NEW DEVELOPMENTS OF SOFTWARE FOR A-LINE FAMILY AE SYSTEMS

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Abstract

The universal A-Line software of Interunis is an integral part of acoustic emission (AE) systems and is designed for solving various problems of data processing and visualization, and for full-scale control of the system hardware component. Simultaneously with development of new generations of the A-Line AE systems the software has been improved, is based on the up-to-date information technologies and programming methods, incorporating real AE applications experience of internal and external users of the A-Line family AE systems. This paper briefly describes the significant functional features of program features implemented recently; a method of approximate location of AE sources using a free-form sensor array on surfaces of thin-wall vessels, information statistical criterion for division of AE sources according to the type and method for evaluating the distance from a sensor to an estimated source on the basis of wavelet-analysis of AE impulse taking into account the dispersion dependencies of group velocities of Lamb waves.

Approximate Location by Free-form Sensor Array (ALFS).

One of principal disadvantages of the classical methods of AE source location on thin-wall vessels is their sensitivity to distortions of the wave front formed by several Lamb waves possessing the propagation velocity dispersion. Often, the source coordinates are computed with an error of the difficult-to-define magnitude. The new method attempts to increase confidence level and accuracy of the AE signal source location by taking into account an influence of various factors on the signal propagation velocity and AE wave front distortion.

The backbone of the suggested method is an assignment of a range (or several ranges) of velocities containing the velocities of basic modes of elastic waves on the structure. This velocity range can be additionally extended for taking into account the wave front distortion due to the test object design features (for example, hatches, branch pipes, welds, etc.) and the anisotropic properties of structure material. The AE source location is calculated on the principle that the wave velocity, whose the front arrival time is recorded by each of the sensors, lies within the selected velocity range.

When describing this location method, it is convenient to operate with a concept of wave “packet”: a set of the AE signals recorded by different sensors mounted on the test object. The packet’s critical feature is its duration, i.e. the time interval between the first and last impulse in chronological sequence as its components. If the packet duration is less than the characteristic magnitude dependent on the object geometric parameters and the evaluation velocity of elastic waves propagation in the object material, it can be expected that the whole set of impulses has been emitted during a single AE event. The ALFS method consists in calculating for each such
wave packet the object region comprising all possible points where the event could be capable to
generate this wave packet at the given arrangement of sensors and the given velocity range of
elastic wave propagation over the object surface. For this purpose the object surface is modeled
with a discrete mesh of finite number of points. For each wave packet, the ALFS method
calculates all nodes of this mesh, near which the given AE event could theoretically occur. The
list of all such nodes is the location region description for the given wave packet.

The location is approximate because for each packet not one point on the object is indicated,
but a region. However, the calculation of a single location point is impossible without an error.
This approximate method is more accurate than the point location, since the desired source of
event is within the obtained region with a high probability. Intersection of the location regions
obtained for the different packets allows the source to be located more precisely, provided that
the several packets of signals have been received from the same source as a result of the several
discrete AE events. When the object regions are displayed in A-Line program the overlay
sections of location regions are different in color depending on how many regions are overlapped
on this section.

The size of the region thus determined can be reduced and so the accuracy of source locating
can be additionally increased by the following several methods:

• Proved reduction of the selected range of elastic wave velocities, for instance, at the cost of
the more accurate measurement of velocities of the wave modes used and exclusion of some
modes from the consideration due to impossible recording of their arrival to the sensors.

• Research of the intersection of regions computed for different wave packets. If the regions
are sufficiently strongly intersected, that is the regions intersection area exceeds the definite
percentage of their combination, appropriate wave packets can be assigned presumably to the
same source, while the intersection of regions found for wave packets relevant to this source
can be assumed as the source location region.

• Selection of the optimum sensor number for calculating each region of the source location,
i.e. the usage of data from the optimum sensor number.

• For some sensors the velocity ranges of acoustic waves can be specified individually, taking
into account that the certain wave modes can, or on the contrary, cannot arrive to one or other
sensor.

To obtain the best results, the operator can change all the above-mentioned parameters of the
method on-line. Figure 1 shows results of ALFS implementation compared to the classical
triangulation location method on the spherical tank surface.

We summarize the basic advantages of ALFS over the classic point location methods:

• The method does not impose restrictions on the sensors’ geometrical order and arrangement
on the test object.

• Specified is the velocity range of elastic wave propagation on the test object surface that is
more realistic than its assignment with the constant or the selection of scalar values.

• The location is carried out by a random number of any impulses in the wave packet (from
one or more), and the maximum number of impulses used for location is specified as an
algorithm parameter.

• The location is carried out with regard to the real geometric shape of an object. This
minimizes the distortions and errors, but requires the more accurate description of the object
geometric shape and assignment of all relevant parameters.
Fig. 1 Results of ALFS implementation (two lower pictures) compared to the classical triangulation location method (two upper pictures) on the spherical tank surface.

- The location result for one AE wave packet is a region on the object wherein the source is positioned with a high probability.
- The location result for a number of wave packets is a set of the regions. The intersection of such regions with each other makes possible to define a small section on the object wherein the source is positioned with an even higher probability.

The authors have obtained the Russian Federation patent on the above method.

**Information Statistical AE-Criterion**

By virtue of a number of the AE characteristic features both of the random process and the irreversible process, the statistical methods of AE information processing appear to be the most acceptable. Such methods can reveal the most typical regularities of process development, on the one hand, and average the influence of statistical spikes, on the other hand. When the behavior of not one attribute of the AE test data is analyzed, but two or three as a whole, we can increase the efficiency of identifying phenomena occurring within the test area. From the classic threshold principle of recording, the AE data are not a continuous signal but a sequence of values of impulse parameters (amplitude $A$, energy $E$, duration $Dur$, etc.), which are obtained directly during the experiment or tests and contain information about a process or a set of processes generating AE. Statistical consideration of these parameters enables to define the criterion of separation of the underlying processes; in particular, we utilize a significant relative change in the statistic characteristics of the impulse parameter distributions. In other words, the moment of transition from one stage of damage development in the test region to another stage can be determined by the moment of violation of AE data flow. To provide access to the information about the set of processes occurring in the test object, the whole sequence of AE impulses
arriving channel-by-channel is divided into samples. In this paper, we have used the sampling with the fixed number of impulses \( n \). The critical characteristic of the histogram obtained is its pattern. Thus, at the stage of dispersed accumulation of micro-cracks the AE impulse flow is usually considered as the Poisson flow, and the main crack growth is accompanied by the deviation from this distribution [1]. One more analysis of the amplitude distribution pattern forms the basis of the widely currently known “Ib-value” criterion [2].

Recently, the Scientific & Training Center of Welding and Control and Interunis have applied one more evaluating characteristic, the distribution entropy \( S^h \) [3]. This allows for evaluating the degree of disordering in the histogram under consideration. The evaluation of data obtained during the model experiments, and also during the industrial testing has shown that the relationship \( F_P = P_{mod}(S^h) \) can be selected as an example of the identification parameter. This \( F_P \) function is dependence of the histogram distribution characteristic \( P_{mod} \), representing the most probable value of the random parameter \( P \) in the sample, on the relative entropy of this distribution \( S^h \). The computational results for different recording channels are plotted on a chart in different colors in the indicated coordinates, whereby the diagnosis diagram is formed. The source can be identified by the group position of points in the diagram field. In Fig. 2a, b and c several examples of resultant diagnostic diagrams for the amplitude distribution are presented: for the loading of a defect-free object (Fig. 2a), loading of an object with active AE source (Fig. 2b) and cyclic loading of standard specimen loaded to failure (Fig. 2c). In Fig. 2a, registered AE signals concentrated into zone I. This zone is defined by entropy value \( S^h_A \) interval [0.3…0.7], and most probable amplitude value \( (A_{mod}) \) increases threshold level on [0…5] dB. Actually, the signals fulfilling this zone appear to be noise of loading object, distributed exponentially. Zone II (Fig. 2b) stands out against a background of zone I by \( A_{mod} \) and entropy value, taking place in \( S^h_A \) interval [0.5…0.8]. This zone appears because the signals with increased amplitude begin to prevail. Entropy in turn increases because the dispersion of amplitude becomes larger.

Zone III corresponds to the leakage signals, defines by \( S^h_A \) interval [0.0…0.3]. In Fig. 2c zone III appearance explains by plastic deformation following by the large number of low amplitude impulses. Besides zone IV, the last one, corresponds to the critical crack appearance before specimen failure. Finally, note that in all cases of the process-type identification (accumulation of dispersed micro-damages, growth of main cracks, leak) by the cumulative attributes (AE signal amplitude mode; entropy of amplitude probability distribution), no preliminary filtration of data has been carried out.

**Some Aspects of Wavelet-Analysis Software A-Line OSC Processing**

In this part of paper one version of the application of continuous wavelet transform for evaluating the distance to an AE signal source is described. This is implemented in the specialized program for waveform processing. The AE signal in-time smearing caused by the group velocity dispersion which noticeably reduces the accuracy of arrival time determination, and as consequence, the AE sources coordinates, has resulted in the development of various methods for the additional processing of signal waveforms. One of the methods of such analysis is the use of the signal time-frequency transform, and the wavelet-spectrograms rather long-used in AE are the most known and convenient among them [4]. To visualize the wavelet-spectrograms, the use is made of the traditional color diagram on which the X-axis corresponds to time, and Y-axis corresponds to frequency, while the energy density distribution is displayed by the different color (or black-white) tones: violet and dark blue (white) tones – minimum density, red and yellow (black) – maximum.
Fig. 2a Diagnostic diagram for the defect-free object loading.

Fig. 2b Diagnostic diagram for loading of an object with active AE source.

Fig. 2c Diagnosis diagram for cyclic loading of standard specimen loaded to failure.

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In a separate window calculated and displayed are the dispersion curves for the specified values of object thickness, and \( C_L \) and \( C_T \) are velocities of the volume longitudinal and transverse waves in the object material. Just here it is possible to select the desired mode of Lamb waves (usually \( A_0 \) and \( S_0 \)) for calculating and displaying, and to indicate the magnitudes of sound speed in liquid, possibly filling up the object. To suit user’s convenience, the program offers the tabulated velocity values for a number of hard materials and liquids. From the plot containing the dispersion curves \( V(f) \), we can obtain the dependences of the arrival times of signal different frequency components to the AE sensor located at the distance \( L \) from the source [5].

![Figure 3 Wavelet-spectrogram window with evaluation results for \( L \), \( t_0 \) and \( d \) and results of wavelet-spectrogram section plot.](image)

Figure 3 presents an example of the wavelet-spectrogram window with the superimposed picture of dispersion curves for the detected waveform. The imposition parameter values \( L \) and \( t_0 \) (\( t_0 \) – time of signal emission relative to the time of waveform onset) are selected on-line by moving the scaling markers (two light-gray verticals) with the mouse in the wavelet-spectrogram
window. The left marker corresponds to the fastest Lamb-wave arrival (mode $S_0$ at $f \to 0$), and the right one to the arrival of high-frequency components (all modes at $f \to \infty$). The horizontal scaling marker allows adjusting obtained curves onto frequency scale, so the wall thickness $d$ value may be corrected if it is not known in advance. As a rule, when selecting the parameters, it is convenient to be guided by the characteristic frequency in the wavelet-spectrogram, in which the values of group velocities of modes $A_0$, $S_0$ and $A_1$ are equal. Under marker movement at the upper right of the appropriate window displayed are: $t_0$, $L$ and $d$, which correspond to the current variant of the dispersion curves superimposed. Moreover, in some instances, it is useful to know the time of wave arrival through the liquid inside the object, and this time is displayed by the appropriately-colored vertical line.

When it is difficult to carry out the correct superimposition of dispersion curves (in case of high noise at the small distance between the source and AE sensor or if a great number of the modes in signal is present [6]), we can apply the wavelet-transform for making more precise the arrival time by determining the energy density maximum in the spectrogram on the preselected frequency. The point of time conforming to this maximum can be applied for AE source location instead of the usually used threshold intersection time or the time of signal amplitude maximum [5, 6]. The A-Line OSC Processing program offers the plotting of the movable wavelet-spectrogram sections by means of the constant frequency and constant time lines, and the appropriate envelope spectra complete the picture in the waveform windows as shown in Fig. 3. The application of the normal wave velocity on the maximum-conformable frequency allows the AE-source coordinates determination error to be reduced.

References