Method for Dispersion Curves Extraction from Spectrograms and its Applications

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E	Young's modulus, GPa
f	Frequency, Hz
h	Wall thickness, mm
L	Propagation distance, m
t	Time, μs
t_0	Source operation time, μs
V_{A_0}	Group velocity of A_0 wave, m/s
V_L	Velocity of bulk longitudinal wave in the object material, m/s
V_{S_0}	Group velocity of S_0 wave, m/s
V_T	Velocity of bulk transverse wave in the object material, m/s
W	Spectrogram
ε	Threshold level, %
μ	Poisson's ratio
ρ	Density of a material, kg/m^3

INTRODUCTION

The main purpose of new researches in the field of acoustic emission (AE) is development of techniques based on intelligent processing of waveforms, rather than on analysis of a limited set of AE parameters.

In most cases AE testing is performed on steel objects (V_L =5.9·10^3 m/s, V_T =3.1·10^3 m/s) with the wall thickness of 3 to 50 mm. On typical AE sensors operating frequencies (30–500 kHz) bulk wave lengths have comparable values from 6 to 200 mm. In this situation a necessity arises to use the model of Lamb waves [1] (Fig. 1). In most cases the major part of energy is transferred by fundamental symmetric S_0 and antisymmetric A_0 modes. For steel the group velocity values vary within the range from 0 m/s:

$$V_{A_0}\left(f \to 0\right) = 2 \cdot \sqrt[4]{\frac{E}{3\rho\left(1-\mu^2\right)}}\sqrt{\pi\ f\ h}$$

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to $5.3 \cdot 10^3$ m/s:

$$V_{S_0}(f \to 0) = \sqrt{\frac{E}{\rho(1-\mu^2)}} = V_T \sqrt{\frac{2}{1-\mu}}\,.$$

Typically AE signal is emitted by a crack as a wideband impulse with the length of order of 1 μs or less. The presence of the frequency dependence of propagation velocity results in that the different frequency components of the signal arrive to an acoustic emission sensor with a spread of tens and hundreds microseconds, that substantially impairs an accuracy of AE source location.

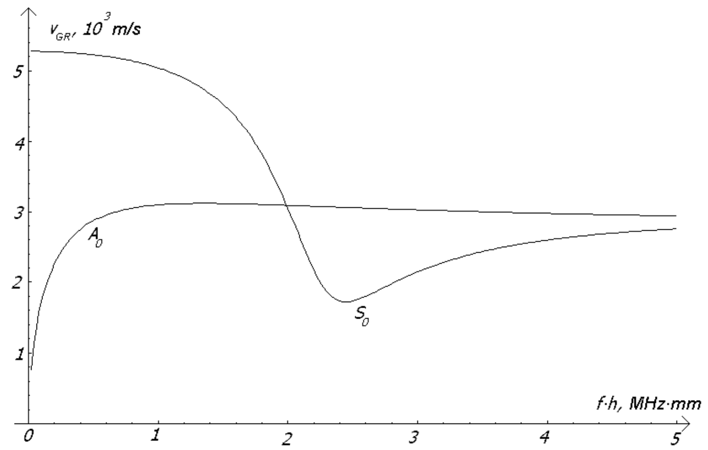

FIG. 1—Lamb waves dispersion curves

The promising method for analyzing AE signals propagating as Lamb waves is application of spectrograms $W(t, f)$ – special transforms (Fig. 2) 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 S_0 and A_0 modes combination and 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 $t = L/V_{S_0} + t_0$ and $t = L/V_{A_0} + t_0$. Accordingly, two distinctive curves specified by equations

$$t(f) = \begin{cases} L/V_{S_0}(f,h) + t_0 \\ L/V_{A_0}(f,h) + t_0 \end{cases} \qquad (1)$$

are shown in the signal spectrogram (Fig. 2).

Thus, knowing the object thickness, the distance to source and the source operation time, it is possible to characterize the AE signal spectrogram; alternatively, having the signal spectrogram, it is possible to determine the propagation distance, the source operation time and the object thickness [4].

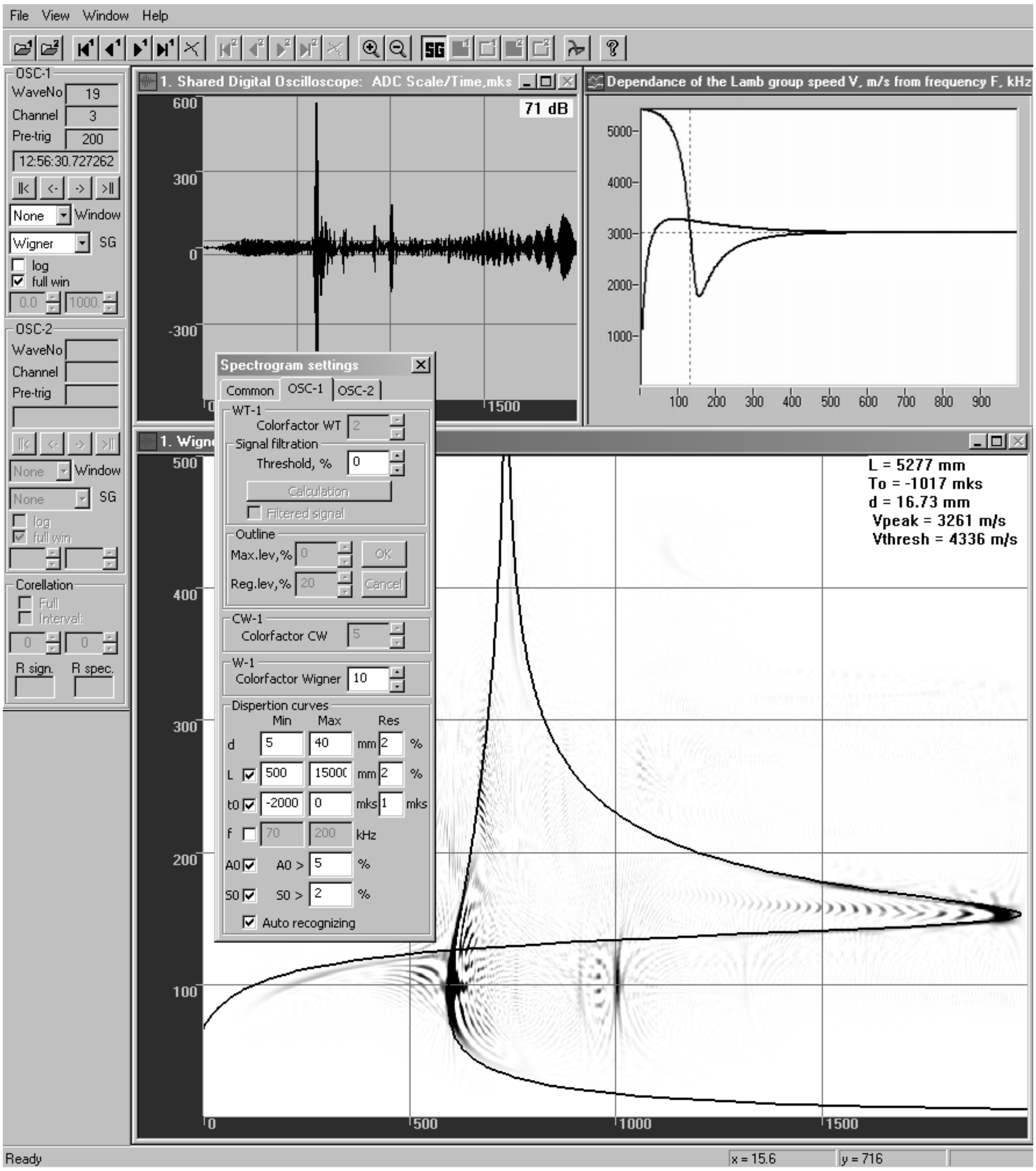

FIG. 2—AE waveform, Lamb wave dispersion curves and AE signal spectrogram

EXTRACTION METHOD

In addition to the parameters specified above, the AE waveform, and thus, the AE signal spectrogram, are influenced by crack type, radiation direction, signal attenuation, frequency characteristic of AE sensor, noise, and edge reflections. The exact values of coefficients, which characterize the influence of these factors, are frequently unknown, so it is impossible to apply the simple analytical methods for calculating the object thickness, the propagation distance and the source operation time.

Therefore, to determine the parameters specified, it has been decided to apply the Hough transform-based method [5] modified for searching the Lamb wave dispersion curves.

Let us consider a family of dispersion curves specified by the equation (1) with parameters $\{L_i, t_i, h_i\}$. This parameters forms a so-called parameter space, each point of which corresponds to a certain dispersion curve on the plane $\{t, f\}$. Each point of the parameter space is assigned with a counter being equal to the quantity of points on the spectrogram, which fulfill the condition $|W(t,f)| > \varepsilon \max(|W|)$ and belong to the dispersion curve (1) related to the given point $\{L_i, t_i, h_i\}$. Here ε is a threshold level specified by the user (usually several percent), $\max(|W|)$ – maximum absolute value of the spectrogram coefficients. Comparison of counters values permits to find the desired dispersion curve, containing the greatest quantity of spectrogram points with absolute values above the threshold (Fig. 3).

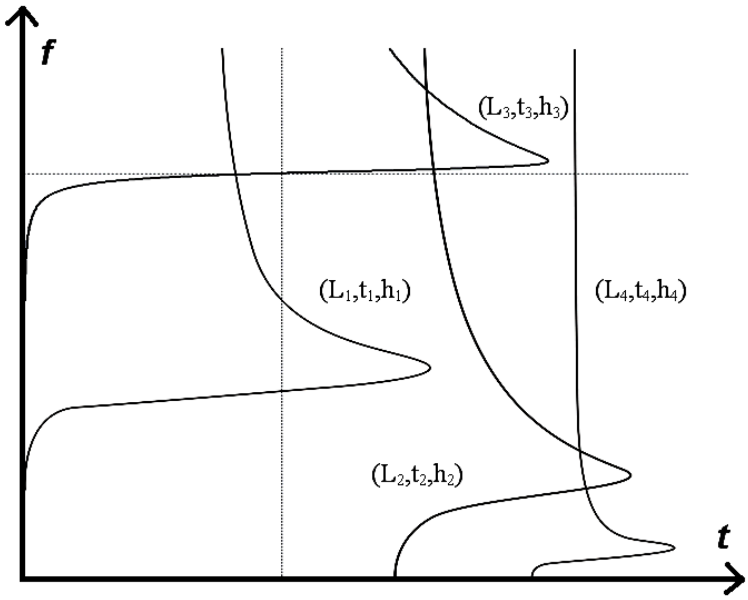

FIG. 3—Family of dispersion curves

It has been found that the spectrograms based on Wigner-Wille and Choi-Williams transforms are the most suitable for the experimental data analysis.

PRACTICAL APPLICATION

For manual and automatic processing of the acoustic emission waveforms and spectrograms, “INTERUNIS” company has developed the customized software “A-Line OSC Processing” (Fig. 2), allowing for making the following operations [6] both associated with the Lamb waves analysis:

- Lamb wave dispersion curves calculating;
- spectrogram calculation based on various transforms (continuous wavelet transform, Choi-Williams and Wigner-Wille distributions);
- superimposition of dispersion curves and spectrograms;

and universal:

- spectrum calculation;
- filtering of waveforms;
- combining and averaging of waveforms, frequency spectra and spectrograms;
- filtering of noise in waveforms;
- calculation of special parameters according to waveforms, frequency spectra and spectrograms: energy values within each frequency range, correlation values according to waveforms and spectra, and frequencies of spectral maxima etc.;
- sorting of signals according to parameters specified above;
- conversion of AE waveforms into a WAV sound format.

Addition of the method of dispersion curves extraction from spectrograms to the capabilities of the software “A-Line OSC Processing” has allowed for developing two fundamentally new techniques.

The first technique makes it possible to determine the distance to AE source if the signal arrives only to one AE 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. In this case, after signals arrival to AE sensors the waveforms are recorded, the spectrograms related to them are calculated and the dispersion curves are extracted with subsequent calculation of the parameter L, characterizing the distance to AE source. The accuracy, in contrast to the standard method based on the arrival time differences, reaches 1% of the distance.

This technique was tried out during testing a buried pipeline with the distance between pits of about 40m. In inspecting the object, a number of AE signals arrived only to one of the mounted AE sensors was registered. The lack of data for the time of arrival to the second AE sensor gave no way of defining the source coordinates, that in turn did not allow for classifying AE sources. The location executed by the offered method showed, that the sources were separated from the AE sensor by 1.0 to 3.5m, and it made possible to classify AE sources as the «noncritical active sources».

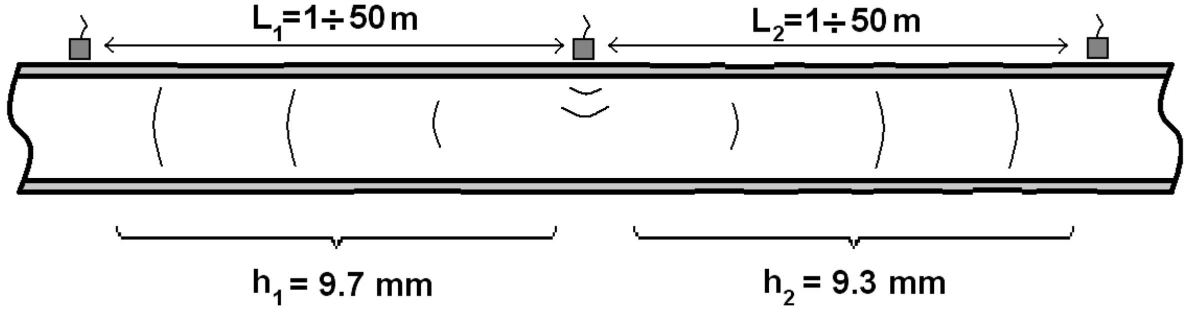

FIG. 4—Emitter and receivers arrangement on the testing object and the average thickness values between them

The second technique substantially enhances the standard AE system capabilities and allows for measuring an average (integral) thickness [7] of the testing object walls (e.g., a gas pipeline or a tank) between two points of access with an accuracy to 1% of the initial value. Such technology is usable for express testing or monitoring the total loss of metal weight. This method is of particular value during inspection of the large-sized object, or during testing the object, when access to the major part of its surface is impossible or complicated, for example, because the insulation removal is undesirable. The work scheme is as follows: an emitter and a receiver are placed on the object at the distance of several meters or tens meters (Fig. 4) from each other. As the emitter and receiver used are the wideband acoustic emission sensors connected to the “A-Line DDM” system manufactured by “INTERUNIS” company. The emitter radiates a wideband impulse with a length of about 1μs. By calculations similar to those described in the first technique, the value of parameter h characterizing the average value of the wall thickness of the object between the source and the receiver is determined from received signal spectrogram.

To check the second technique, a series of experiments were performed on pipelines and cut portions of pipes having a wall of 8–17 mm thickness and 530–1220mm diameter with and without insulation, liquid-filled and empty, and also on a spherical gasholder with a 40mm thick wall. The experiments performed on the gasholder and on the gas pipeline with new factory insulation have shown that the area once only tested from the source to the receiver can amount up to 12m. The experiments on a gas pipeline without insulation proved the effectiveness of this technique at distances of at least 56m.

CONCLUSIONS

1. The Hough transform-based method is developed for automatic dispersion curves extraction from spectrogram with defining their parameters – the distance to the AE source, the source operation time and the object thickness.
2. The technique has been successfully tested using the experimental data both from the AE signal simulator, and also from the actual acoustic emission sources.
3. The developed technique allows for calculating the distance to the signal source with an accuracy to 1% even when the signal arrives only to one sensor that gives the chance to perform the AE testing both in case of buried pipelines with the large distance between pits, and in case of one-sided access to a particular extended object.
4. The automatic dispersion curves extraction substantially enhances the capabilities of usual AE equipment, making it possible through the use of "emission-reception" mode to perform measurements of the average (integral) wall thickness of the testing object (for example, a gas pipeline, a tanker or a tank) between two access points with an accuracy to 1% of the initial value. Such technology can be used for express measuring or monitoring the total loss of metal weight. The distance between two access points can amount up to 56m.

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