

LOCALIZATION OF AE SIGNALS IN PIPES WITH ONE-SIDED ACCESS.

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While conducting acoustic-emission (AE) diagnostics of operating pipelines great importance is attributed to the accuracy in localizing revealed faults with the most critical goal being the precise definition of continuous faults coordinates in hard-to-reach sections of pipelines with limited access. This paper proposes the technique based on the analysis of autocorrelation functions for localization of continuous AE in pipelines with one-sided access. The proposed technique consists in spatial filtering of AE signal in the pipeline.

It is known that within the frequency range 20-40 KHz (AE spectrum maximum) the pipeline is a stratified-nonhomogeneous waveguide. The waveguide is formed by the pipeline wall, pumpable product, and the ground. In the specified frequency range several normal waves (modes) can be exited in the waveguide. The acoustic path of signal propagation is nonhomogeneous and can be represented by a set of several homogeneous acoustic paths. At each point of the pipeline normal waves (modes) interact with each other and thus form a complex interference pattern that predetermines the signal spatial spectrum. Thus, a signal recorded by the sensor can be expressed in the form of a convolution sum

$$y(t) = \sum_{i=1}^M \left(\int_0^{\infty} h_i(\tau) x(t-\tau) d\tau + n_i(t) \right) \quad (1)$$

Here, i indicate the pipeline mode, $h_i(\tau)$ is the unit-impulse response of the i th pipeline mode; n_i is the total pipeline noise, and M is the number of pipeline modes.

Under the assumption of signal-independent noise, the spectrum of signal being recorded by sensor is determined by the expression

$$S_y = \frac{1}{n_d T} \sum_{k=1}^{n_d} \sum_{i,j=1}^M H_i^*(f) H_j(f) |X_k^2(f)| \quad (2)$$

where n_d is the number of averaging steps; T is the duration of the actualization; $H_i(f)$ is the unit-impulse response of a pipeline's i th mode; and $X_k(f)$ is the Fourier transform of the k th leak-signal actualization at the location of its appearance. According to [1], the unit-impulse response of a pipeline's i th mode at distance L from the signal source can be presented in the form

$$H_i(f) = A_i(r, \varphi) e^{\left(-j2\pi f \frac{L}{c_i} - z\alpha_i(f) \right)} \quad (3)$$

where $A_i(r, \varphi)$ is some real-valued cylindrical-coordinate function describing the signal-energy spatial distribution thought the pipeline cross section; $\alpha_i(f)$ is the signal-energy absorption coefficient arising from internal losses and losses due to radiation into the environment; $c_i(f)$ is the phase velocity; and j is the an imaginary unit.

We can rewrite (2) with (3) taken into consideration in the form

$$S_{yy} = |S_y| e^{j\Theta} = S_{xx} \sum_{i,j=1}^M A_{i1}(r, \varphi) A_{j2}(r, \varphi) e^{-2L(\alpha_i + \alpha_j)} e^{j2\pi f \left(\frac{L}{c_i} - \frac{L}{c_j} \right)} \quad (4)$$

where $S_{xx} = \frac{1}{n_d T} \sum_{k=1}^{n_d} |X_k^2(f)|$ is the leak-signal spectrum at the location of its appearance. Here and

below, dependence of velocities, amplitudes, and absorption coefficients on frequency and coordinates is omitted to shorten expressions.

From expression (4) we shall find autocorrelation function which according to the Wiener-Khinchin theorem is equal to inverse Fourier transform of a cross-spectrum. Thus for autocorrelation function we shall receive

$$R(\tau) = F^{-1}[S_{yy}(f)] = F^{-1} \left[S_{xx} \sum_{i,j=1}^M A_{i1}(r, \varphi) A_{j2}(r, \varphi) e^{-2L(\alpha_i + \alpha_j)} e^{j2\pi f \left(\frac{L}{c_i} - \frac{L}{c_j} \right)} \right] \quad (5)$$

where F^{-1} is the operator of inverse Fourier transform.

Neglecting dependence of absorption coefficients on frequency (It can be made for a narrow spectral band), we can rewrite expression (4) in the form:

$$R(\tau) = \sum_{i=1}^M A_i^2 e^{-2\alpha L} R_{xx}(\tau) + \sum_{\substack{i,j=1 \\ i \neq j}}^M A_i A_j e^{-2L(\alpha_i + \alpha_j)} R_{xx} \left(\tau + \frac{L}{c_i} - \frac{L}{c_j} \right) \quad (6)$$

If AE spectrum is limited in terms of frequency by white noise (signal autocorrelation function is in this case has a single maximum), then the presence of several acoustic paths leads to the enveloping curve of autocorrelation function having a number of maximum values with the coordinates equal to:

$$\tau_{ij} = \frac{L}{c_i} - \frac{L}{c_j}; \quad (7)$$

Where τ_{ij} is the delay time of i-wave in relation to j.

When the velocities of normal waves are known, the distance to AE source can be determined by measuring the delay time. The implementation of the technique will bring about some difficulties related to the absence of a priori information about the released interference component since the excitation efficiency and the propagation rate of certain modes depend on numerous factors that cannot be considered beforehand. In order to overcome this, another measuring channel is introduced. Receiving transducer of the second measuring channel is located at the distance d from the first one. Given this the distance to the source is calculated by a simple equation:

$$L = \frac{d}{\tau_{ij}^{(2)} - \tau_{ij}^{(1)}} \tau_{ij}^{(1)} = \frac{d}{\Delta \tau_{ij}} \tau_{ij}^{(1)} \quad (8)$$

The suggested method was tested using an 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 cylinder. Pressure in the pipeline in all the experiments was 2 atm, flow rate was 12 l/hr.

Leakage location algorithm was tested on five cases of sensor installation. Fig. 2 shows relevant autocorrelation functions of signals registered by sensors located 2 and 5 m away from the leakage, as well as their cross-correlation function. As figures show, cross-correlation function has no clear peak, and autocorrelation function domain over statistical noise is rather large. Since the effective width of signal ranges is more than several kilohertz, such autocorrelation function and cross-correlation function pattern is indicative of a large number of acoustic paths. At the same time, the diagrams make it quite hard to visually define peaks corresponding to a certain path. Moreover, even the calculation of envelope peak coordinates using Hilbert transformation with subsequent differentiation does not enable to easily match autocorrelation function peak coordinates of each path for calculation purposes. This is due to the fact that peaks can merge. It is evident that in this case the easiest way is to select the first side peak and make calculations for it. Calculation results are shown in the table below.

Table

Distance to leakage, m		1 st ACF peak delay, μ s		Location results, m	Error, m
Sensor 1	Sensor 2	Sensor 1	Sensor 2		
2	5	526	270	3,16	1,16
6,5	8,5	265	215	8,5	2,5
7,5	13	937	479	5,75	1,25
13,5	14	195	177	14,16	0,66
14	15,5	177	158	12,8	1,2

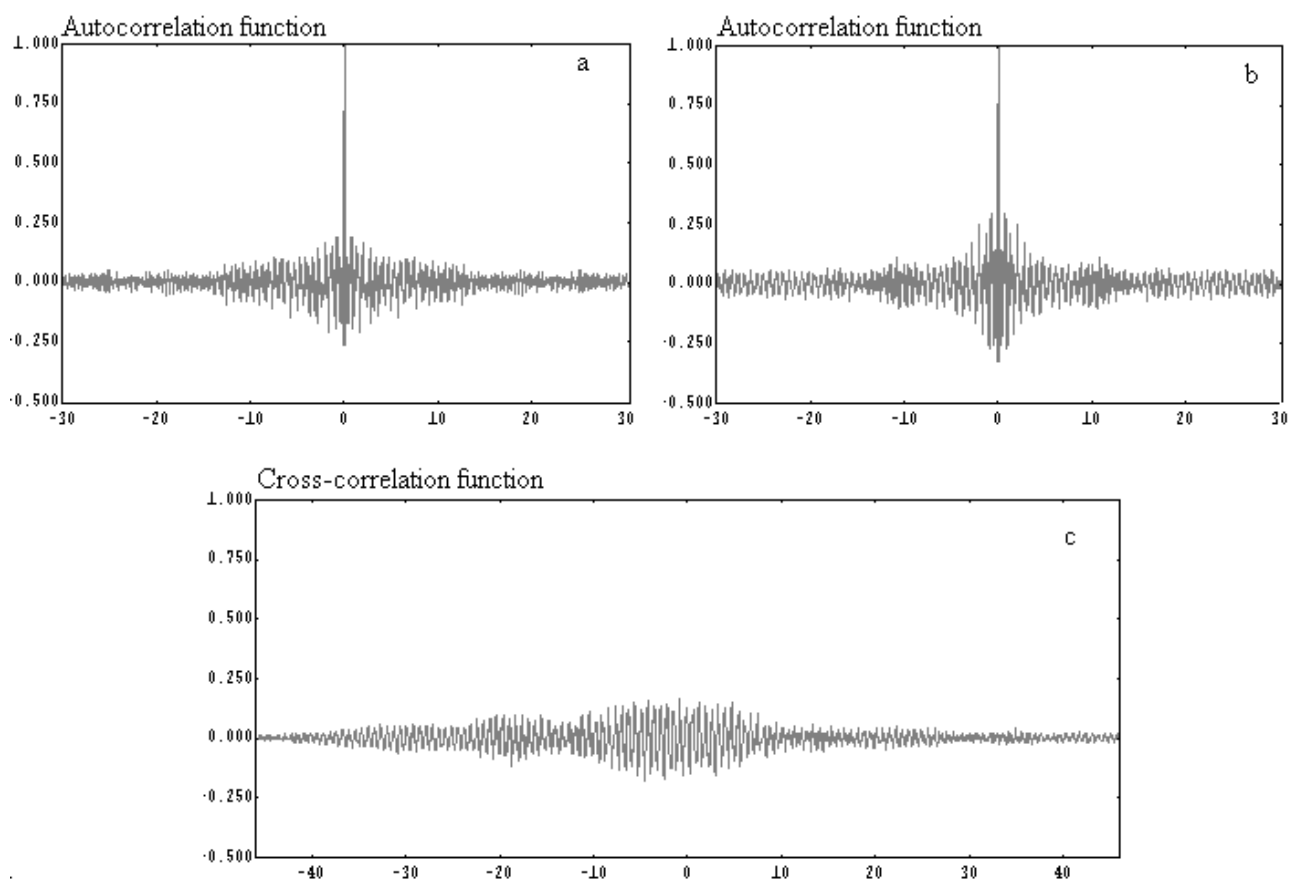
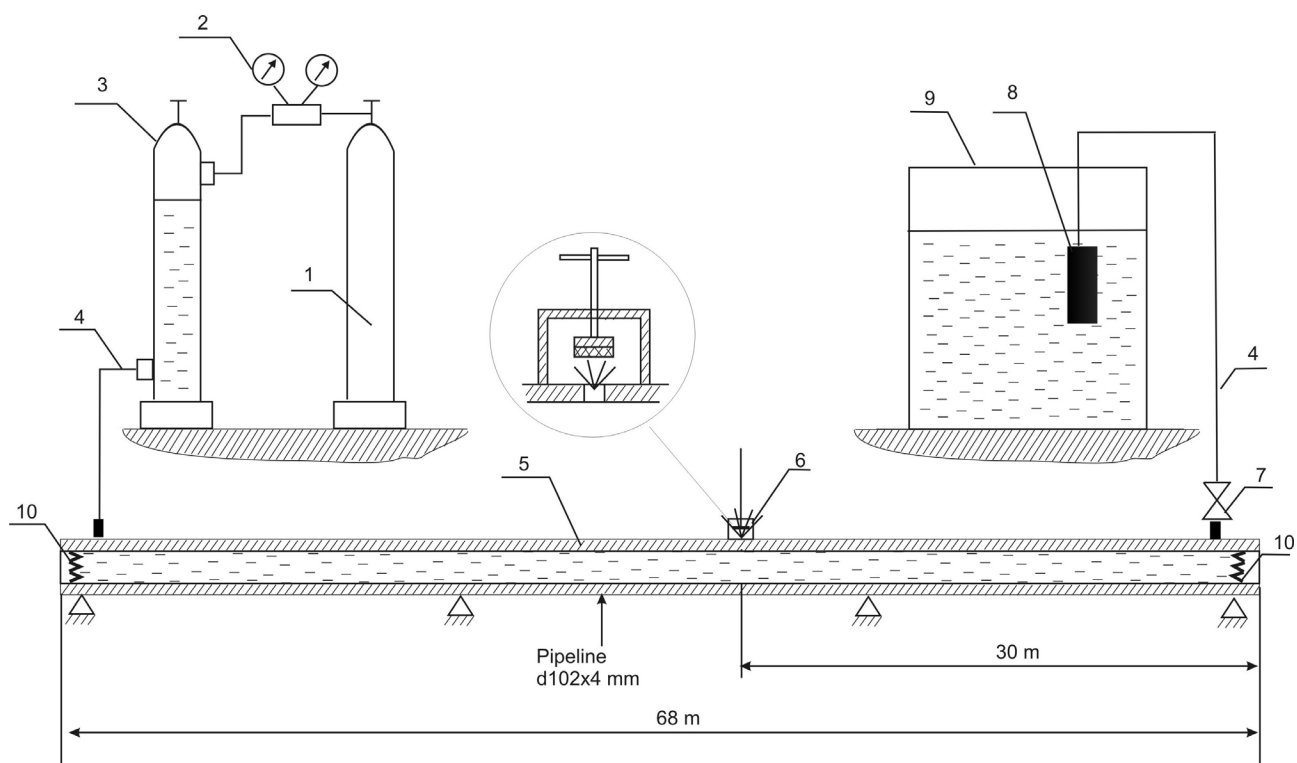


Fig. 2. Correlation functions
a, b - autocorrelation functions of signals are recorded by sensor 1 and sensor 2, respectively;
c – cross-correlation function

As the table above shows, the location error in all calculations is less than 3 m. Such location accuracy is considerably lower than that of conventional correlation algorithms. However, it is suitable for practical purposes, because in cases of accidents a pit 3-4 m in size is made to access the pipe.

References:

1. What's happen in pipe leak detection // Pipe Line Ind. - 1979. - 51, N4. - P.54 -56,58