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Inaccuracy of acoustic measurements in dual-frequence method of sounding

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Abstract. The article describes the new method of defining time coordinate of the moment when echo-impulse comes. The principle of the method consists in consecutive sounding of the (head) well with the signals of different frequencies and analysing the received reflected signals. The article shows the graphs with dependence of measurement inaccuracy when the operating threshold of the comparator for different ratios of frequencies changes. If the comparator works out in different (in order) periods of the received signals then measurement inaccuracy will be 1-2 periods of the carrier frequency.

1 Introduction

Echo acoustic method gained widespread use in modern industry thanks to its advantages like decent accuracy limited by the radiator wavelength, non-contact capability, the ability to measure geometric parameters of the objects and measure a great range of distances. The peculiarity of the method is the possible loss of accuracy in the calibration of distance because of the incorrect defining of the moment when the reflected impulse comes [1-3].

While passing through the acoustic path the signal distorts and handover of the rising flank of the envelope takes place because of time delay in spreading modes of different kinds.

The vital task is the development of the universal method for the analysis of acoustic impulse that enables to gain the information about the depth or distance to the object with the proper accuracy.

Application of comparatively low frequencies in acoustic location leads to the propagation time and the period of sound oscillations to become commensurable quantities and that is why, as a rule, the instantaneously received radio impulse and not its envelope is fed on the input of the comparator. If to use a square-wave modulation or a similar modulation form maximum inaccuracy will be equal to the quarter period of the carrier frequency [4, 5]. The regulating system AGC (automatic gain control) is used to increase the accuracy of acoustic measurements but at the same time, there exist the tasks with the solutions that cannot be essentially resulted in the signal with ramp amplitude of the rising flank of the echo-signal envelope. The task of defining the time position of the echo-impulse is vital for acoustic devices with the acoustic path, which is the essential

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contribution into changing the shape of the signal envelope. The devices of this type can be distance finders and depth finders [6-8].

The basic inaccuracy of measuring for ultrasound depth finders and distance finders is associated with inaccuracy of defining the coming of the ultrasound impulse. The use of Hilbert transform to get the echo-signal envelope and further defining of its homepoint requires much calculating which does not take place in hand-held devices [9].

One of the innovative methods for defining the temporary propagation delay of the ultrasound is the search method of zeros of a signal [10].

The authors offer to use the dual-frequence method of sounding to define the distance to the monitored object. The use of the signals with two different frequencies enables to exclude the essential amount of measurement errors[11, 12].

2 Description of dual-frequence method of sounding

The principle of the new method is radiating of two signals at different frequencies and measuring two time intervals between the radiated and the received signal according to the moment when the signal reaches the triggering value (Figure 1) [13, 14].

In the result we have two time coordinates t_1 and t_2 and the difference between them will depend on sounding frequencies and the number of period when the comparator has worked out [15]. Calculation for the time position of the received echo-impulse is done in accordance with the time intervals t_1 and t_2. Comparison of these time intervals and their correction takes place after calculating the time intervals between the radiated and the received signals and is done according to this expression:

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

where T_1 – the period of oscillations of the first ultrasound wave, T_2 – the period of oscillations of the second ultrasound wave, *i*– the number of correction, Δt_1– the first measured time interval, Δt_2– the second measured time interval. The expression $(\Delta t_1 - i \cdot T_1)$ is used to define the distance to the reflective surface.

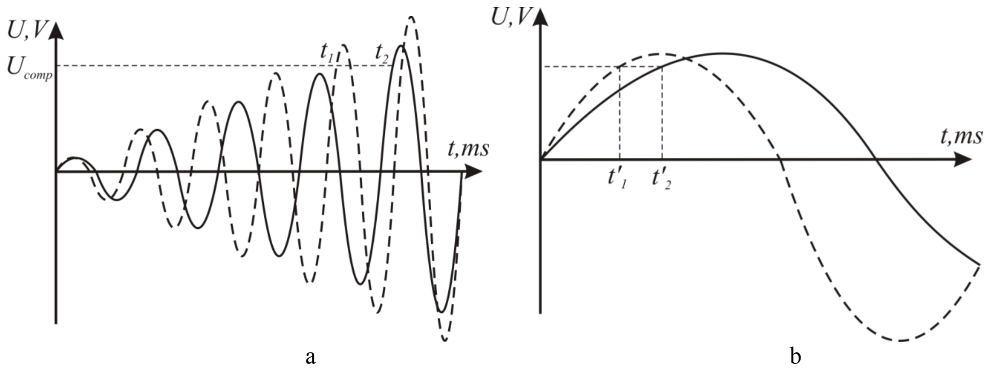


Fig. 1. Oscillograms of the initial part of the two echo-signals (full line graph - the first echo-signal with the repetition period T_1) a - the moment when the comparator has worked out, b - the result of performing the correction where U_{th} – threshold voltage of the comparator; t_1, t_2 – the time when the comparator has worked out, for the frequencies 1 and 2 respectively; t'_1, t'_2 – time intervals after performing the correction.

3 Inaccuracies of the method

3.1 Basic inaccuracy of the method

Measuring inaccuracy of the method is determined by the phase when the comparator has worked out. If the comparator has worked out for the signals with two different frequencies in the same (in order) period of the signal from the moment of its appearance then inaccuracy will be in the range 0 – T/2. To reduce inaccuracy one should increase the frequency of the radiating signal, however, it decreases the range of the measuring distances. The other variant is implementing the phase correction for data processing. Defining the phase of the signal when the comparator has worked out is possible if to analyze the signal at the output of the comparator. Figure 2 explains the principle of calculating the signal phase that takes part in the correction of the calculated distance [16-19].

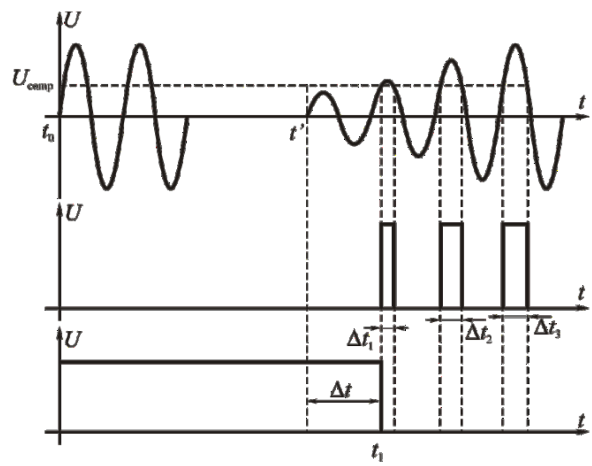


Fig.2. Phase correction of the measurement result based on the signal analysis on the output of the comparator.

Two actions enable to reach high accuracy without sufficient influence on the operation time for the calculation: defining the time coordinate for the point of the first period of the received signal and phase correction of the found time coordinate [20].

Propagation time for using phase correction will be calculated according to the formula:

$$t_0 = (\Delta t_1 - i \cdot T_1) - \varphi \qquad (2)$$

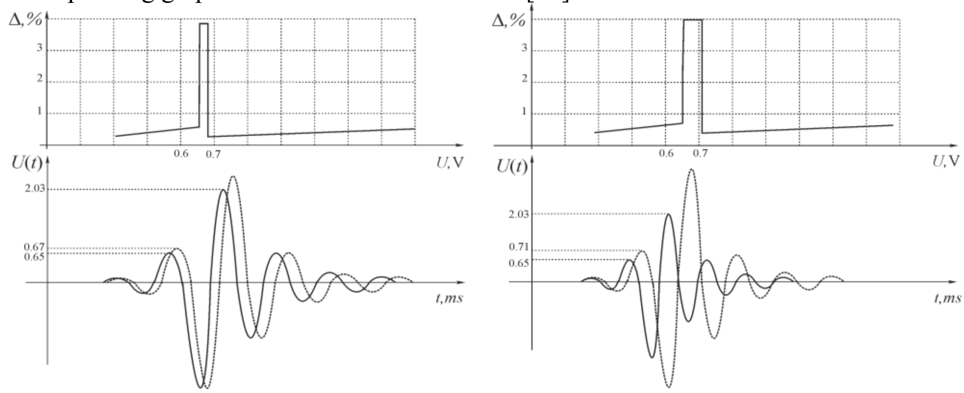
where φ – correctional coefficient which is proportional to the phase of the signal at the moment when the comparator has worked out:

$$\varphi = \frac{T/2 - \Delta t}{2} \qquad (3)$$

3.2 Response of the comparator in the different periods when processing the signals of different frequencies

The worst errors in measurements appear in cases when the comparator works out in different (in order) periods of the signals with different frequencies. It happens because of different attenuation coefficient for different transmission frequencies. In case when the radiating frequencies differ from each other by several times it is more possible for this inaccuracy to appear. The error in this case will be 1–2 periods because defining the first period of appearing is impossible while performing the iterations [21, 22].

To define the possible measurement errors the series of experiments was carried out. It is necessary for the voltage level at which recording of the time interval happens to be higher than noises for the false responses of the device to be avoided that is why the level of the triggering value lower than 0,5 B is not considered in the experiment [23]. At the same time it is essential for the fixed triggering value of voltages not to be higher than the maximal level of the signal. The response does not occur in other circumstances. Figure 3 shows the graphs of the received signals for different ratios of the frequencies and their corresponding graphs of the measurement errors [24].



a b

Fig. 3. Dependences of measurement errors when the response level changes from 50 mV to 2 V, for the case a) f1=950 Hz, f2=1000 Hz, b) f1=800 Hz, f2=1000 Hz.

The graphs shown in Figure 3 enable to give the right triggering value of the response of the comparator avoiding the essential measurement values and to make changes in processing the signal. In the first time intervals of signal growing, at the moment of signal appearance in the receiver its level is comparable with the level of noises [25-27]. That is why big errors are possible when setting the triggering value of voltage on the level of the first period of the received signal. In this case, the waveguide is often noisy and false responses of the comparator are possible. When the comparator works out in the same period (in order) in relation to its appearance, we have the measurement inaccuracy that does not exceed 1% from the measured depth for the both frequencies.

Maximal inaccuracy is in the range 3–4% and appears in the case when response of the comparator happens at different (in order) periods of signals for the chosen frequencies. The possibility of the comparator to work out in different (in order) periods increases with the growth of the difference between the frequencies of the signals. The reason is that the signals of higher frequency attenuate faster and, consequently, come to the receiver of the signal with the lower amplitude [28].

To minify the measurement error we implement the signal processor – the module of automatic gain control (AGC) that enables to adjust the signals to amplitude, reduce the possibility of the comparator to work out in different periods.

To prevent the possibility of the comparator to work out in different periods it is also necessary to do 3–5 consecutive measurements. In this case, one can change the triggering value of the voltage to get the stable result [29, 30].

4 Conclusion

The described dual-frequency method of sounding used with the properly chosen threshold voltage and the ratio of frequencies gives inaccuracy less than 1% from the measured depth.

In case when the comparator works out in different (in order) periods of the received signals the measurement error will be 1-2 periods of the carrier frequency. If this happens, AGC systems help to avoid the big error.

Implementation of phase correction into the processing of the received signals helps to increase the accuracy of acoustic measurements when applying the dual-frequence method of sounding.

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