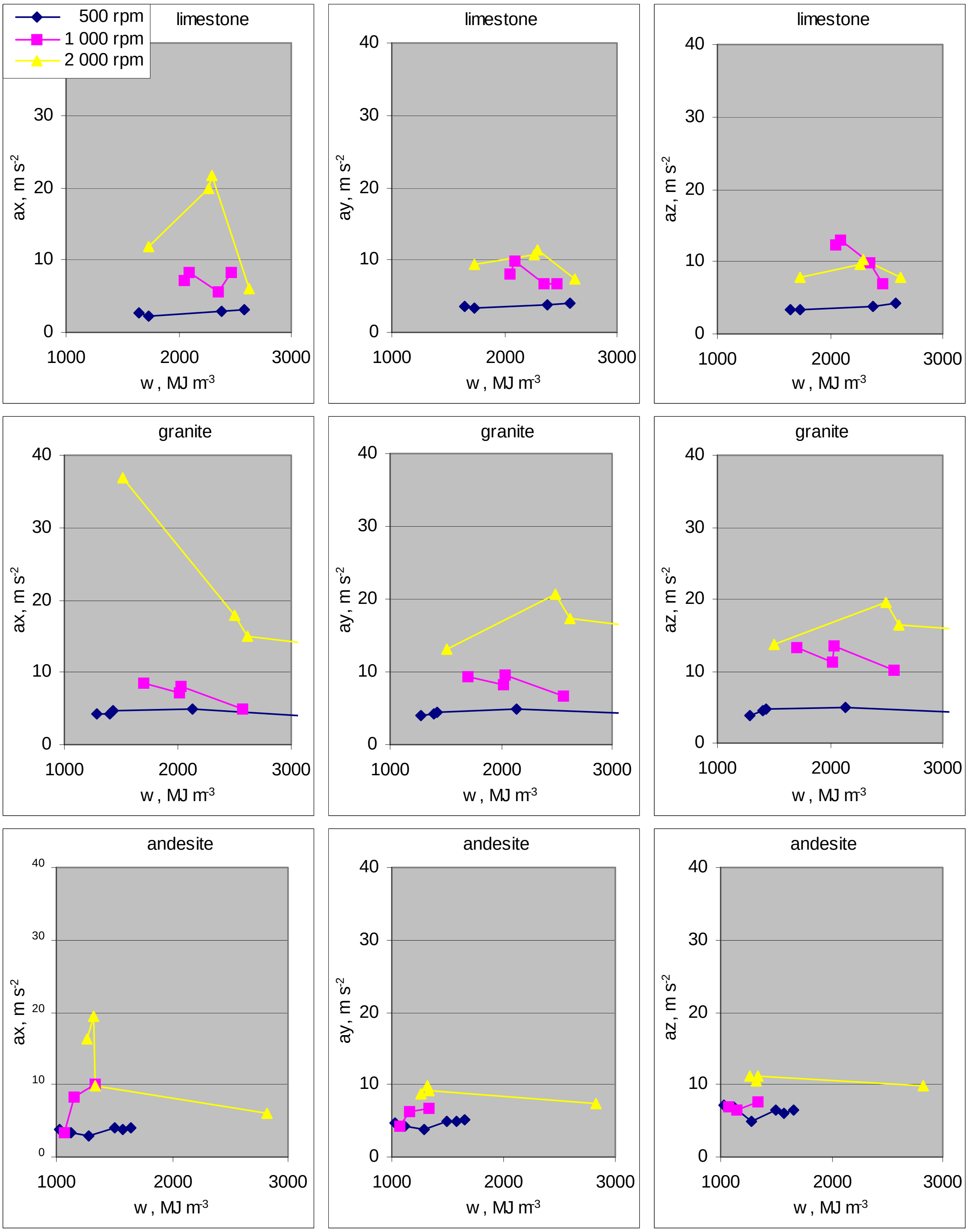

Fig. 3. Dependencies of effective values of acceleration of vibration signal ax, ay, az on specific disintegration energy w.

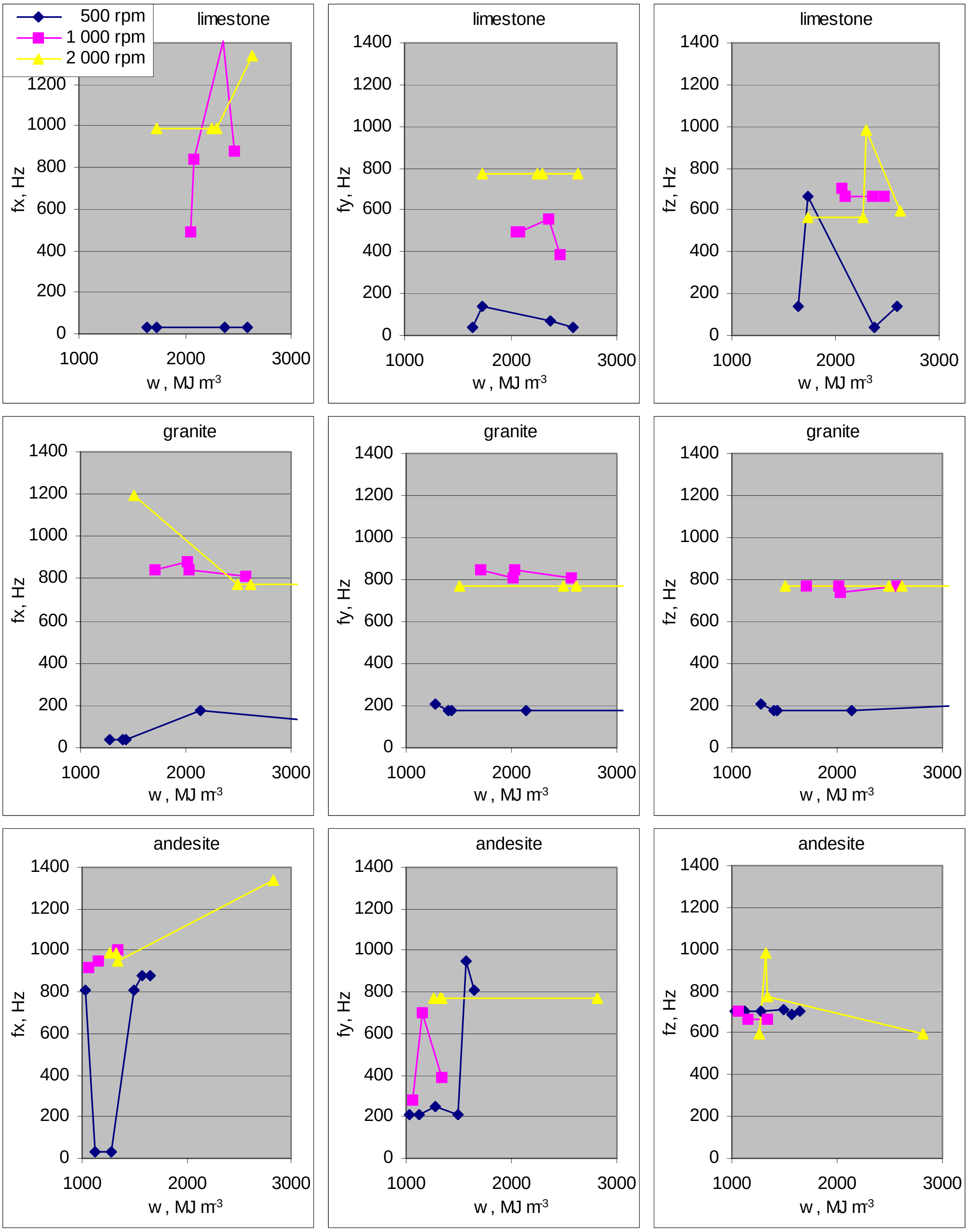

Fig. 4. Dependencies of dominant frequencies of vibration signal fx, fy, fz on specific disintegration energy w.

Figures 3 and 4 illustrate the behaviour of *ax*, *ay*, *az* and *fx*, *fy*, *fz* depending on specific disintegration energy *w*. The dependencies do not exhibit an explicit trend.

Comparisons of effective values of acceleration *ax*, *ay*, *az* in the figure 3 show that the individual curves *ay* and *az* show similar characters and their values are principally comparable, and *ax* show higher values.

Values of acceleration *ax*, *ay*, *az* are equal in drilling with applied revolutions n = 500 min^{-1}, or differ only slightly in andesite drilling (*az* > *ay* > *ax*). Higher applied revolutions n = 1 000 min^{-1} induce higher vibration acceleration, with *az* > *ay* > *ax*. Revolutions n = 2 000 min^{-1} show also higher values of vibration acceleration, however *ax* > *az* > *ay*.

This means that the increase of revolutions *n* induces the increase of effective values of vibration acceleration in all three observed directions. The vibration acceleration in the direction perpendicular to the drilling direction increases as the first one and in further increase of revolutions, the acceleration in the drilling direction prevails. The fact that $az > ay$ is given by the construction of the drilling stand, i.e. the experimental laboratory stand is fixed on the floor and the drilling tool is confined against vertical oscillations by the limiting grooves on the fixing cylinder. Highest applied revolutions during the experiments result in the dominant vibrations in the direction of drilling. Vibration signal depending on the regime parameters was analysed in more details in lit (Miklúšová et al. 2009).

Previous investigation showed that the dominant frequencies attained usually discrete levels of their values during the experiments with applied regime parameters. Higher thrust force *F* and higher revolutions *n* result in higher values of dominant frequencies, which range in similar limits for all used rock types.

This has to be taken into account in assessment of the behaviour in the figure 4 documenting that the revolutions $n = 500\ \text{min}^{-1}$ result in $fz > fy > fx$, revolutions $n = 1\ 000\ \text{min}^{-1}$ in $fx > fz > fy$, and revolutions $n = 2\ 000\ \text{min}^{-1}$ in $fx > fy = fz$.

The trends are not clear, dominant frequencies of vibration signal increase with the increasing revolutions, with maximal values occurring in the direction of drilling.

The dependencies in the figures 3 and 4 do not provide an explicit determination of vibration signal characteristics in order to secure the minimum energy consumption for rock disintegration.

Experience from previous experiments showed that the drilling rate *v* increases with higher values of regime parameters. In case of need for reaching high drilling rates *v*, higher revolutions *n* of the drilling tool should be set, which would reflect in the highest obtained values of effective acceleration *ax* and dominant frequencies *fx*.

The presented issues are complicated due to the distinction of rock materials. The properties of disintegrated rock vibration signal reflect in specific disintegration energy *w* and in vibration signal as well, as shown in Fig. 5.

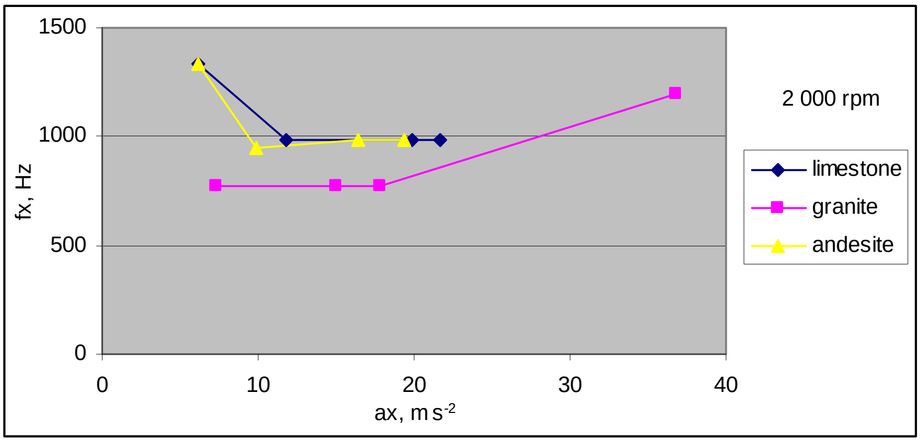

Fig. 5. Dependencies of characteristics of the vibration signal in the drilling direction for individual rock types.

The Figure 5 illustrated that the character of presented dependencies is similar for andesite and limestone, but granite does not fit into such trend. Drilled rocks were divided into two groups concerning the induced vibration signal. This is valid also for the directions y and z, even if the trends differ in these directions.

Conclusions

The main research task is to utilize the vibration signal in the control of disintegration process without the need of additional scanning of the thrust force *F* and revolutions *n*. Results obtained so far show that the vibration signal responded to the change in the drilling regime, to the change of rock type and also reflects the change of drilling tool.

Recent results have outlined that the determination of the area of optimal rock disintegration regarding the energy demands could be possible even without the scanning of regime parameters, as relatively explicit dependencies can be found between the vibration signal and regime parameters of disintegration process, (Miklúšová 2010).

Explicit findings for the values of vibration signal characteristics in the area of minimal specific disintegration energy were expected in order to enable the optimization of drilling process requiring the minimization of its energy demands. As the results did not prove such findings within the boundaries of investigated regime variables, the universal recommendations for all rocks tested in experiments were not achieved, and deductions have to be made for every rock material individually. The particular rock types will be probably divided into several groups according to the character of vibration signal they induce.

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