ESTIMATION OF SOME ERRORS OF CORRELATION LEAKDETECTOR AND WAYS OF THEIR REDUCTION.

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Nowadays acoustic leak detectors with correlation processing of signals have widespread application in testing pipelines for leak-tightness. The operating principle of these devices is based on passive location of acoustic noise (acoustic emission) that arises when the liquid flows through discontinuity flaw at the surplus pressure in the pipe. The leakage location is defined by two transducers installed at the pipeline wall on both sides of the proposed leakage point. The signal propagation time to each of the transducers is different and depends on the fault location. The difference in noise signal arrival time (delay period) can be determined by the maximum of the cross-correlation function that characterizes probabilistic relation of the process values divided by time interval.

In practice the correlation function with the only maximum is extremely rare in occurrence, for instance, at recording the signals propagating by air in the absence of reflecting surfaces. In most practical cases the correlation function contains numerous correlation maxima that can overlap; the magnitudes of some maxima can alter in time and depend on the point of the sensor installation on the pipe. Thus, the correlation maximum appears diffused. This results in the error of delay period measurement, which impairs the accuracy of localization and sometimes even leads to gross miscounts.

The analysis of signal propagation in pipes with liquids shows that major causes of the diffused correlation maximum are the presence of external noise, the formation of stationary wave in the pipe, the sound velocity dispersion in the pipeline, and the excitation of several modes of vibration in the pipe. The correlation leak detector TAK-2005 developed by the authors represents the implementation of the acoustic signals filtration technique that allows minimizing this component of error. The core of the proposed technique consists in distinguishing a narrow spectral band within signal spectra where the coherence function is maximum and relatively level while the phase of cross-spectral density is a sawtooth function with several sections properly approximated by linear dependence. In other words, unlike most contemporary leak detectors with the filter pass band being determined only by the coherence function maximum value, our analysis also involves the phase of cross spectrum. This allows minimizing the impact of multi-mode pattern of propagation and the presence of sound velocity dispersion in the pipe. This is achieved by the following way. As is known, in case of a single path without dispersion the phase of cross spectrum has the appearance of linear sawtooth function. Hence, while isolating the sections with linear phase we select for analysis the waveband where the leak signal propagates predominantly through a single path.

The verification of the proposed technique was carried out both at the experimental unit and in operating pipelines.

The experimental unit consisting of an end-plugged pipe segment 68 m in length, 100 mm in diameter (Fig. 1.). The leakage was 30 m away from one of the ends and was modeled by a through cylindrical hole 0.8 mm in diameter. Pressure in the pipeline was created by supplying compressed gas through a buffer tank. Pressure in the pipeline in all the experiments was 2 atm, flow rate was 12 l/hr. In all the tests, the distance between sensors was 34.5 m, while the distance between sensors and the leakage varied from 0.5 to 27.5 m at 1 m intervals.

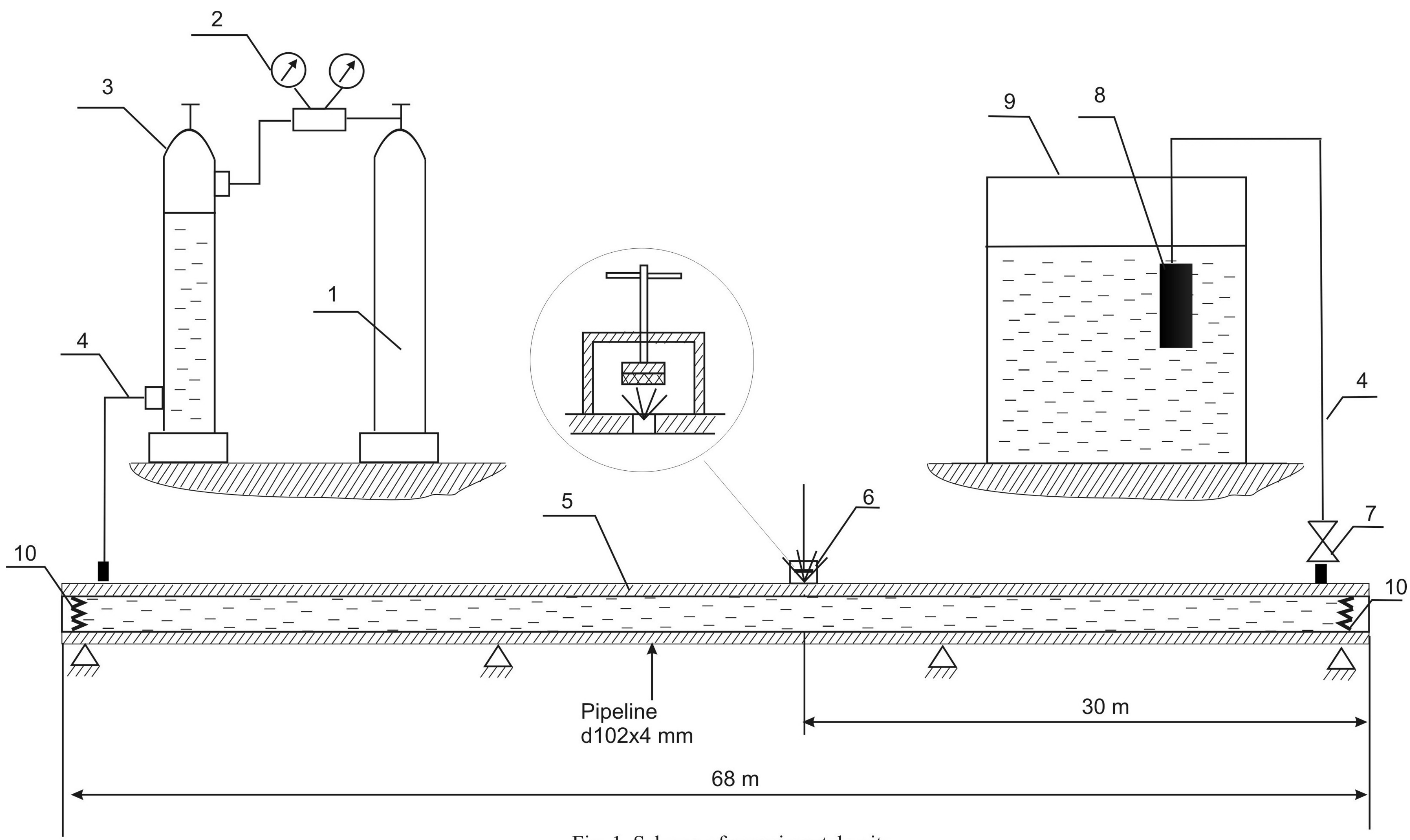

Fig. 1. Scheme of experimental units.
1- gas cylinder; 2 - gas presure regulator; 3 - water cylinder; 4 - hose; 5 - pipeline;
6 - leak with valve; 7 - valve; 8 - pump; 9 - reservoir; 10 - sound-proof tampons

Fig. 2 shows a typical cross-correlation function of unfiltered signals.

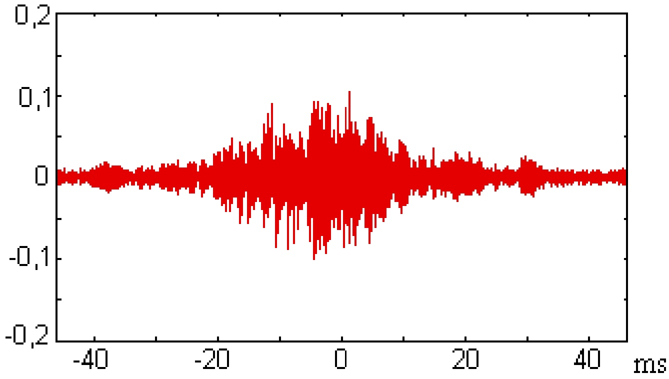

Fig. 2. Typical cross-correlation function of unfiltered signals

Predictably, the cross-correlation function of unfiltered signals has many peaks from which it is hardly possible to select the peak corresponding to the exact location of the leakage. Use of bandpass signal filtering in the band where the coherence function reaches its peak does not bring the desired result either. This is due to the fact that, as Fig. 3 shows, the registered signals are coherent almost throughout the frequency range. Cross-spectrum phase analysis revealed a band (Fig. 4) where the phase was a saw-tooth function with multiple segments which are easily approximated by a linear function.

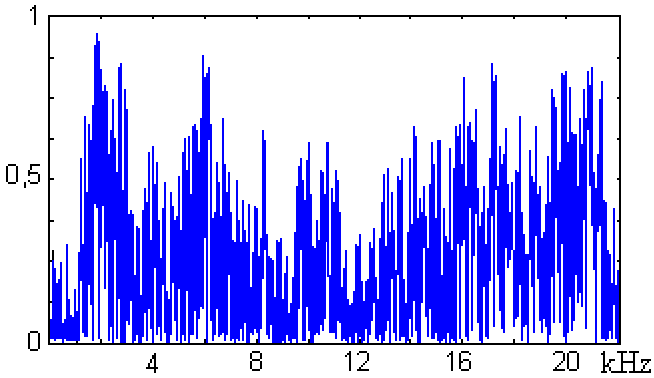

Fig. 3. Coherence function

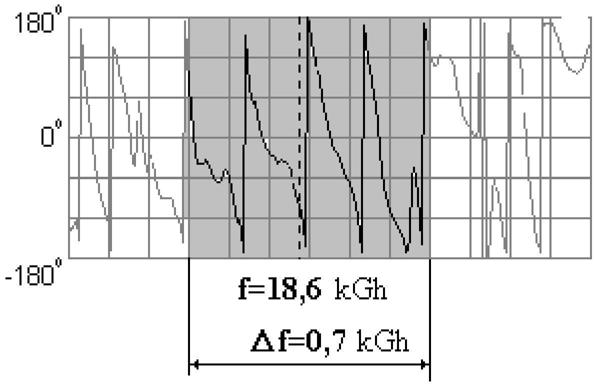

Fig. 4. Phase of cross-spectrum with several sections properly approximated by linear dependence

After signal filtering in this band, the cross-correlation function got one clear peak (Fig. 5).

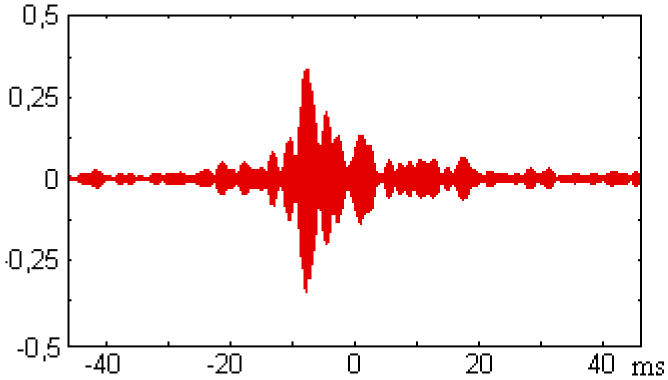

Fig. 5 Cross-correlation function after signal filtration

Fig. 6 shows diagrams of leakage location accuracy and distance to leakage calculated at sound velocity defined by Zhukovsky velocity and experimental velocity obtained by averaging experimental velocities for each test.

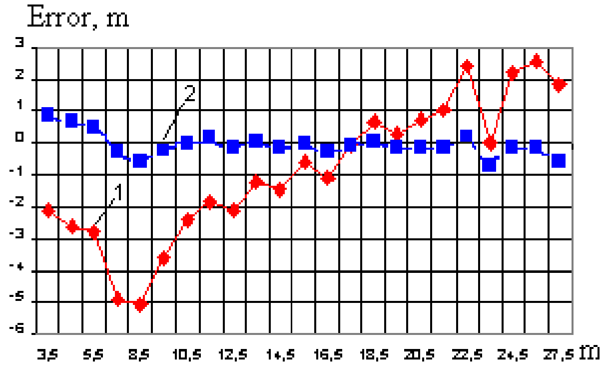

Fig. 6 Dependence of an error of localization on distance before leak at various values of sound velocity
1 - Theoretical velocity (c=1250m/s),
2 - Experimental velocity (c=1108m/s)

As Diagram 1 (Fig. 6) shows, using the theoretical value of velocity in calculations results in low method accuracy. At the same time, if calculations are based on experimentally measured velocity value, location error depends on random factors (Diagram 2 (Fig. 6)). In most cases, the error is less than 20 cm. Exceptions occur when the distance to the leakage is large, and they are due to reflecting surfaces.
The tests confirmed the effectiveness of the applied technique. Nevertheless some drawbacks were encountered one of which is the equivocation of sound velocity in the pipeline. This is stipulated by the fact that a priori it is unknown which mode is most effectively exited and propagated in the pipeline. Thus, sound velocity should be pre-measured when the test is carried out.
The suggested signal filtering method helped us locate the leakage otherwise undetectable by conventional algorithms.
Pressure testing of TomskStroyTrans Company heat supply networks revealed system depressurization. To locate the damage, comprehensive examination of the whole network was carried out which revealed two defects (holes less than 2 mm in diameter). The first defect was located in the main pipe segment 126 m in length. This leakage was easily detected and accurately located. The second defect was in a bend of the main pipe. The length of the whole bend was 60 m. This included 33 m of an underground segment, 6 m of a vertical indoor segment and 21 m of a horizontal indoor segment. Pipe diameter was 219 mm. The underground segment was examined. One sensor was installed in the chamber, the other – in the vertical indoor segment. The distance between sensors was 36 m. Fig. 7 and 8 show relevant cross-correlation function and coherence function diagrams, respectively.

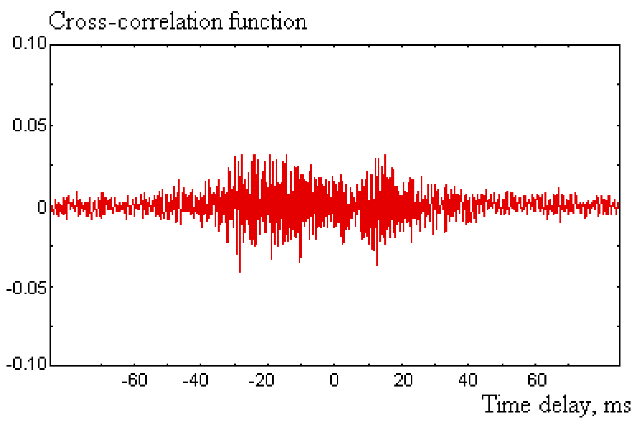

Fig. 7. Cross-correlation function of unfiltered signals

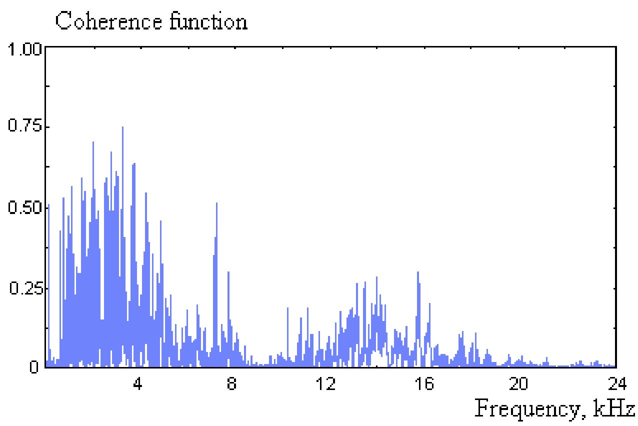

Fig. 8. Coherence function

As Fig. 7 shows, cross-correlation function does not have the peak to uniquely determine the distance to the leakage. The coherence function reaches its peak in the frequency range between 200 and 5,000 Hz. In addition, there is a peak in the frequency range between 12 and 16 kHz. Following the traditional methods of signal filtration, the band between 500 and 5,000 Hz should be used. However, the cross-spectrum phase in this band is characterized by complex dependence and is quite far from linear (Fig. 9). On the other hand, the phase in the frequency range from 12 to 16 kHz is easily approximated by a linear function (Fig. 10).

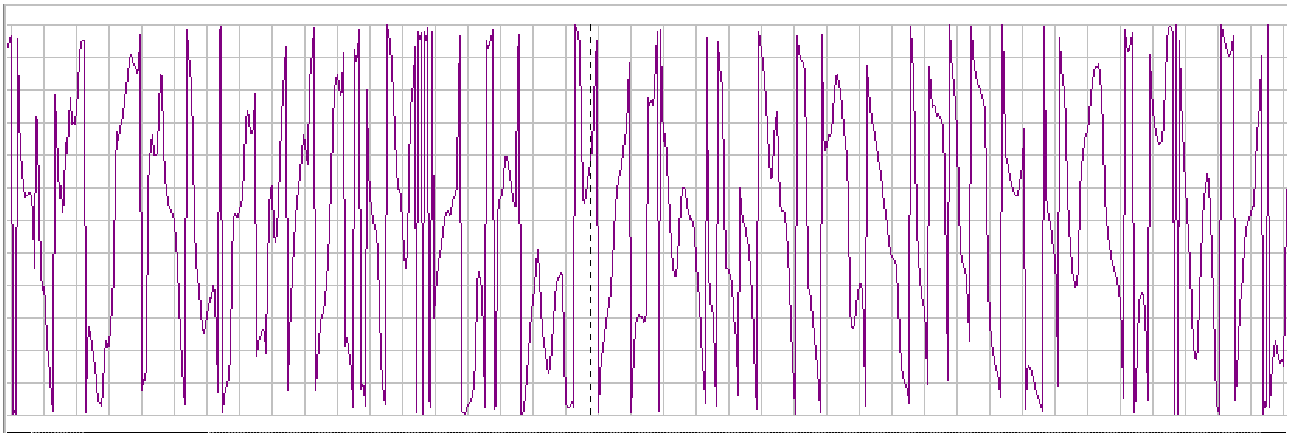

Fig. 9. Phase of cross spectrum in the frequency range from 1 to 3 kHz

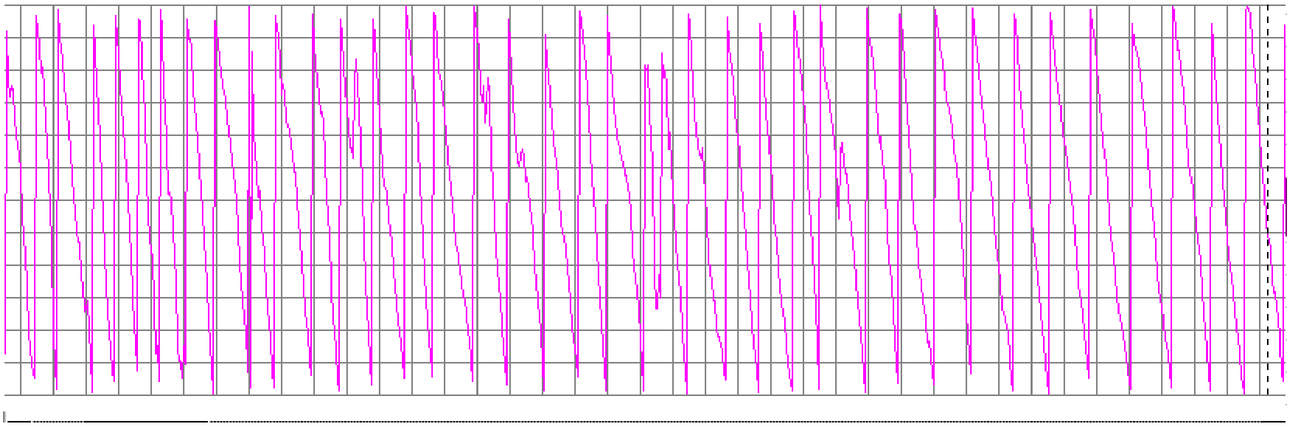

Fig. 10. Phase of cross spectrum in the frequency range from 12 to 15 kHz

Fig. 11 and 12 show cross-correlation functions after signals filtration in the band of 500-5,000 Hz and in the band of 12-16 kHz

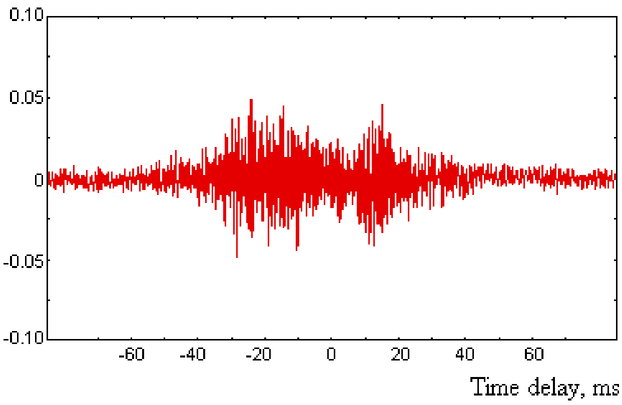

Fig. 11 Cross-correlation function after signals filtration in the band 500 to 5,000 Hz

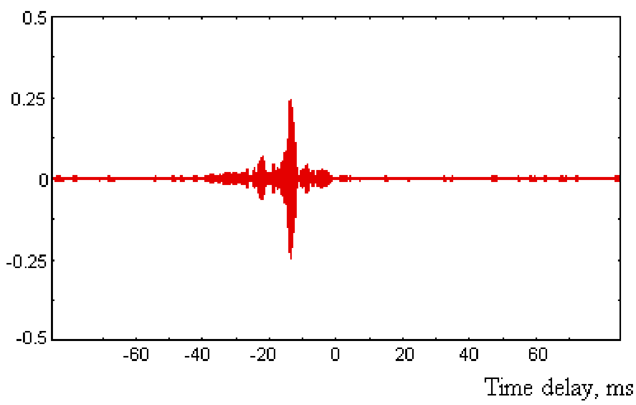

Fig. 12 Cross-correlation function after signal filtration in the band 12 to 16 kHz

As Fig. 11 shows, filtration in the band of 500-5,000 Hz caused almost no changes in cross-correlation functions appearance, while filtration in the band of 12-16 kHz resulted in only one peak in the cross-correlation functions. The accuracy of leakage location for this peak was 20 cm. Possible errors in this case are caused by inaccurate measurement of the distance between sensors and velocity setting error with the velocity not measured during testing.