

The Analysis of Efficiency of Acoustic Emission Diagnostic Method for the Determination of Defect Coordinates

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Abstract – Acoustic emission (AE) method is widely used as a non-destructive control tool of vehicle points and construction and also as a tool for technical condition monitoring. One of the most important AE diagnostic technological operations is the determination of AE source defect coordinates. Modern defect location techniques allow detecting coordinates of developing defects with high accuracy and reliability. There are several AE source detection methods, but the most popular one is a signal arrival time difference method.

Keywords – Acoustic emission, defect coordinates, diagnosis.

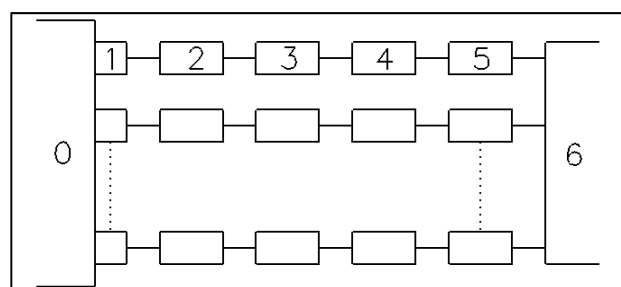


Fig. 1. Multichannel AE hardware functional diagram: 0 – control object, 1 – converter, 2 – preamplifier, 3 – filter, 4 – main amplifier, 5 – acquisition system (signal processing block), 6 – determination block of source location (coordinates).

I. INTRODUCTION

One of the most perspective methods for evaluating the technical condition of industrial objects, such as vehicles, pipelines, reservoirs, is the acoustic emission (AE) method [1] – [6]. Acoustic emission is the radiation process of elastic waves caused by the local dynamic restructuring of the internal structure of the material. AE is a passive method of non-destructive inspection method, because the elastic oscillation source is an object that emits as a result of its external effects, such as mechanical loads, pressure, temperature changes.

AE method in comparison with other non-destructive test and diagnostic methods has a number of advantages, including the possibility of controlling small as well as bulky items throughout the volume of production, test and operation process. The given method allows keeping track of defects in real-time without interrupting the resource tests. The main advantage of this method is the high susceptibility to the development of existing defects.

During the control process using AE method, a control object is in the loaded condition. Crack or other defect that develops in the loaded object emits acoustic waves that are recorded with the help of acoustic emission converter (AEC) 1 (see Fig. 1). Afterwards, AE signal is strengthened by preamplifier 2, but noise is filtered by filter 3. The signal is again reinforced in main amplifier 4 and converted from analogue to digital format in order to further process the required data in signal processing block 5 and in determination block of source location 6.

Determination or localization of AE source coordinates is one of the most important technological AE diagnostic operations. Determination of coordinates is defined in a plane without detecting the depth of material defect of the controlled object. When determining the AE signals that come to several AE converters, it is possible to determine the parameters of the source coordinates. For this purpose, the signal arrival time and amplitude are used. Values of the above-mentioned factors vary depending on the distance between the defect and AEC.

In practice, time difference of arrival (TDOA) methods are frequently applied. These methods include linear, planar and spatial location, as well as regional detection methods [7]. Two methods for the detection of continuous AE (continuous emission can be characterised by a low amplitude and high signal frequency) sources are used:

1. cross-correlation function-based method;
2. method, where attenuation is evaluated.

II. DEFECT DETECTION METHODS OF ACOUSTIC EMISSION

A. Acoustic Emission Defect Coordinates Using TDOA Method

The most common AE source localization is performed by a signal arrival time difference method, where the signal arrival time is determined by the maximum amplitude or reaching a threshold.

In linear objects such as tubes, pipes or bars, fault location can best be determined by a linear localization method. Linear localization method requires two AE converters (AECs): if the defect is located midway between the two converters, arrival time difference $\Delta t = 0$, while if the defect is closer to any

converter, $\Delta t = 2\Delta l/c$, where Δl – the source of deviation in relation to the centre point, c – the speed of ultrasound in the object. In this case, c is a certain value, while Δl is determined during control; thereby it is possible to determine coordinates of the object with respect to a line central point joining two AECs.

The plane has been examined on which there are 2 AECs at a given distance $\Delta d_{1,2}$. TDOA signal to these AECs is registered and known – $\Delta d_{1,2}$. Knowing the oscillation propagation velocity of this material, the hyperbole, on which there is a defect, can be determined. Working with three AECs, the source will be on the intersection of two hyperboles; each is fixed to its AEC pair.

Time difference of arrival for the first and second AEC pairs can be expressed as follows:

$$\Delta t_{1,2} = t_2 - t_1 = \frac{\Delta d_{1,2}}{c} = \frac{\sqrt{(x-x_2)^2+(y-y_2)^2} - \sqrt{(x-x_1)^2+(y-y_1)^2}}{c} \quad (1)$$

where (x_1, y_1) – the first AEC coordinates; (x_2, y_2) – the second AEC coordinates; (x, y) – object coordinates; c – the speed of ultrasound in the object; $\Delta d_{1,2}$ – the distance between the first and second AEC.

Time difference of arrival for the first and third AEC pairs is expressed in the same way; therefore, there are only two unknown values x and y in the equation and they can be easily calculated.

In cases, when the material is anisotropic, defect localization becomes more difficult [7] – [9] because the oscillation propagation speed becomes dependent on the direction defined by angle θ . Consequently, for this case (1) looks like this:

$$\begin{aligned} \Delta t_{1,2} = t_2 - t_1 &= \frac{d_2}{v_2} - \frac{d_1}{v_1} = \\ &= \frac{\sqrt{(x-x_2)^2+(y-y_2)^2}}{v_2} - \frac{\sqrt{(x-x_1)^2+(y-y_1)^2}}{v_1}, \end{aligned} \quad (2)$$

where d_i – the distance to a converter; i, v_i – the speed of ultrasound in a particular direction with a direction vector

$$\tan(\theta_i) = \frac{(y-y_i)}{(x-x_i)}. \quad (3)$$

Thus, it is necessary to have three AECs in order to determine AE source coordinates on the plane. However, in practice four or more AECs are often used to reduce methodological errors of the coordinates. [10]

Equilateral triangle-centred scheme [11] is more often used for AEC placement (see Fig. 2). By applying this scheme, the source coordinates can be determined using expressions that are given in [12]:

$$x = (r_3 - r_1)(2R + r_2 + r_3)/2B\sqrt{3}; \quad (4)$$

$$y = B^2 - r_1(2R + r_1)/2B; \quad (5)$$

$$R = (3B^2 - r_1^2 - r_2^2 - r_3^2)/2(r_1 - r_2 - r_3), \quad (6)$$

where B – the distance between central and peripheral converters; x and y – AE signal source coordinates; R – the distance between source and central converters; $r_i = \Delta t_i$; Δt_i – the time difference of arrival on peripheral converters in relation to central AEC; c – the speed of ultrasound in the object.

It should be noted that in cases where the defect is outside the triangle, there is a huge increase in the coordinates of a position error that otherwise would not exceed $\Delta R/B < 0.1$ [13].

Usually, a coordinate network [14] is created before the registration (see Fig. 3). In this network, the time difference of arrival for each point is calculated. Theoretical values are compared to the ones obtained in practice after logging AE source signals. The point, at which there is the lowest square sum of theoretical and the real TDOA, is taken as the real location of AE signal source:

$$\Omega = \min \left(\sum_{j=i+1 \rightarrow 4} [\Delta t_{i,j}^{apr}(x_n^{apr}, y_n^{apr}) - \Delta t_{i,j}(x_r, y_r)]^2 \right) \quad (7)$$

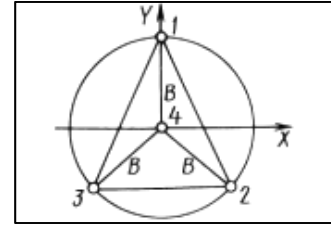


Fig. 2. Equilateral triangle-centred scheme for AEC placement.

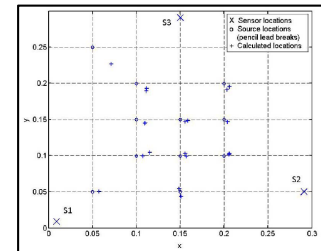


Fig. 3. Coordinates network with coordinates of sensors, real and theoretical sources.

Coordinates of spatial objects are analogous to (1) and (7):

$$\begin{aligned} \Delta t_{1,2} &= \frac{\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}}{c} - \\ &- \frac{\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}}{c} \end{aligned} \quad (8)$$

$$\Omega = \min \left(\sum_{j=i+1 \rightarrow 4} [\Delta t_{i,j}^{apr}(x_n^{apr}, y_n^{apr}, z_n^{apr}) - \Delta t_{i,j}(x_r, y_r, z_r)]^2 \right) \quad (9)$$

B. Zone Location

Zone detection method [11] is based on the principle that AEC, which has registered the highest signal power or

amplitude value, is the most closest to the AE source. This method has the minimum amount of information, because it allows identifying a zone rather than a specific point, in which a defect occurs (Fig. 4). By using the higher number of AECs it is possible to determine the sequence of arrival of a signal to them, thus increasing the detection accuracy.

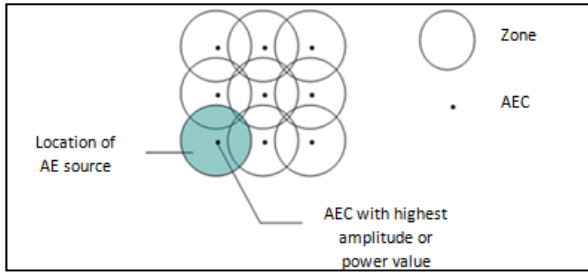


Fig. 4. Zone location.

III. ACOUSTIC EMISSION HARDWARE AND SOFTWARE

Acoustic emission hardware is characterised by the need to work in a relatively large dynamic range, which is due to the fact that it is very important to discover single small amplitude of AE signals, as well as recording AE signals during crack acceleration development process, which is characterised by an intense high amplitude impulse flow.

Acoustic emission hardware consists of the following assemblies:

- AE converters (AECs), the number of which depends on the chosen localization methods;
- preamplifiers and main amplifiers;
- signal identification and processing equipment, including threshold equipment, AE signal extraction and measurement equipment, data recording and presentation equipment;
- additional parameter measuring instruments;
- controllers.

Waveform and spectrum unification in clusters is carried out after the recording of AE signals. Clusters, unifying number of signals correspond to an event or defect. Different statistical methods use AE signal clustering in order to prevent the possibility of combining different event-driven signals in the same cluster.



Fig. 5. General use of AE equipment.

After processing AE signals proceed to the display, where the object expansion corresponding to the surface of the object and the converter arrangement can be seen. This type of signal

is shown in Fig. 6 [5]. To assess the defect risk level, sources are classified according to amplitude, integrated or local dynamic criteria. Classified defects according to their degree of danger are shown in different colours, so it is possible to locate on the map not only the fault location of the object, but also the degree of risk involved, thus making it possible to objectively determine the defect impact on the control object capacity.

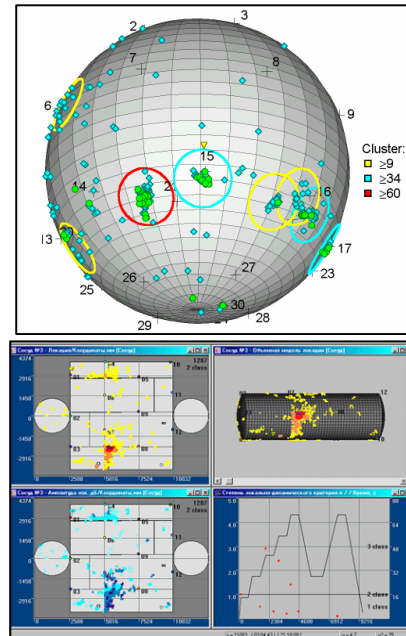


Fig. 6. Display of AE equipment with information and defect localization depiction.

In recent decades, localization methods have evolved rapidly due to high-speed hardware capabilities. Today, the coordinates of the source position error usually constitute 3–5% of the maximum distance between converters, but not less than the wall thickness of the controlled object. The last aspect is related to the fact that the location of source on a controlled object layer is not determined; the subject of research is epicentre of source of the epicentre on the object surface.

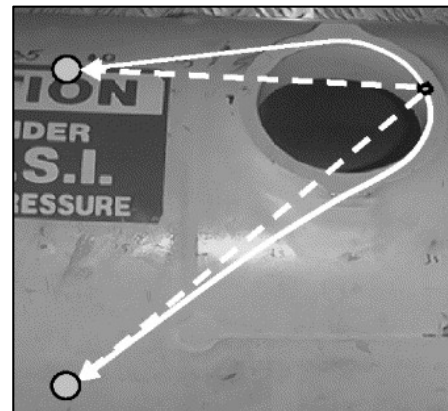


Fig. 7. Real (continuous line) and theoretical (dashed line) emission trajectory of waves.

Coordinate calculation error is determined by the time difference of signal arrival (TDOA) measurement errors. There may be many sources of error, for example:

- improper determination of sound propagation speed in the object;
- incorrect determination of the coordinates of the AEC, which is a laborious process. One of the possible ways to prevent these errors is the automation of AEP coordinates, which is offered in [6];
- time interval error that depends on the signal structure, its forefront growth in nature, noise level, etc.;
- actual propagation path mismatch, as shown in Fig. 7. [16];
- signal propagation velocity anisotropy existence;
- changes in signal shape during spreading in a structure;
- signal overlapping, as well as multi-source simultaneous operation;
- different types of waves, which spread at different speeds, login with converters.

Despite rapid development of localization methods by AE method, their application is difficult because of the acoustic wave reflection, transformation, decay, and other factors.

When solving defect localization tasks in real time, a range of tasks has to be solved, e.g., signal decoding, signal detection misconceptions, AE informative parameters for specific design and specific loading conditions. It should be noted that the loading equipment also transmits acoustic noise, and the amplitude and spectrum are identical in the fault signals. Future research is aimed at specific localization algorithm development for individual structures and units in order to increase the localization accuracy.

IV. CONCLUSIONS

The article has examined the capability of defect coordinate localization by means of acoustic emission method. Time difference of arrival (linear, planar, and spatial) and zone detection methods, as well as the main sources of measurement error have been considered. As far as multichannel acoustic emission hardware options are concerned, it has been concluded that the defect tracking error ranges from 3% to 5%.

The currently used AE tracking methods are generalized and cannot be used for the control of any object. Consequently, further research in this area will be devoted to the development of algorithm specific products for diagnostic purposes.

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