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RESEARCH REVIEW OF THE INFLUENCE OF MILLISECOND DELAY ON INTENSITY AND STRUCTURE OF VIBRATIONS INDUCED WITH BLASTING WORKS IN POLISH STRIP MINES

1. Introduction

Blasting works conducted in strip mines of raw rock materials means blasting masses of explosives in order to get the required mine run of required granulation. As a result of MW detonation, a substantial quantity of energy is propagated inside the rock mass, which results in a specified level of vibration intensity which can be recorded in the surrounding rock mass. In most research concerning the constraint of para-seismic vibrations', the mass of explosive charge sused and the distance from the protected objects are taken into consideration. The remaining factors (e.g., geological structure, the used system of initiation and quantity of millisecond delay etc.) are generally difficult to define; therefore their influence is analyzed in given local conditions. A very important element of the research is to read only the parameters of the blasting works conducted towards the epicenter, where the vibrations are propagated, so as to decrease vibration interactions with local constructed building objects.

Since the possibility arose of delaying charge detonations, research into the influence of time quantity among explosives on the effect of blasting works began back in the 40s and 50s, and as a result of research work conducted in the USA, millisecond blasting was regarded as a form of blasting work engineering, decreasing vibrations, and enabling the required mine run break-up [1, 2]

In Poland, there were also numerous researches on the influence of millisecond delay on intensity and frequency of structure vibrations induced by blasting works in strip mines.

2. The systems used for blasting explosives

The development of blasting charge explosives has been aimed at working on more precise methods of inducing delays, enlarging the possibilities of delay method choice and increasing security by minimizing the danger of misfire occurrence. Electric millisecond

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firing was gradually replaced with a safer non-electric systems (more and more commonly used in Polish strip mining), and an electronic version, which has an even greater accuracy of delay.

Before non-electrical systems were introduced to the Polish market, attempts had been made to eliminate the shortcomings of electrical systems, such as poor accuracy of delay and limited quantity, by making use of a millisecond blaster machine as the source of induction. In the mid-1970s, in the Shooting Engineering Department of The Strip Mining Institute at AGH, research on the millisecond blaster machine was conducted. The result of the work was a prototype of the *ZT-480t* blaster machine [3], with which practical experience was gained. A completely new design was the Explo 201 blaster machine for mining plants. That blaster machine enabled the possibility of detonating up to 60 detonators (depending on the detonator class, type and length of detonator) with a delay 0–99 ms every 1 ms (Fig. 1) [4].

Fig. 1. Millisecond blaster machine EXPLO-201 [4]

It was successfully used in strip mines until 1997, when the non-electric system was introduced. Afterwards, further research on improvement of this blaster machine and its possibilities came to an end.

3. Researches conducted in Poland

The first findings can be found in the scientific work [5–8], whose authors notice that delay time depends on many factors, and then they present nomograms of delay dependence on burden (Fig. 2) and rock firmness (Fig. 3).

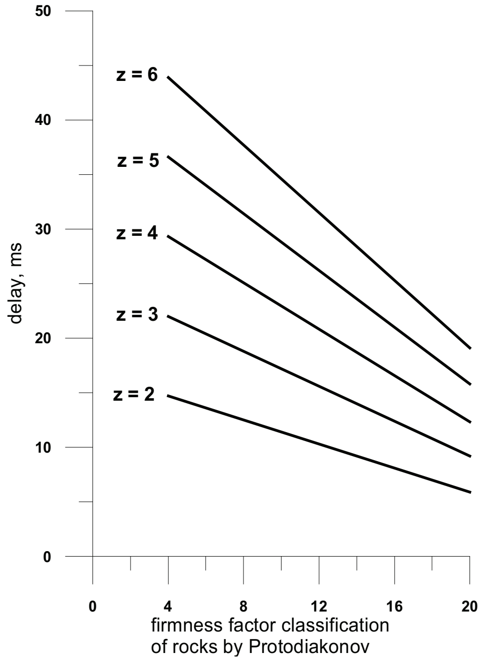


Fig. 2. Delay dependence on rock firmness for different burden [5]

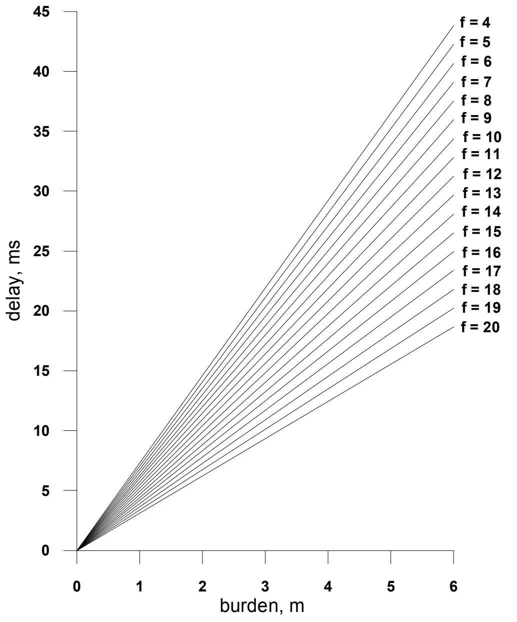


Fig. 3. Delay dependence on burden for different types of rock firmness [5]

In these scientific works, particular attention was paid to the lack of possibilities to change the delay rate in a wider range than multiples of 25 ms, which resulted from technical possibilities of the electric system.

In the years 1987–1990, research was conducted [9], in several strip mines of different raw materials, with using millisecond blaster machine *ZT-480t*, and then, from 1996 with millisecond blaster machine EXPLO-201.

Several experimental series were blasted, proving moderately stable, for exploitation blasting work, parameters of shooting blast hole networks and the explosives used combined with the delay rate and the total in a series. Only the delay from the interval 0–150 ms was changed. As a result of the research conducted in a gypsum mine, using the *ZT-480t* blaster machine, it was found that the bigger the delay, the smaller the vibration amplitude, the longer the pulse duration until the delimitation of a complete cycle of vibration (Fig. 4 and 5) [9]. A similar statement can be found in the research [10], where the results of research on limestone deposits, in which: 5, 10, 15, 20, 25, 30, 40, 50 and 60 ms delays were used. Due to the level of recorded vibrations, the most beneficial proved to be 60 ms, but due to worsening of the degree of fineness, a delay 40 ms was chosen.

In the case of it being impossible to lower the vibration intensity by using shorter delay times, obtained from individual explosive, the intensity of recorded vibrations can be kept on the level of individual explosive by using long delay time emitting pulse (Fig. 4 and 5).

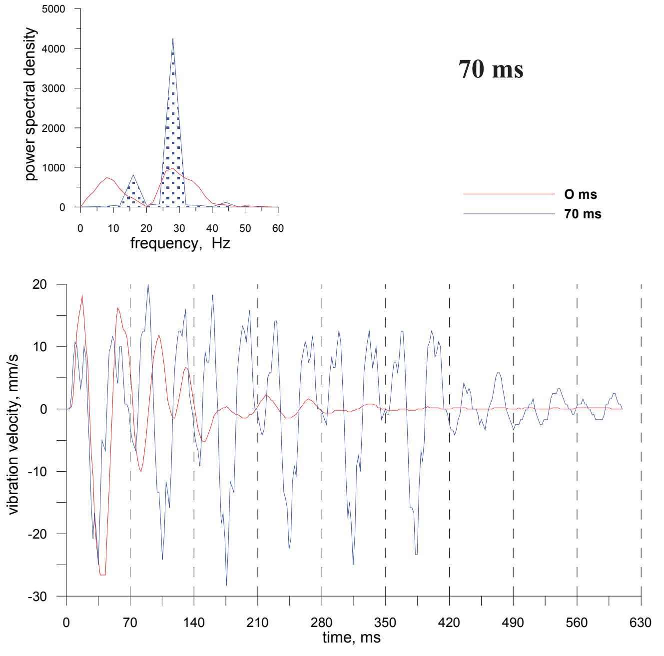


Fig. 4. Partial emission of pulse with used delay 70 ms

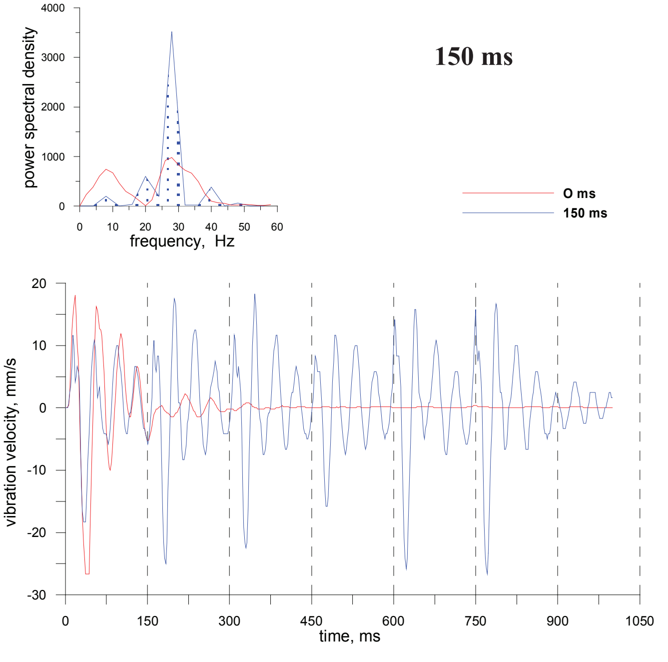


Fig. 5. Total emission of pulse with used delay 150 ms

It is seen in Figures 4 and 5 how the recorded pulse from the blasting of individual explosives can be partially or totally separated from the signal of the series of 6 holes blast with delays 70 and 150 ms. It is simultaneously noted that in both cases the structure of the frequency of vibrations had not changed, and the dominant frequency maintains within the limits of 30 Hz.

Winzer and Biessikirski [11] present the research results obtained in the gypsum mine, on the basis of which, it was found out that a poorly chosen delay can cause an intensification of recorded vibrations (Fig. 6).

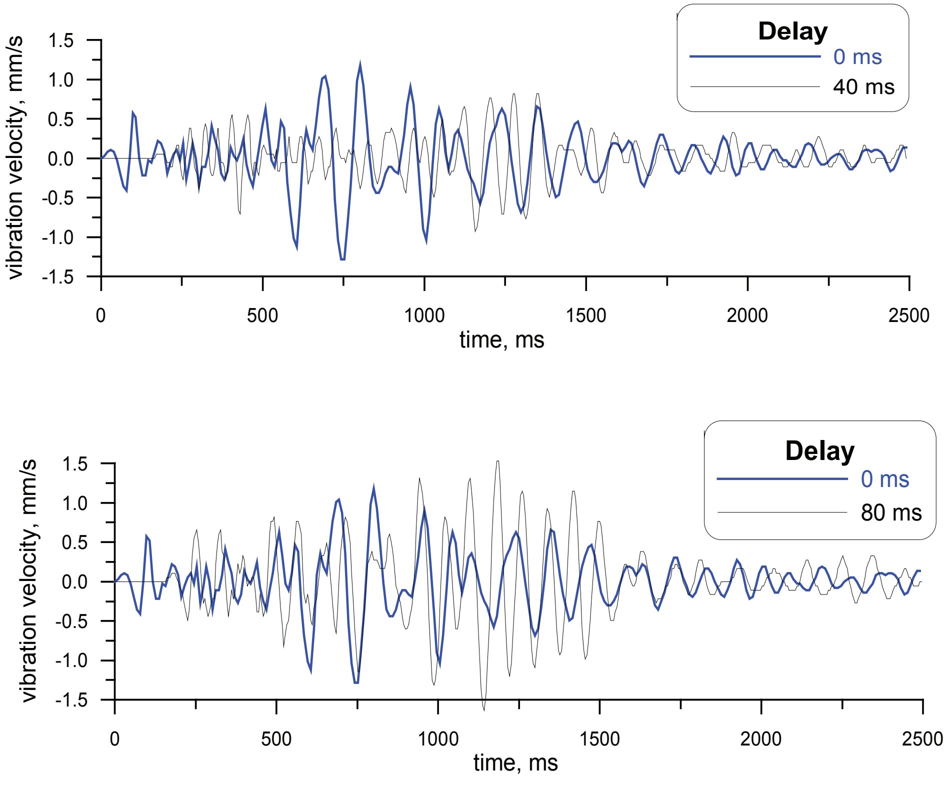


Fig. 6. Comparison of recorded vibrations level from blasting of individual explosive and series with different delay [11]

It clearly follows from Figure 6 that the use of 80 ms delays caused an increase in the level of recorded vibrations in comparison with the level of an individual charge explosive blasting. For 40 ms delays, the obtained vibrations' level is smaller than that of one individual blast hole. At the same time Winzer and Biessikirski [11] state that generally a delay not longer than 60 ms should be analyzed, because up to that value smaller vibrations can be obtained than those obtained from an individual blast hole.

In the scientific papers [12, 13] the authors show the comparison of the speeds of recorded vibrations, in a dolomite mine, from charge explosives blasting with delay 500 ms and 25 ms (Fig. 7).

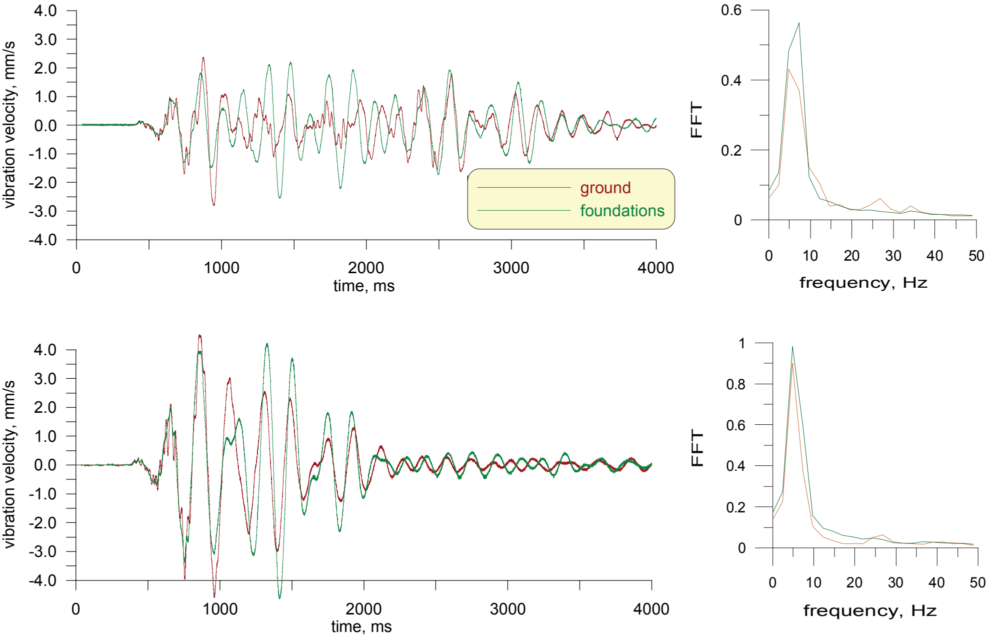


Fig. 7. Comparison of recorded vibrations level from blasting of explosives series with delay 500 ms and 25 ms [12]

It follows from Figure 7 that the level of recorded vibrations during the blasting of charge explosives with a delay of 25 ms is much higher than for a delay 500 ms. The fact should be taken into consideration that despite different delays, the frequency characteristics of the recorded vibrations did not change in the bed rock or the foundation of the object.

After the introduction of non-electrical systems in Poland, research into the influence of millisecond delays on the intensity of recorded vibrations [13–16] continued. For example, Biessikirski *et al.* [14] showed how the level of recorded vibrations, duration time and frequency are altered. In Figure 8 the seismograms of the vibrations recorded on the foundation of the object while blasting in series of 6 with the same number of holes and mass explosives, are recorded which differ only due to the millisecond delay used. The holes in series 1 and 4 were placed in a row and constant millisecond delays of 17, 25, 42 and 67 ms was used.

The intensity change of recorded vibrations is clearly seen in Figure 8, the longer the delay, the longer the duration of the recorded signal. Also, the change of frequency structure of vibrations is visible, which proves frequency analysis (Fig. 9).

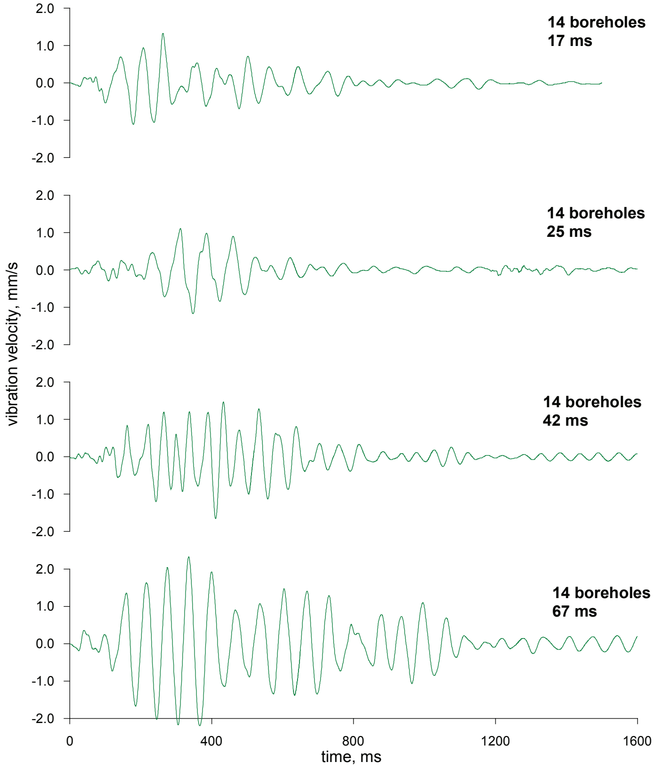
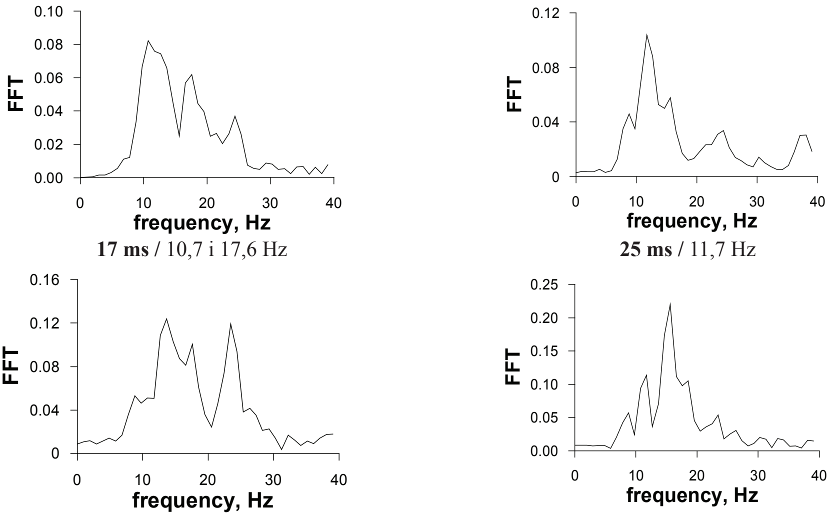


Fig. 8. Seismograms of recorded vibrations while blasting 14 charges explosives [14]



17 ms / 10,7 i 17,6 Hz

25 ms / 11,7 Hz

42 ms / 13,7 i 23,4 Hz

67 ms /15,6 Hz

Fig. 9. Results of spectrum analysis (FFT) for vibrations shown in Figure 8 [14]

Small delays of 17 and 25 ms induce vibrations of relatively lower frequencies than delays of 42 and 67 ms of higher frequencies, but distinctly relate to the frequency of the blasting charge explosives. Delay 42 ms – frequency 23.4 Hz, and 67 ms – 15.6 Hz.

Biessikirski *et al.* [14] also pay attention to the actual time of firing while using non-electric systems, in the case of multi-series nets. The delays used do not relate to the actual times, in which the individual charges explosive are shot. For example, in Figure 10, the distribution of actual millisecond delays are shown, obtained while blasting a two-row series with delays 17 and 25 ms.

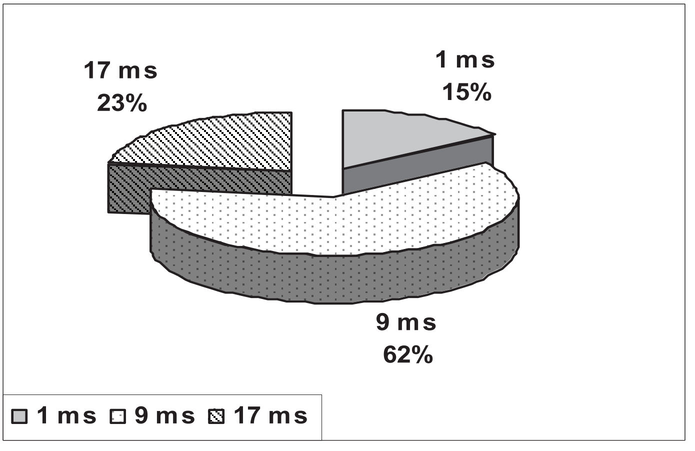


Fig. 10. Actual millisecond delays for two-row series [14]

As seen, the actual delays between the charges explosives do not have much in common with the used time retarder (connectors).

However, Modrzejewski [15] presents theories regarding the method for determination of the optimum delay time and many rules, which should be followed during the calculation of optimum millisecond delays. Some delays were also recommended, which should be used during blasting for particular types of rocks (Tab. 1).

TABLE 1

Recommended delay for given type of rock [15]

Rock type	**Recommended delay, [ms]**
Basalt	42, 67
Dolomite	25, 42
Granite	17, 25, 42
Granite-gneiss	25, 42, (67)
Melaphyre	25, 42, 67
Limestone	42, 67, 109

In contradiction to the results presented above, the research results described in [12, 13] can be presented, in which discrepancies were shown after using the same delay for the same type of rock, but for different beds (Fig. 11).

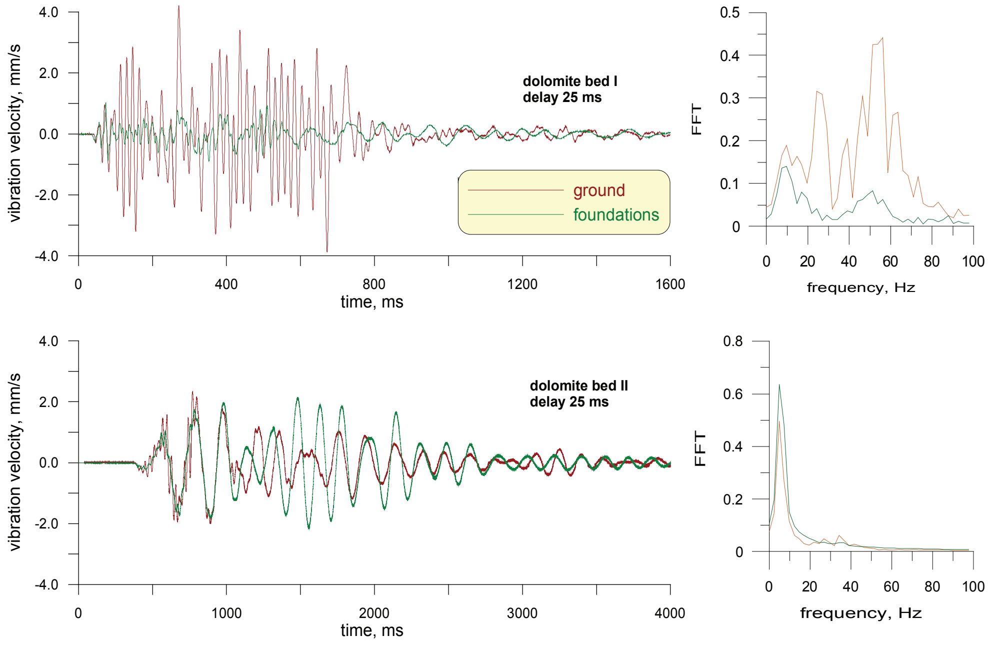


Fig. 11. Comparison of recorded vibrations level while blasting charges explosives with delay 25 ms for different dolomite deposits [12]

In Figure 11, differences are seen in the recorded vibration signal while blasting a series of charges explosives with the same millisecond delay of 25 ms. In dolomite deposit I, the vibrations recorded in the subsoil are of a significant intensity, but after transition to the object a reduction occurred, whereas in case of dolomite deposit II, the level of recorded vibrations in the subsoil and on the foundation of the object are the same. There is also a difference in the frequency of the vibration structure.In the first case, high frequencies of about 55 Hz dominate, which are filtered off and leaving frequencies of 10 Hz which occur on the object. In the other cases, both in subsoil and also on the foundation, low frequencies below 10 Hz dominate, which are not filtered off during the transition from the subsoil to the foundation.

The authors of the scientific [15–18], refer to McKenzie [19], in which a formula is given for the quantity of optimum millisecond delay τ depending on the lengths between charges explosives *a*, which should amount to:

— for one-row blasting:

$$\tau = (2.5 \div 4,5) \cdot a \text{ [ms]} \tag{1}$$

— for multi-row blasting:

$$\tau = (5 \div 15) \cdot a \text{ [ms]} \tag{2}$$

Intensity dependence on the quantity of blasting charges explosives with millisecond delay should amount to:

$$u = u'[1 + (n - 1) \cdot 0.5 \text{ [ms]} \tag{3}$$

where:

- u' – speed of vibrations measured at blasting one charge explosive [mm/s],
- u – calculated speed of vibrations [mm/s],
- n – number of charges explosives.

Moreover, Onderka [16] assumes vibrations model as simple harmonic motion and from the condition for wave interference coming from consecutive explosives, assumes that the delay should be in the interval:

$$T > \tau > T/2 \tag{4}$$

where:

- T – period of vibrations [s], $T = 1/f$, f – frequency [Hz].

Onderka [16] also mentions that delays lower than 18 ms should be avoided, and the best effects of limitation of paraseismic vibrations are obtained for delays in the interval 25–50 ms.

Summarising the results obtained hitherto, related to the choice of millisecond delay for blasting long holes in strip mines, it should be pointed out that:

- there is no possibility of using empirical formulas,
- delay not necessarily must be the factor minimizing vibrations' level,
- using millisecond delays, the seismic effect can be lowered, even below the intensity induced with a single charge explosive,
- too big a delay does not always influence the decrease in vibrations, and even can contribute to their intensification,
- too small a delay, in some cases, causes a sudden increase in intensity, compared with the effect of prompt shooting,
- millisecond delays influence the frequency characteristics of the recorded vibrations,
- delays cannot be attributed to a particular type of rock, but rather to particular local conditions.

4. Summary

Delay quantity should be determined empirically in reference to the given geological-mining conditions, because any calculations allow for univocal results to be obtained. In the case of dealing with the assessment of vibrations', the influence on building objects, which are in the mine surroundings, it is necessary to carry out an analysis of the frequency structure of the recorded vibrations, because frequencies determine the classification of vibrations among imperceptible, perceptible and harmful groups. While choosing the optimum delay, the whole process of vibration transmission to the protected object should be taken into consideration: source – vibrations' propagation – receiver.

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