The increase of ultrasound measurements accuracy with the use of two-frequency sounding

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Abstract In the article the new method for detection of the temporary position of the received echo signal is considered. The method consists in successive emission of sounded impulses on two frequencies and also the current study is concerned with the analysis of ultrasound fluctuation propagation time to and from the deflector on every frequency. The detailed description of the mathematical tool is presented in the article. The math tool used allows the authors to decrease the measurement error with help of calculations needed.

Introduction

As a matter of fact, blasting operations are the main step in mining preparation process of coal, iron ore and other mineral resources. What is more, expenses to carry out the blasting operations comprise a significant part of mined rock production cost. Hence the errors in hole depth measurement lead to increase of the mined rock production cost, and also it might result in the risk of a top horizon downfall where mining occurs.

A basic error in ultrasonic depth-gauge measurement is conditioned by inaccuracy in determination of ultrasonic impulse arrival. Generally the moment of ultrasonic impulse arrival is defined with a comparator but with help of complex shape of ultrasonic impulse, and the comparator operating time doesn't concur with the impulse initiation.

Nowadays existing ultrasonic hole depth-gauges have measurement errors and a high value of uncontrolled area. However the major issue concerning the hole formation depth measuring lies in a low accuracy of measurement connected with the hole shape fault, which takes place due to earth movement. Therefore, the development of universal method of acoustic impulse analysis which allows receiving the accurate information about the depth is the research objective of the current study.

As regards to the use of comparatively low frequencies in acoustic position, it leads to the situation when the time of propagation and the period of sounded fluctuation become commensurable quantities, thus as a rule, the received radio impulse but not its envelope is supplied directly to the comparator inlet. In case of square-wave modulation use or similar to it in shape, the maximum error will be equal to carrier frequency quarter-period.

For this reason the regulating system AGC to increase accuracy of acoustic measurements is used, however there is a range of problems solving which it is impossible to get a pulse with linearly-growing amplitude of the front edge of an echo signal envelope. Among them there are acoustic hole depth-gauges where unpredictable and imperfect hole shapes (fracture, roughness) often occur, and also the influence of a wave guided propagation pulse results in significant change of the shape of the received impulse, besides, the side reflection occurrence leads to infeasibility of the AGC system application. The shape model of the beginning of the echo signal of wave guided acoustic path is demonstrated in figure 1.

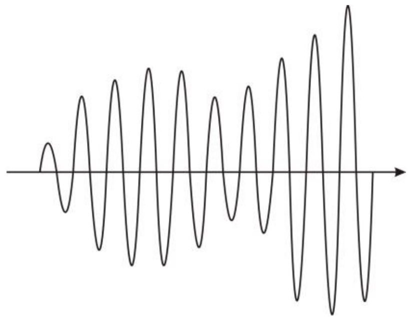

Figure 1. Oscillogram of the front edge of a received signal.

The method used to detect the accuracy of pulse initiation moment consists in ultrasonic signal supply to the comparator inlet and the moment of occurrence of a high logic level on the outlet of the device is considered to be the moment of echo impulse arrival. This method error makes up to tens of periods of the carrier frequency and it is impossible to take into account the error because of the unpredictable envelope change of the front edge of an echo signal at the wave guided propagation. Moreover the use of Hilbert transform for receiving the echo signal envelope and later detection of its initial point requires high computer performance and resources which portable apparatus don't have [1].

The research objective to determine the temporary position of the echo impulse is applicable and actual for acoustic instruments, the acoustic path of which contributes to the impulse envelope shape change. One of the innovative methods for the time delay detection of ultra sound propagation is the zero-crossing detecting [2–4].

1. Two-frequency sounding method description.

The authors of the present study offer a method which uses the signals of two different frequencies to measure the distance and as the result, it will allow excluding the major part of measurement mistakes connected with the wave guided propagation of an ultra sound and also, to increase the measurement accuracy.

The method principle consists in the emission of two signals at different frequencies and in measurement of two time intervals between the impulse emitted and the impulse received when the comparator comes into action (figure 2).

For two received signals of different frequencies the comparator response occurs at different time relative to signal stimulation – point t_1 and t_2, and the calculation of a temporary position of an echo impulse is estimated in relation to these points.

After the time intervals measurement between the emitted and received signals, the comparison of these intervals is carried out and the correction occurs according to the formula:

$$(\Delta t_1 - i \cdot T_1) - (\Delta t_2 - i \cdot T_2) = \min , \qquad (1)$$

Where T_1 – the fluctuation period of the first ultra sound wave, T_2 – the fluctuation period of the second ultra sound wave, *i*– correction number, Δt_1 – the first measured time interval, Δt_2 – the second measured time interval. The formula $(\Delta t_1 - i \cdot T_1)$ is used to determine the reflection surface distance.

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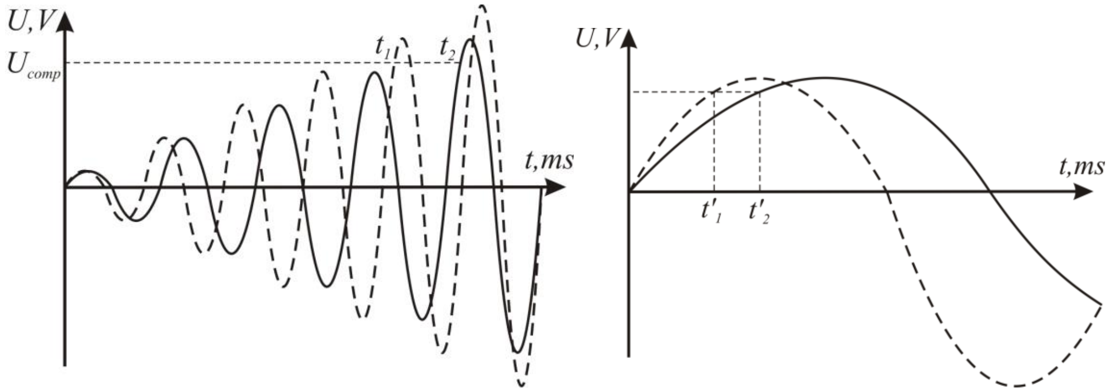

Figure 2. Oscillograms demonstrating the beginning of two echo signals (firm line – the first echo signal with the recurrence interval T2, dotted line – the second echo signal with the recurrence interval T1), a – the operation time of a comparator, b – correction works result, where $U_п$ – threshold comparator voltage; t'_1, t'_2– time intervals after correction.

2. Math modeling of errors

The time calculation of comparators shifting for different response levels has been carried out with the use of MathCad program and using its incorporated functions we solve the equation of the form:

$$k \cdot n \cdot \frac{2t}{T} \sin(n\omega t) = U_{comp}$$

Where n – correlation of frequencies $\frac{f_1}{f_2}$, t – the first period of comparator response, U_{comp} – comparator operation threshold, k – coefficient of the front edge signal growth.

Correction is carried out with the received time intervals.

To determine the limits of method applicability the math modeling has been used. As the point in question, coordinate plane zero has been chosen herewith the differential interval depending on iteration number is shown in figure 3.

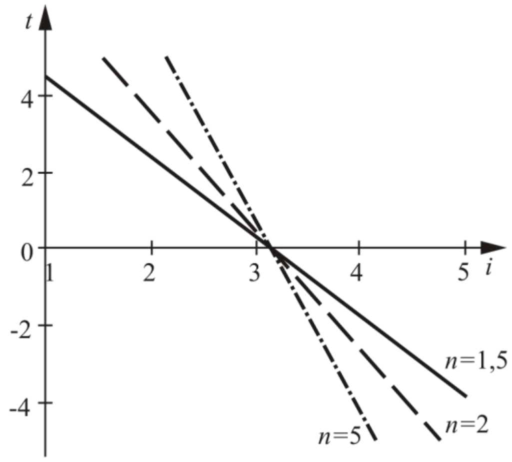

Figure 3. Dependance of differential interval on the iteration number for different ratio of emitted frequencies.

Figure 3 depicts iteration straight lines for different frequencies ratio. It is assumed from the graph that with the increase of the second operational frequency, the incidence angle of the graph to the axis increases as well. The cross-point with the axis indicates the number of iterations conducted to minimal discrepancy. In this case the comparator response occurred in the 4^{th} period of received signal, thereafter, three time iterations lead to the minimal positive value of correction expression (1).

The accuracy of the impulse arrival moment detection will be defined with help of the signal phase at the comparator operation time, otherwise, the closer the comparator level to the change of a period, the more significant measurement error can be. Consequently, to increase the measurement accuracy it is necessary to increase the second emitted frequency; however the maximum possible measured distance decreases.

For the reason of error detection of the current method it was conducted the error measurement modeling. Changing the operation threshold of the comparator, the graph with the error dependence on the threshold voltage was received (Figure 4). Increasing the operation threshold when approaching to sinusoid peak leads to the gradual non linear increase of error. When the period changes the error reduces.

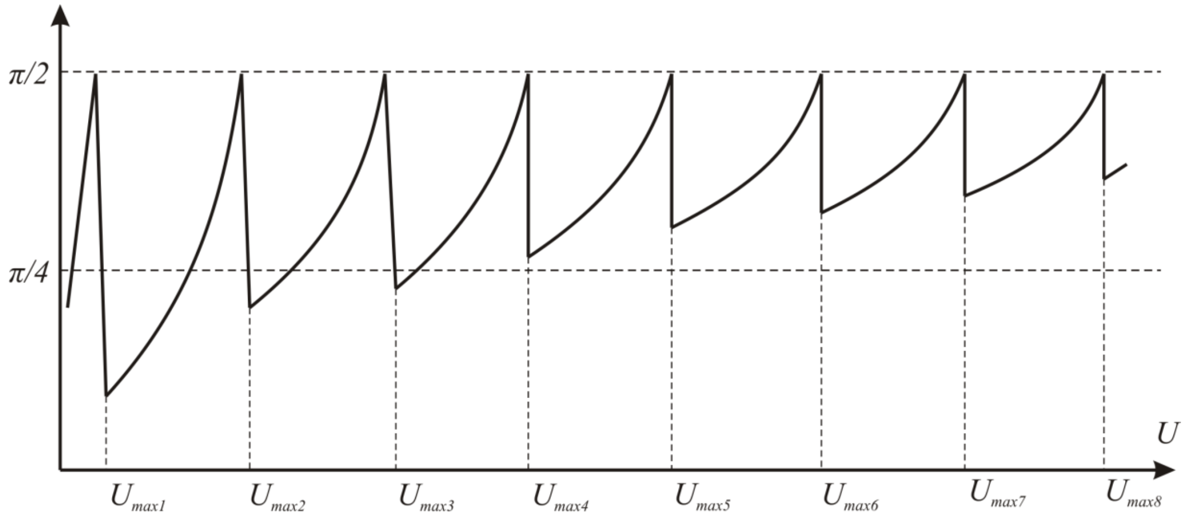

Figure 4. The measurement error dependence graph on the comparator operation threshold, where U_{max} – maximal amplitude of the signal, Δ – an error.

According to the graph data, the measurement error depends directly on the operation threshold chosen, but it doesn't exceed the quarter-period which can be taken as an advantage of the method. Besides it can be inferred from the graph that the measurement error at any operation threshold won't be equal to zero.

For further improvement of accuracy of the current method, the average error must be found for every period when the comparator response might occur. In this case, the number of conducted iterations to reach minimal expression value (1) and awareness about the average value of the error for the period can increase the measurement accuracy.

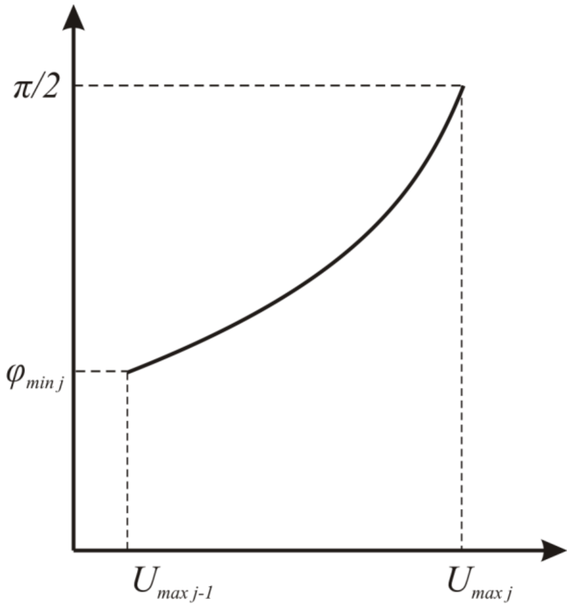

Figure 5. Minimal phase for any period will depend on the amplitude level of the previous period.

Thus, the following equitation is obtained:

$$\varphi_{\min_i} = \arcsin\left(\frac{U_{i-1}T}{t}\right)$$

where $U_{\max_{j-1}}$ – amplitude of the previous period of the received signal, $U_{\max_j}$ – amplitude j-the period when the comparator response occurs.

The average error value for j-period is defined with the formula:

$$\Delta_j = \frac{1}{\left(\varphi_{\min_j} - \frac{\pi}{2}\right)} \int_{\varphi_{\min j}}^{\pi/2} k \cdot n \cdot \frac{2t}{T} \sin(n\omega t) dt,$$

Where n – frequency ratio $\frac{f_1}{f_2}$, k – coefficient showing the envelope slope of the front edge of a signal, $\varphi_{\min_j}$ – minimal phase when the comparator might come into action in j-period.

3. Conclusion

The obtained value Δ_j can be applied to increase the detection accuracy of the temporary position of the received signal, thus the expression for the moment determination of echo impulse arrival will be the following:

$$t_0 = (\Delta t_1 - i \cdot T_1) - \Delta_j,$$

where j=i-1, i – iteration number, j – the period number of echo signal arrival when the comparator operation occurred, T_1 – the fluctuation period of the first ultrasound wave of higher frequency, Δt_1 – time interval between the emitted impulse and the moment when the comparator comes into action.

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