AN ACOUSTIC METHOD OF DETERMINATION OF LEAKAGE COORDINATES IN GAS PIPELINES

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The present paper describes an important leak-proofness of pipe-lines transporting gas, oil and other chemical liquids. It is revealed that one of the more perspective methods of detection of leakage coordinates of gas-lines is the acoustic correlation method. The employment of whistling acoustic noise propagating in the gas media filling the pipeline is proposed for the detection of leakage coordinates of gas pipelines. In accordance with the length of the pipe section under control and the desired precision of the determination of the leakage coordinates in the pipes, a method of choicing an optimal bandwidth of the filter and a sampling rate of received signals was developed. The results of experimental investigations are submitted. The method can be effectively used in checking the state of the pipe network as well as for solving the problems of management of the power economy objects and environmental protection.

1. Introduction

The control of leak-proofness of pipelines transporting natural and liquefied gases, oil and other chemical products is of great importance in modern technology. Leak-proofness is very significant in performing commerce and technological operations and satisfying the requirements of environmental protection [1].

At present the leak test is mostly performed by the methods of chemical analysis. But the accuracy of the chemical methods, when used for the determination of the coordinates of the leakage in gas pipelines, is low. Thus the mentioned above methods did not satisfy the requirements of modern technology. Methods of ultrasonic non-destructive testing and acoustic emission methods of searching of gas leakage in pipelines were applied only within the last decade. The methods of ultrasonic non-destructive testing, in spite of the good results, are of low capacity and are not acceptable due to the great length of the modern gas pipelines. Good results of leak tests are obtained by acoustic emission methods [1, 2]. They are used for periodical control of the leak-proofness of pipelines transporting oil products and for pipelines of head-supply systems. For this purpose there are often used portable ultrasonic units. The principle of operation of those units is based on the analysis of acoustic noises generated in the sites of leakage of the pipeline.

2. Methodology and instrumentation

There are two groups of ultrasonic devices for the determination of leakage of pipe-lines [2]:

1. Devices in which the intensity of acoustic noises is measured.
2. Devices in which the correlation measurement method is utilized.

Measuring units of the first group have many limitations. The main of them is the low sensitivity and noise immunity. The level of acoustic noises generated in unhermetic places must be much higher than that of received noises and the random noises of the environment. By using this method, it is difficult to determine the coordinates of the damaged place of the pipeline. These shortcomings are not significant for devices in which the correlation measurement method is employed [3, 4]. Piezoelectric accelerom-eters are used, as a rule for the detection of vibrations propagating in the walls of the pipeline. However, the intensity of the noises generated in the walls of the pipeline filled by gases under low pressure $(0, 8 \ldots 4\,\mathrm{kPa})$ is small. In practice the intensity of acous-tic noises propagating in the walls of a gas pipeline a distance of few tens of meters from the damaged place is commensurable with the receiver noises. Besides, the gas pipelines of low pressure usually lays in inhabited places of towns and their structure is very complicated. This leads to multiple reflections of the acoustic signals propagating in the walls of the gas pipeline and the level of random noises is increased. For this reason, a correlative method based on the analysis of acoustic noises propagating in the walls of a gas pipeline is not acceptable for the control of low pressure gas pipelines. Furthermore, gas pipelines in the towns have usually an underground structure which lays under side-walks and other structures. This restricts the direct acoustic contact of the electroacoustical transducers with the walls of the pipeline. In order to solve this problem, a correlation measurement method was developed in which acoustic signals propagating in the gas media filling the low pressure pipeline are used. The employment of a whistling acoustic noise propagating in the gas media filling the pipeline is proposed for the detection of the leakage of low pressure gas pipelines.

Experimental investigations showed that the maximum of the energy of the acoustic noise generated at the damaged sites of the gas pipeline is concentrated in the band of $30 \ldots 50\,\mathrm{kHz}$. It is almost independent of the gas pressure inside the pipeline and of the shape and linear dimensions of the damaged places. It is necessary to note that the spectrum of the acoustic noise is changed when the signal propagates in the pipeline. The components of high frequency are suppressed and maximum of the energy spectrum of the noises moves toward lower frequency. For example, at a distance of one hundred meters from the site of a leakage, the maximum of the signal energy lays usually in the band of $2 \ldots 3\,\mathrm{kHz}$. For the registration of signals of such a low frequency piezoelectric transducers of flexural vibrations were constructed. The piezoelectric transducers are connected with the pipe under control by special tube-like insertions which are screwed to the inspection pits of the gas pipeline. This ensures a direct contact of the piezoelectric transducer to the gas media filling the pipeline under control. A block diagram of the correlation system for the determination of the leakage coordinates in the pipelines is shown in Fig. 1.
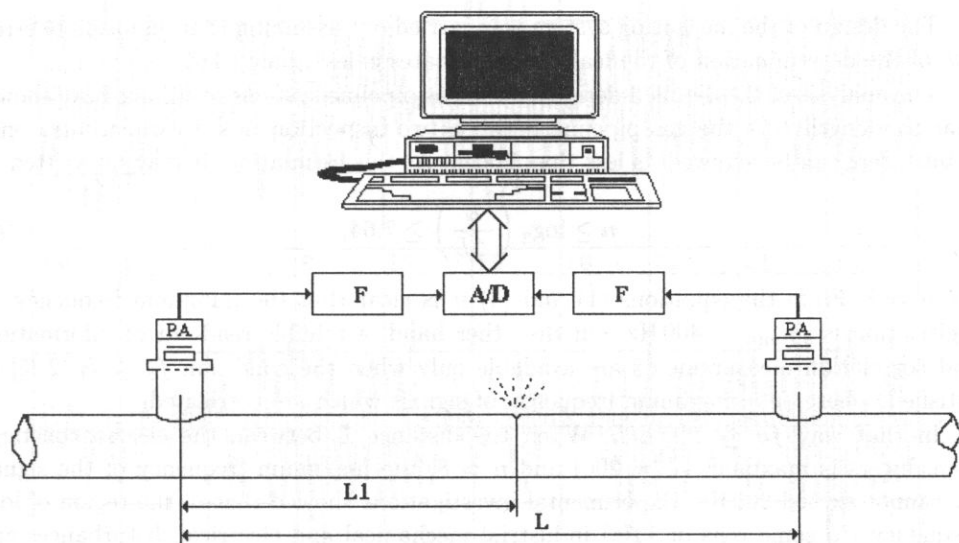
Fig. 1. Block diagram of the correlation system for the determination of a leakage in pipelines.

The acoustic noise signals received by the piezotransducers, after amplification in a primary amplifiers (PA), are sent by coaxial cables to the filters of the signal processing unit. This unit consists of filters (F), an analogue-digital (A/D) converter and a personal IBM computer. After introducing the data of the velocity of sound c in the gas under control and of the distance L between the electroacoustical transducers, the computer determines the frequency f_T of the digitisation of the analogue-digital converter. The digitisation frequency f_T is chosen in accordance with the time needed by the acoustic signal to travel the distance L in the controllable section of the pipeline:

$$f_T = \frac{2^n c}{L} ; \tag{1}$$

where 2^n is the quantity of countings of the received signal; $n = 1, 2, 3, ...$; c is the speed of sound in the controllable gas filling the pipeline.

As a result of the correlative analysis of the received signals, the difference in the input time Δt of two similar signals is determined. The distance L_1 from one of the transducers to the damaged site of the pipeline is given by

$$L_1 = \frac{L - \Delta t \cdot c}{2} . \tag{2}$$

When processing, the function of correlation is obtained by the algorithm

$$K(j) = \sum_{i=1}^{M} (X(i) + Y(i + j)), \tag{3}$$

where $j = 1, 2, 3, ..., N$; $i = 1, 2, 3, ..., M$; X and Y are the digitised values of the received signals; $N = 2^n$ is the number of correlative points of the signal; M is the number of digitised points of the signal.

The design of the measuring system was carried out assuming that an absolute error ΔL of the determination of the leakage coordinates is less than ± 1 m.

The analysis of the detailed designs of the gas pipeline systems of Vilnius have shown that the length L of the gas pipeline between two inspection pits, to which ultrasonic transducers can be screwed, is less than 200 m. At this estimation, it may be written

$$n \geq \log_2 \left(\frac{L}{\Delta L} \right) \geq 7.64, \tag{4}$$

i.e. $n = 8$. From the equations (1) and (4) it is clear that the minimum frequency of digitisation is $f_{T\,min} = 400$ Hz. On the other hand, a reliable read-out of information and correlation measurements are available only when the condition $f_S \leq f_T/2$ [5] is satisfied, where f_S – maximum frequency of signals which are correlated.

In that way $f_S \leq 2^{n-1}c/L$. When the distance L between the electroacoustical transducers is maximal, ($L = 200$) and $n = 8$, the maximum frequency of the signal f_S cannot exceed 200 Hz. Experimental investigations showed that in the region of low frequency (to some tens of 1 Hz) industrial mechanical and electrical disturbances are very considerable. Therefore this region of frequencies cannot be used for correlation measurements; they need much higher frequencies. Thus the number n must be increased, but this implies a considerably increased measuring time.

Experimental investigations showed that $n = 9$ is the optimum number. The band of passing frequencies required for the correlation measurements is supported by a band-pass filter. The lower boundary of the transmission frequency depends on the intensity of industrial disturbances and lays in the region of 20...80 Hz. The higher boundary of the passing frequencies is chosen twice less than the frequency of digitisation and depends on the length of the pipeline under control. When the length of a section of the pipeline is $L = 200$ m, the frequency of digitisation is $f_T = 440$ Hz. If the length of the pipe section under control is less, the frequency of digitisation increases to a few kHz.

3. Results and discussion

The software of the system developed permits the operator to watch the noise signals on the screen of the computer (Fig. 2) and to adjust their levels before the digitisation. Besides, according to the level of the received signals, the operator can preliminary decide on the condition of the gas pipeline under control.

In order to provide, reliability of the correlation measurements, the signals before their correlation ought to have similar frequency spectra. The spectrum analysis of the signals conveyed to the analogue-digital converter enables one to solve this problem. The frequency band of the signals passing the filter is chosen in accordance with the similarity of the spectra of the received signals in both the channels (Fig. 3).

After that the correlation curve and the numerical information of the location of the leakage of the gas pipeline appears on the screen of the computer (Fig. 4). In the case of a high level of environment noises and when the correlation curve has not a single clearly expressed maximum, a summing of the results of separate correlation measurements
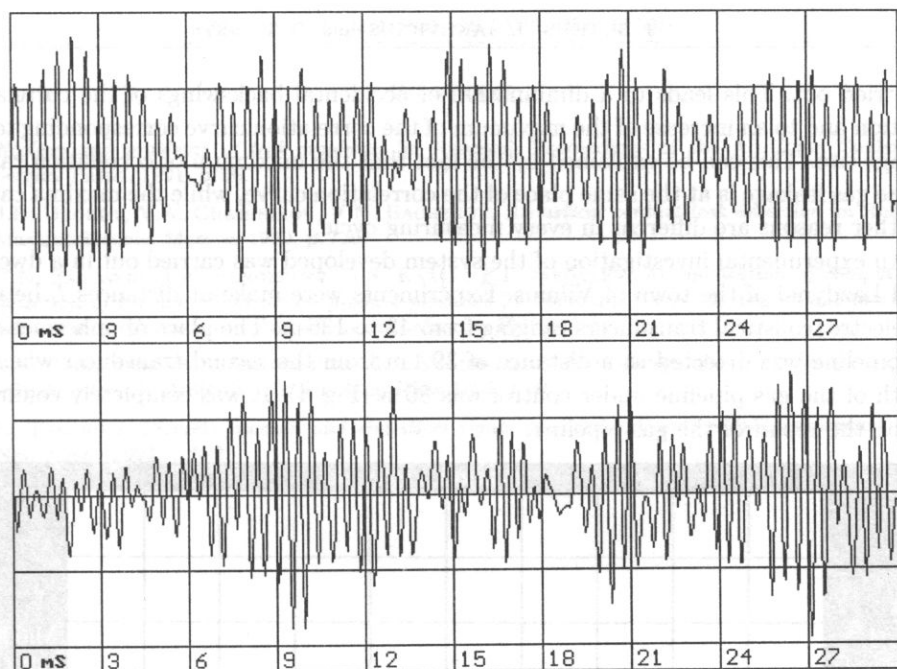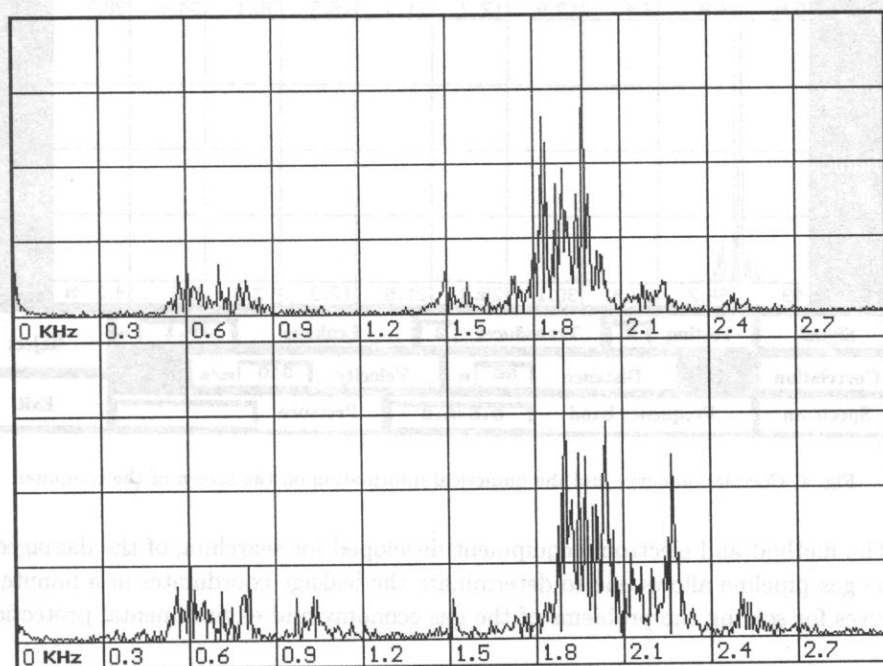
Fig. 2. Noise signal on the screen of the computer.

Fig. 3. Spectra of the received acoustic signals in both channels.

is carried out. This leads to a diminnation of accidental backswings of the correlation function and to an increase of the maximum of the correlation curve corresponding to the leakage site. This can be explained by the fact that the maximum of correlation caused by the gas leakage is at the same place of the correlation curve, while the maxima caused by other reasons are different in every measuring cycle.

An experimental investigation of the system developed was carried out in a dwelling ward Lazdynai of the town of Vilnius. Experiments were make at distances L between the electroacoustical transducers ranging from 43 to 136 m. The place of unhermeticy of the pipeline was detected at a distance of 39.1 m from the second transducer when the length of the gas pipeline under control was 86 m (Fig. 4). It was completely confirmed during the repair of the gas pipeline.
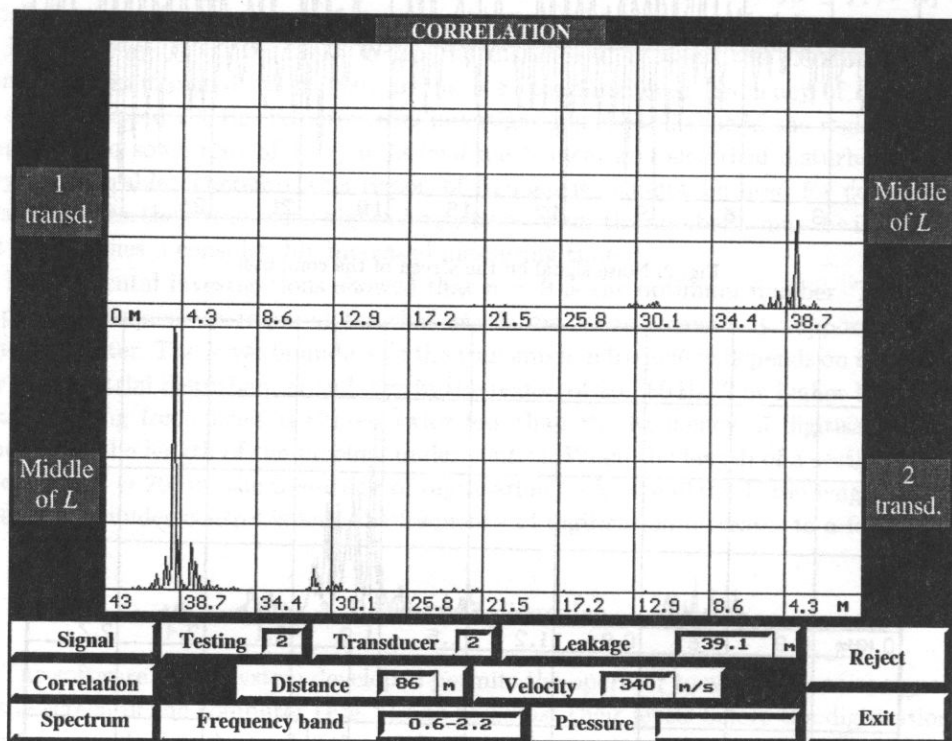

Fig. 4. Correlation curve and the numerical information on the screen of the computer.

The method and electronic equipment developed for searching of the damaged sites of the gas pipeline allows one to determinate the leakage coordinates in a minute time. It serves for solving the problems of the gas economy and environmental protection.

Acknowledgment

References

[1] *Ecology and problems of leak-proofness* [in Russian], Proceedings of the All-Union Conference, Sergiev Pasad, 1991, p. 86.

[2] J.B. DROBOT, V.A. GRESHNIKOV, V.N. BACHEGOV, *Acoustical contact leak detection* [in Russian], Mashinostroenie, Moscow 1989, p. 120.

[3] V.N. ZAGOSKIN, J.A. VENGERCEV, A.S. KAZAK, E.I. JAKOVLEV, *An application of computer for detection of leakage of petroleum product pipelines* [in Russian], Series: Transport and storage of petroleum products and hydrocarbon raw, Moscow 1989, p. 60.

[4] V.S. GODLEWSKIJ, A.A. VLADIMIRSKIJ, I.A. VLADIMIRSKIJ, *Methodology of application of correlative leak detector* "KORSHUN" [in Russian], Kiew 1992, p. 46.

[5] C. THERRIEN, *Discrete random and statistical signal processing*, Prentice-Hall, Englewood Cliffs, New Jersey 1992, p. 392.