Methods of Leak Search from Pipeline for Acoustic Signal Analysis

Emil Rinatovich Saifullin1*, Evgenia Vyacheslavovna Izmailova2 and Shamil Gayazovich Ziganshin1

1Kazan Federal University, Kazan, Republika Tatarstan 420000, Russia; mr.emilsr@gmail.com, shamil.Gz.87@gmail.com
2Kazan State Power Engineering University, Kazan, Republika Tatarstan 420034, Russia; Evgenia.vy.22@yahoo.com

Abstract

Objectives: The article describes the method of defect location determination in the pipelines according to the analysis of their vibrio-acoustic signals. Methods: In particular, the timely detection of transported product leaks will prevent accidents and reduce environmental damage. The graphic programming environment Lab VIEW was used to implement the algorithm of leak search and identification as a working tool. Results: The description and the operation method are provided for the software developed by the authors to record and process the acoustic signals. Conclusion: The aim of the research is to develop methods of transported product leak search according to the analysis of acoustic signals. This work was supported by RFBR grant №16-38-00261.

Keywords: Diagnostics, Energytics, Nondestructive Testing, Petro Chemistry, Vibroacoustics

1. Introduction

The pipelines of various purposes with the total length of about 230 thousand km are operated in Russian Federation. The bulk of which (over 60% of their length) is the main gas pipelines, and the rest ones transport such hazardous liquids as oil, petroleum products, condensate, and a large fraction of light hydrocarbons, ethylene, and liquid ammonia. About 40% of them have worked over 20 years. With the increase of pipeline length and their operation period the number of their stops also increases. The corrosion of pipe material leads to serious accidents which cause irreparable damage to the environment, economy and often may be the cause of death. Therefore, a reliable operation of the pipeline network is not only a technical problem but also a social one, because it directly affects the population interests. To ensure safety, the constant increase of diagnosis volume and quality, material and the financial support of repair and object reconstruction are required. Traditionally the problem of pipeline service life extension is solved by carrying out major repairs with the continuous replacement of pipes or with insulation coating replacement.

2. Research Subject Description

Depending on a measured parameter, an effect accompanying leakage and operation principle the leakage control methods include flow control in one or several pipeline points, the pressure in one or several pipeline points, the sound level in a pipeline and the presence of a radioactive substance near a pipeline. Acoustic control methods include the vast area of materials and product test, based on the registration of elastic wave parameters excited by or appearing in a test object. The correlation method of environmental leak detection and the detection of their locations is based on the measurement and the processing of Vibrio acoustic signals generated by the leak, using two sensors mounted directly on a pipeline Figure 1. The leak detector works on the following principle. Sensors convert the vibrio-acoustic signals in the measurement points into electrical signals, which are supplied to the preamplifiers connected to the amplifying the incoming signals. Then the signals are transmitted to a processing unit by a cable or a radio channel. The processing unit performs analog-to-digital signal conversion and transmits the converted

*Author for correspondence
Methods of Leak Search from Pipeline for Acoustic Signal Analysis

The distance to the leak is determined by the difference of a signal spread period from leak to the first and the second sensor. The delay is determined according to the maximum signal correlation function measured by sensors. This delay can be due to mismatch between signals addressed in equation 5. Leakage location is determined by the calculation according to the following formula:

$$l_{1,2} = \frac{l + v \cdot t}{2}$$

Where $l$ - the distance between the sensors; $v$ - the speed of sound distribution in a pipe (m/s); $t$ - time delay determined by the maximum signal correlation function measured by two sensors; $l_{1,2}$ - the distance from the leak to one (1) or the other (2) measuring sensor. Correlation-acoustic leak detection technology, Figure 2 and correlation leak detectors which implement this technology, have the following high operational and technical characteristics and advantages. High sensitivity, i.e., the ability to detect small leaks; the high precision of leak location determination; high reliability of results at the determination of leak locations; the independence of results on pipeline laying depth; high noise immunity at the determination of leak locations; high performance of pipeline inspection. LAB - the distance between the point A and B (measured along the pipe); LA - the distance from the point A to the leakage; LB - the distance from the point B to the leakage. $t$ - Time delay of signal arrival at the point A about the point B; $v$ - the velocity of signal spread along the pipe. The sign ± is determined by the leak distance determination to one of 2 sensors.

The disadvantages of technology:

- Reveals only the defects of “leakage” type.

It does not demonstrate leaks in the following cases:

- Pipelines with the diameter more than 1 m and (or) the pressure less than 1 atm.;
- Sectional concrete and cast-iron pipes with a “soft” seal between sections;
- The distance of more than 1 km (depends on a pipe type and the mode of occurrence);
- Pipelines for the transfer of viscous liquids (e.g., commercial oil);
- Pipes, which have strong resonance oscillations (usually with a tunnel lining);
- Severe breaks of pipes with the damage of more than 2/3 of the cross section; and
- Pipelines with low acoustic conductivity.

3. Achieved Results

The program of pipeline leak determination is developed by LabView.

The program consists of three sub-programs, which provide the performance of the following functions:

- Signal recording into audio files from two piezotransducers (wav and wrm files);
- Recorded data processing;
- Determination of sound distribution velocity in a studied product;
- Determination of distances to a defect from the first and the second sensors; and
- Report drawing up.

All components are combined in a single shell.
The sub-program “Registration and record of acoustic signals” allows you to record a signal transferred from piezoelectric sensors signal into WAW or WRM format with a user-defined sampling rate and record duration.

The front panel of this subprogram is set with:
- Checked area data;
- The number of recorded signals and their duration;
- Signal sampling frequency; and
- File directory.

The program operation algorithm is shown on Figure 3.

To determine the distance from one of the sensors to a defect it is necessary to know the speed of pulsation distribution in the fluid that fills a pipeline and distributing waves from a defect along a pipeline. This speed is slightly below the speed of sound in the fluid filling a pipe, because the occurring elastic deformation of pipeline walls leads to the distribution speed loss among these fluctuations. This value ranges from 1100 m/s to 1300 m/s for steel and iron pipes. Theoretically, the velocity \( V \) is determined by in equation:

\[
V = \frac{\rho \frac{D}{h}}{[1 + \frac{k}{(\rho D)^2}]} \tag{2}
\]

Where\( \rho \) - liquid density; \( K \) - volumetric modulus of liquid elasticity; \( D \) - inner diameter of a pipe; \( h \) - pipe wall thickness; \( G \) - elasticity modulus of the pipe material.

Speed rate accuracy under this formula makes \( \pm 10\% \). The ratio \( D/h \), making the part of the formula (2) may change during the operation due to wall wear and films on the wall. Besides, the sections of different thicknesses may be located at one pipeline section. It leads to the fact that the calculated values of the velocity may vary considerably, leading to errors in leakage location calculation. Besides, the formula (2) does not consider the damping influence of heat insulation. It is also valid only for relatively small acoustic frequencies (up to 1000 Hz). More high-frequency vibrations that are typical of bending and shell forms of pipe vibrations may distribute with different speed values. In this case, the total signal perceived by sensors will contain the components that come in several ways with their propagation periods. It will lead to the appearance of additional peaks in the correlation function, and the additional errors during the search for a leak. It is necessary to determine the pulsation speed during each measurement to have an actual value of flow pulsation distribution velocity in a particular pipeline and improve the accuracy of measurements. This function is performed by the sub-program “Sound speed determination”. It compares the signals which come from two piezoelectric sensors and calculates the time delay of the signal \( \tau \) arrival \( \tau \), which is determined by correlation function maximum. It is necessary to know the distance between the sensors \( L \) on the front panel of the program Figure 4, after which the following formula determines the speed: \( v = \frac{L}{\tau} \). The program algorithm is shown in Figure 5. If there is a leak between the sensors, its location can be determined by analyzing mutual correlation function of the signals recorded by the sensors from a defect to the first and the second sensor according to the signal distribution time. The delay is determined according to the maximum of signal correlation function measured by sensors. At the known signal distribution velocity (sound) along a pipe with the information about the distance between sensors.
the sensors, one may determine the location of a defect by the calculation accurately according to the following formula:

\[ l_{1,2} = \frac{1}{2} \left( l \pm vt \right). \]  \hfill (3)

where \( l \) – the distance between sensors; \( v \) - the speed of sound distribution in a pipe (m/s); \( t \) - time delay defined by the maximum of signal cross-correlation function measured by two sensors; \( l_{1,2} \) - the distance from a defect to the first (1) or the second (2) measuring sensor. The sign \( \pm \) is determined by the fault distance determination to one of 2 sensors. The sub-program “The definition of the fault location” calculates the distance from each of two sensors to the point of defect location. The front panel of this program Figure 6 has the following indicators:

- The velocity of sound distribution through a pipe;
- The distance between sensors;
- File directory containing the recorded signals from the first and second sensors.

Program operation algorithm is shown on Figure 7.

![Figure 5. Sound speed determination algorithm.](image)

![Figure 6. Front panel of the subprogram “Defect location determination”.](image)

![Figure 7. The algorithm of leak location determination.](image)

4. Conclusions

The reliability and the economy of city and industrial project heating depend primarily on the actual technical condition of pipelines and in particular on the corrosive state of pipes. With the increase of length and pipeline operation period, the number of their stops also increases. Hidden corrosion leads to serious accidents which cause irreparable damage to the environment, the economy and often it may be the cause of death. Traditionally the problem of pipeline service life extension is solved by the performance of major repairs with the continuous replacement of pipes or with the insulation coating replacement. To ensure the trouble-free operation of pipelines, it is necessary to have reliable information easy to understand and use concerning the actual technical condition of pipes, by
which one should carry out the replacement of the “old” parts in time. The methods which are currently used to control pipelines are based on inaccurate knowledge concerning the degree of a pipeline wear. Thus, the significant amounts of repair, including the repairs on pipe replacement are performed either with a large excess or are not carried out at all. The developed software allows you to receive the data about the place of a transported product leak.

5. Summary

The control methods are necessary which allow detecting not only the leakage of a heat carrier but also the levels of pipeline metal corrosive damage to improve the reliability of heat supply to the organizations operating heating networks. One of the most promising monitoring methods of a pipeline condition is the acoustic method. The characteristics of the pipeline material mechanical properties, its stress-strain state, the presence of various scale defects may be determined by various physical properties analysis in the acoustic field of a controlled pipeline. The analysis of monitoring object acoustic signal characteristics and the test signals distributing in an object material allows performing diagnostics, both on micro and macro levels. The degradation of an object is determined by the characteristics of its oscillations in the low-frequency (sound) range, and the material condition, the presence of stresses is determined according to the change of test pulses distribution characteristics within the ultrasonic range. An important element of further research is the development of new signal processing methods. The existing methods for the analysis of noisy signals and spectra, based on traditional methods of Fourier transformations introduce the mistakes (Gibbs effect oscillations and uncontrollable correlations), which makes their use impossible at the analysis of noisy signals characteristic for a pipeline control. It is expected to apply the methods of data processing and data analysis in the future based on wavelet transformations. During the processing of acoustic signals, they have to encounter the analysis of large amounts of data collected from experiments. The use of personal computers makes it possible to process such amount of data, but there are difficulties when you write the software recognition algorithm and the algorithm for defect classification.

6. Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. This work was supported by RFBR grant №16-38-00261.

7. References

1. Arundas PH, Dewangan UK. Compressive Strength of Concrete based on Ultrasonic and Impact Echo Test, Indian Journal of Science and Technology. 2016 Jun; 9(23):1−7.
2. Vankov YV, Ziganshin SG, Izmailova EV, Politova TO. Methods Check the Piping using a Neural Network, Conference Series: Materials Science and Engineering. 2015 Jun; 86(1):1−3.
3. Timashev S, Bushinskaya A. Diagnostics and Reliability of Pipeline Systems, 1st Edition, Springer: London, 2016 Mar.
4. Nagarajan S, Rajendran N. Comparison of Fault Diagnostics on Z-Source and Trans Z-Source Inverter Fed Induction Motor Drives, Indian Journal of Science and Technology. 2015 Nov; 8(32):1−9.
5. Samoilov EV, Tuzhilkin YI. Detecting Leaks in Plastic Pipes, Journal American Water Works Association. 2000 Feb; 92(2):82−94.