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Ultrasound measurements with two-frequency sounding

The ultrasound measurement instruments capable of providing reasonable accuracy in the whole measured area with an adjustable range of the measurement depth at an instrument frequency shift are often preferred to measure the distance in the sphere of industry. The major error of the ultrasound measuring instrument is caused by the error of the ultrasound pulse arrival. There are two approaches to measure the distance by means of the ultrasound. The first approach is based on the measuring phase deviation between an emitted signal and a received signal. The phase between the emitted signal and the received signal is proportional to the measured distance. The applicability of the described approach is restricted by the distance equal to the wave length. The second approach is based on determining the moment of the reflected signal according to the set tension level. For distance measuring, the time interval between the emitted signal and the time interval required for the received signal to build up to the threshold point are used. The threshold point is chosen to be higher than the noise level. Due to the complicated form of the ultrasound pulse, the comparator response time does not coincide with the sound initiation. The error of this measurement technique can be tens of the carrier cycles, and it cannot be taken it into account due to unpredictable changes of the front echo signal envelope in waveguide propagation.

The task of determining the time echo signal position is very urgent for acoustic devices in which the acoustic path dramatically contributes to the change in the signal envelope shape.

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

The method principle implies the emission of two signals at different frequencies and measurement of two time intervals between the pulse emitted and the pulse received when the comparator comes into action (fig. 2).

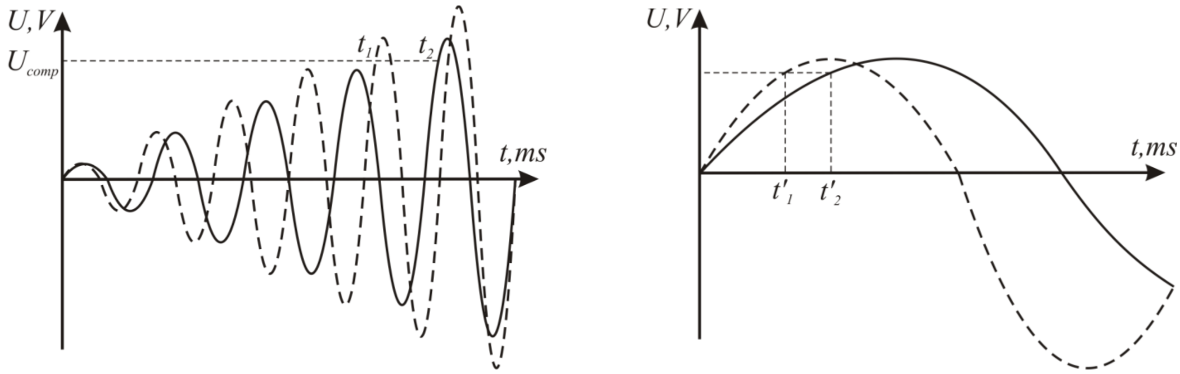

Fig. 2. Oscillograms demonstrating the beginning of two echo signals (solid line indicates the first echo signal with the recurrence interval T2, dotted line refers to the second echo signal with the recurrence interval T1), a is the operation time of a comparator, b is the correction work result, where U_{comp} is the threshold comparator voltage; t'_1 and t'_2 are time intervals after correction

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 the time position of an echo pulse is estimated in relation to these points.

After the time intervals measurement between the emitted and received signals, these intervals are compared, and the correction occurs according to the formula:

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

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

Algoritm of distance measuring by means of dual-frequency method

To obtain information about the distance being measured the following steps are efficient:

1) *Choosing search frequency.* The first is to choose the highest frequency. This frequency choice is determined by the maximum measured distance. The choice of the second frequency is determined by the emitter properties. Generally, it is recommended to range the coefficients from 1.2 to 2.

2) *Emitting of two signals* and saving the comparator response time points for each of them, t_1 and t_2.

3) *Derivation of the following matrix*:

$$\begin{bmatrix} (t_1 - T_1) - (t_2 - T_2) \\ (t_1 - 2T_1) - (t_2 - 2T_2) \\ \vdots \\ (t_1 - nT_1) - (t_2 - nT_2) \end{bmatrix}$$

4) *Determining i*, the number of the smallest positive elements of the derivate time matrix.

5) *Calculating the time interval* according to the following formula:

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

where $j = i + 1$, *i* is the number of iterations, *j* is the number of the echo signal interval, during which the comparator responds, T_1 is the fluctuation period of the first ultra sound wave having greater frequency, Δt_1 is the time interval between the emitting signal and the moment of the comparator response.

Processing a signal with the help of the described algorithm enables considerable improvement of the distance measuring accuracy. The error of distance calculation via the given formula makes not more than 1/12 of the smaller frequency interval. The presented method can be used to measure the distance in the interval of 100 meters in the air.

Significant variations in measurement errors when using the single comparator are due to the waveguide propagation of ultrasonic vibrations, which leads to a significant change of the pulse shape at various distances. Based on these data, we can conclude a substantial increase in measurement accuracy by increasing the measured distance. At distances greater than 12 m the error frequency method does not exceed 1 % (confidential interval was ± 0.2 %), while the error of the method with one comparator is greater than 7 % (confidential interval of ± 1 %).

References

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