Use of Lamb Wave Dispersion Curve Extraction from AE Signal Spectrogram for Determination of Distance to AE Source

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Abstract
Case of AE testing of gas pipeline is described. Owing to the large value of acoustic signal attenuation and the large distance between sensors, signals from AE sources arrived only to one of the nearest sensors. This made it impossible to carry out usual location of sources based on the arrival time differences. At the same time the Lamb wave dispersion curves were observed on a number of AE signal spectrograms. Therefore, the technique of Lamb mode dispersion curves extraction from AE signal spectrograms by using the Hough transform was applied. Application of the offered technique on these objects appeared successful. The sources co-ordinates were calculated, and then, with the use of the known attenuation coefficient the effective amplitudes of signals were calculated, that enables AE classification. Furthermore, the use of dispersion curves analysis allowed for determining an average value of the wall thickness between AE source and AE sensor.

Keywords: Lamb waves, guided waves, signal processing, tubes and pipes, AE source location, average thickness, Hough transform

1. Introduction
The safe operation of high-pressure pipelines of municipal gas supply network is a vital problem in the connection with its great potential damage. The increased demands are imposed upon the quality of design, construction and further maintenance of such gas pipelines. The important component in service is the technical diagnosis, which provides a way of evaluating the technical state of pipelines and making a forecast for the next years. The present paper shows some novel approaches to the technical diagnosis of high-pressure gas pipelines within the city through the example of the pipeline section laid along Ozernaya St., Moscow, (Table 1) which is operated by “MOSGAZ” company.

Table 1. Parameters of pipelines under testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Nominal diameter</td>
<td>DN 1020 mm</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>10.6 mm</td>
</tr>
<tr>
<td>Pipe section length</td>
<td>500 m</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>10.8 atm</td>
</tr>
<tr>
<td>Fluid transported</td>
<td>Gas</td>
</tr>
<tr>
<td>Type of pipelining</td>
<td>Subsurface. Two runs of pipeline in a single duct</td>
</tr>
<tr>
<td>Service life</td>
<td>32 years</td>
</tr>
</tbody>
</table>

The purpose of testing was to evaluate the technical state according to the analysis of acoustic emission data. On performing the testing, the AE system “A-Line PCI-8” produced by “Interunis” company and the acoustic emission sensors “GT200” produced by “GlobalTest” company (Russia) were employed.

2. Quasi-monitoring
When carrying out the diagnostics, the experts had to solve two specific problems connected with gas pipeline operation in an urban setting.
The initial problem was that an internal pressure in pipelines of this type is generated at the gas distribution station, and a value of outlet pressure is maintained constant. A conventional pressure buildup procedure needed for carrying out the AE testing would require interruption of the gas supply to consumers. To carry out the testing, it was decided to take into account the fact that the gas consumption by users results in daily fluctuations of internal pressure. The amplitude of these fluctuations is up to 10 to 15% of the nominal pressure. For this reason the AE testing was performed in the mode of so-called quasi-monitoring consisting in that the AE data were collected during the time period extended to 4–5 h, sufficient to record the signals associated with degradation processes in the metal of pipe. The following defects may be detected in such conditions: stress corrosion cracking at the stage of crack coalescence, delayed fractures, significant corrosion damages of the pipe wall surface, fatigue cracks at the stage of the critical length, when the uncontrolled growth is expected.

3. Method for dispersion curves extraction from spectrograms

The next problem was related to provision of the required number of pits since they are the only way to access the buried pipeline during the AE testing. Due to crossings of the pipeline with roadways, the pits were excavated at considerable distances from each other (Table 2).

<table>
<thead>
<tr>
<th>Table 2. Pit numbers and distances between them</th>
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<tr>
<td>Pit numbers</td>
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<td>Distances between pits, m</td>
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The noise level and attenuation of the acoustic signal at the pipeline under testing were equal to 21-25 dB and 1-1.5 dB/m, respectively. The use of the conventional method for AE source location based on arrival time differences of AE signals recorded by nearest sensors was possible only on the section of 42-m length between pits #7 and #8. Analysis of AE data showed that this pipe section had no active AE sources.

For solving the problem of AE source location on pipe sections having the length from 70 to 80 m, a waveform analysis technique was used. The principle of this technique is as follows. In most cases AE testing is performed on steel objects having the wall thickness of 3 to 50 mm, and the typical operating frequencies of AE sensors are within the range of 20-1000 kHz. In this situation the signal received by any AE sensor, as a rule, is a combination of fundamental modes of Lamb waves ($S_0$ and $A_0$) [1]. The main feature of this type of waves is dispersion, the frequency dependence of the propagation velocity. For steel the values of group velocities vary within the range from 0 m/s to 5.3 $\times$ 10^3 m/s. Therefore, in spite of the fact that the crack emits an AE signal as an impulse with the length of order of 1 µs, different frequency components of the signal arrive to any sensor with a spread of tens and hundreds microseconds.

The promising method for analyzing AE signals, which propagate as the Lamb waves, is application of spectrograms, which give a signal energy distribution in both time and frequency [2-3]. Let’s consider the case of a short wideband AE signal emitted by the source at the time point $t_0$, which propagates along the object of thickness $h$ in the form of the combination of $S_0$ and $A_0$ modes and which is received by the AE sensor being at the $L$ distance from the source. Each of the frequency components arrives to the acoustic emission sensor twice, namely, at the time points $t = L / v_{GR} \cdot S_0 + t_0$ and $t = L / v_{GR} \cdot A_0 + t_0$. Accordingly, on the spectrogram of the AE signal there are distinctive portions of two curves, which are specified by equations:
A modification of the generalized Hough transform has been developed [4-6]. It enables the automatic dispersion curves extraction from spectrogram by determining their parameters, namely, the distance to the AE source L, the source operation time $t_0$, and the object wall thickness $h$.

Addition of this technique to the capabilities of the customized software "A-Line" [7] has allowed AE source location even when the AE signal arrives only to one acoustic emission sensor. Necessity for such technique arises, for example, when testing buried pipelines with a large distance between pits, or when only one-sided access to any extended object is available. Thus, the technique enables AE source location in some instances when it is impossible to use the traditional method based on the arrival time differences, which requires the AE signal arrival at least to 2 nearest sensors.

The experiments conducted with the use of a Hsu-Nielsen source have shown (Fig. 1), that the location accuracy when employing the developed technique reaches 1% of the distance between AE sensor and the source [4].

\[
t(f) = \begin{cases} 
  \frac{L}{v_{GR}} s_0(f, h) + t_0, \\
  \frac{L}{v_{GR}} a_1(f, h) + t_0. 
\end{cases}
\]

4. AE data analysis

When analyzing AE signals received from the pipe sections between pits #1 and #7, particular
attention was given to a number of AE signals with amplitude from 57 to 68 dB, arriving to the sensor mounted in pit #5, but not reaching the AE sensors mounted in adjacent pits #4 and #6 because of signal attenuation. The location executed by the present method showed that the sources were separated from the AE sensor in pit #5 by 1.0 to 3.5 m (Fig. 2). The effective amplitudes of signals were calculated with the use of known attenuation coefficient that made possible to classify AE sources as the “noncritical active sources”.

![Waveform, spectrum and spectrogram of the AE signal received by the AE sensor in pit #5, as well as the corresponding dispersion curves and their parameters](image)

Fig. 2. The waveform, spectrum and spectrogram of the AE signal received by the AE sensor in pit #5, as well as the corresponding dispersion curves and their parameters

It is interesting to note that the analysis of dispersion curves makes it possible in some instances to determine the average wall thickness of pipeline along the line between the AE signal source position and the acoustic emission sensor position. The data analysis showed that the average wall thickness was equal to 11 mm. This result is consistent with the measurements of wall thickness in the pits.

5. Conclusions

1. The AE testing of high-pressure gas pipeline within the city was carried out.
2. The AE testing was performed in the mode of so-called quasi-monitoring consisting in that the daily fluctuations of internal pressure were used and the AE data were collected during the time period extended to 4–5 h.
3. The use of the technique of dispersion curve extraction from spectrograms based on the Hough transform enables the location of AE sources, using AE signals that arrive
only to the nearest sensor.

4. This technique also allows AE system to measure the average wall thickness between AE sources and AE sensors.

References