AE Source Location by Means of Acoustic Waves Imitation in Segmental Grid Model

Alexey SAMOKHVALOV *
* DIAPAC Ltd. Moscow, Russia, www.diapac.ru, e-mail: asamokhvalov@diapac.ru

Abstract. The Segmental Grid Model (SGM) is proposed which allows to represent the geometric form of complicated object and acoustic waves propagation in it. The specific of AE sources location using this computational-graphic model is the usage of scaled map containing flat segments representing the surface of the structure. SGM makes it possible to take into account such circumstances as waveguide effect in welds, differences in sound speed and attenuation in different parts of object, wave reflections which mixes with primary wave signals. Method of building of SGM is considered as well as AE sources location using this model. Beside possibilities to take into consideration the number of acoustic effects and object properties the model has good natural visual representation and could be comfortably built using simple graphic editor.

Introduction

Different methods of location are used in acoustic emission area. The difference between them lays in the ways of the modelling of acoustic waves and object's shape. The geometrical modelling is usually done by simple shapes (plane, cylinder, sphere, etc.) or by network. Particularly, we have offered model based on regular cubic grid [1].
Nevertheless, each of these ways has its own limitations and implementation difficulties [2, 3].
Taking into consideration different location techniques experience, the goal was set to develop the method which would be sufficiently convenient for data input, visual representation and maximum universal. As result, the location technique based on flat segments was developed which essence is described below.

1. Model Building

1.1 General Considerations

The goal of model is to take into consideration:

- Arbitrary complex shape and structural elements.
- Different waveguide characteristics in different parts of the object.
- Registering equipment properties.

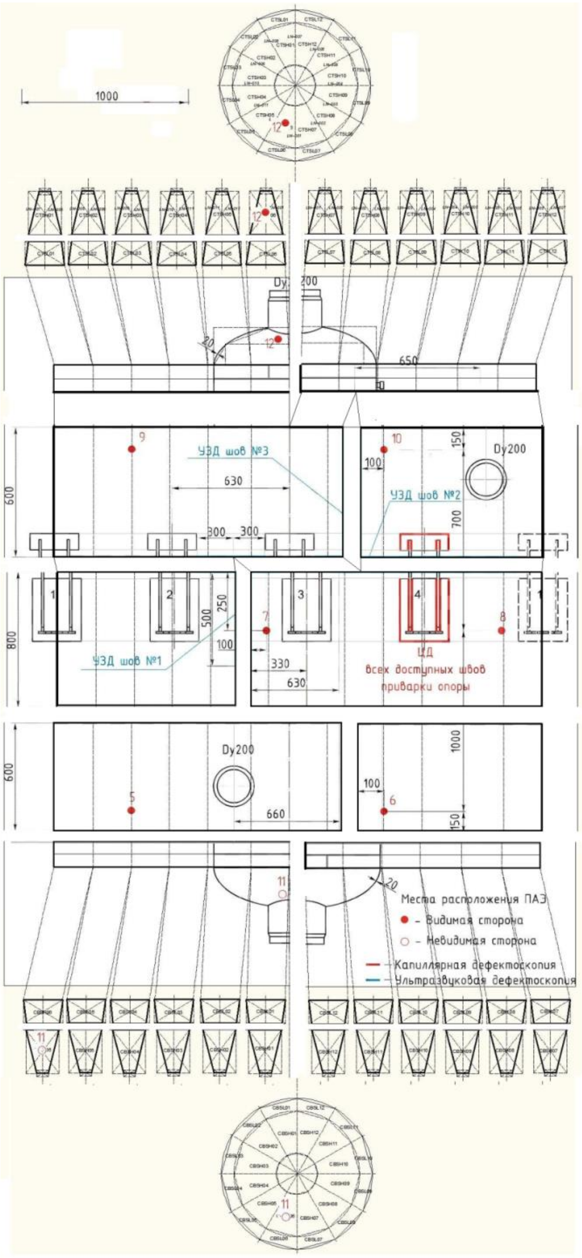
Also, the model is to provide the greatest visibility and be made closer to the engineering drawing.

The initial graphic representation of the model is transformed into computational graph.

1.2 Main Elements

1.2.1 Flat Segments Map

The map of flat segments (Pic. 1) serves as graphic representation of facets, vertices (points) and at the same time it is used for computation of link lengths. Location results are also shown on the map. Object elements (facets) are drawn in the same known scale.



Pic. 1. Sample of Flat Segments Map. The cylindrical part of vessel is partitioned by welds. Demi-elliptical heads are partitioned by 12 sectors, each consisting of 2 flat segments.

1.2.2 Facets (Flat Segments)

Each facet is the fragment of the surface which is conventionally considered to be flat with the same waveguide properties. Facet border should be convex polygon.

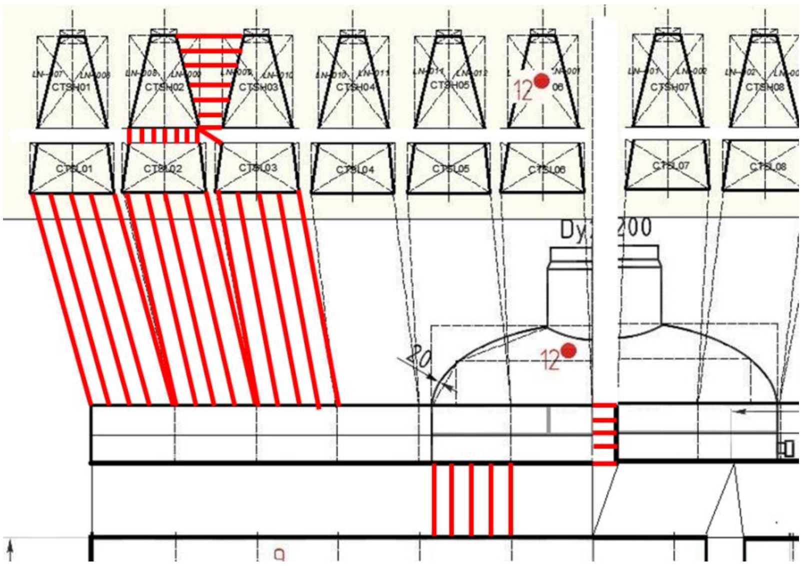
The partitioning of surface to facets is done by structural elements, primarily by welds.

1.2.3 Vertices

Each vertex is considered to belong to some facet or multiple facets simultaneously. Internal vertices belong to one facet only while vertices placed on the borders (edges) – to two (or more) adjacent facets. The link between vertices and facets is performed through **points**.

1.2.4 Points

Each vertex is represented on the map by one or multiple points. Points belong to facets (one or multiple) and, accordingly, determine the belonging of vertices (Pic. 2).



Pic. 2. Positioning of points: red lines are drawn between points representing the same vertex (samples).

1.2.5 Links between Vertices

While building computational graph, links (edges) are set between vertices belonging to the same facet by "each with each" principle. The number of edges inside facet therefore is N = n(n - 1)/2, where n – the number of vertices in facet.
Edge lengths (the distances between vertices) are determined as lengths of line segments on the plane.

1.2.6 AE Sources

Generally, each vertex in the model can be AE source. Vertices have special attribute indicating whether the vertex is considered as potential source of AE.

1.2.7 Sensors

Selected vertices are marked as sensors. Characteristics of the sensor are:

- Attenuation coefficient in the contact area. May be 1 or less according to contact quality; checked by calibration test.

- Channel gain coefficient.
- Threshold, dB (minimum sensitivity of the sensor).
- Block time (matters for reflected waves).

Signal amplitude written into file (registered) is associated with the actual amplitude of the signal that has reached the sensor as follows:

$$A_{sens} = A_{wave} \cdot k_{cont} \cdot k_{gain} \text{ , dB}$$

where:

A_{wave} - wave (impulse) amplitude that has reached the sensor point in material, dB;
k_{cont} - attenuation coefficient in the contact area коэффициент ($<= 1.0$);
k_{gain} - channel gain coefficient;

In practice, when difference between channels could be ignored, coefficients k_{cont} and k_{gain} could be set to 1.

Impulse amplitude A_{wave} which takes part in this formula and which is modelled at wave propagation, generally speaking, is not so much actual value but the value registered by sensor (channel) taken as reference (standard) for this equipment.

1.3 Automation of Model Building

To expedite the construction of the model following techniques are used:

- Creation of facet from points (vertices) by selected rectangular area.
- Creation of common edges “in 4 clicks”: the position of two line segments are set, which in fact represent one common edge of two adjacent facets; thus there is the automatic generation of vertices and points.
- Generation of vertices by rectangular grid with given step

etc.

1.4 Model Validation

The model should be complete, i.e. all vertices should be covered by total "spanning tree".

The model should not be contradictory, i.e. each vertex must be represented in one facet only by one point.

If the link (edge) is established between two vertices, then they should belong to the same facet or, alternatively, to different facets within the same **massive segment**.

1.5 Special Effects

1.5.1 Local Effects in Welds

In some cases the effect of local attenuation can be observed at wave propagation through the weld. Sometimes welds waveguide effect is observed, i.e. effect when sound travels along the weld faster and with less attenuation than the adjacent metal plates [4].

Modelling of these effects, if necessary, is done by introducing separate narrow segments denoting the weld zone, with their own waveguide properties.

1.5.2 Reflection of Waves

Reflection from obstacles is taken into account through the creation of "secondary" (reflecting) sources. For this purpose vertex has an attribute indicating whether it is reflective. When the impulse is received the reflecting vertex initiates a new wave propagating in all directions. To prevent improper reproduction of reflected waves the principle of single reflection is used, i.e. secondary wave can not produce other secondary waves; only a primary wave has such ability.

1.5.3 Anisotropy

Anisotropy of the material is taken into account in the waveguide properties. For an anisotropic material two sets of waveguide properties is given: for X and Y axes, respectively.

Waveguide characteristics during the passing of the distance between vertices in an arbitrary direction are determined as the weighted arithmetic mean by the components of the direction vector.

Using of anisotropy is optional.

1.5.4 3D-coordinates

3D-coordinates can be introduced for linking the data with 3D image and/or taking into account the massive filling. 3D-coordinates of the vertices are calculated automatically by flat coordinates on the map and the position of a facet in space. Facet position in 3-dimensional space is defined by specifying the 3D-coordinates for any three vertices of that facet that do not lie on the same line.

1.5.5 Consideration of Liquid Content

In some cases the tested vessels are filled with liquid. For underground pipelines and vessels the sound decays faster in the metal wall than in liquids. This leads to the need to consider the propagation through the fluid content. For this the grouping of facet bounding liquid volume is created in the model ("massive segment"). Massive segment is attributed by its own waveguide properties. Sound can travel directly between the nodes of different facets of the group representing massive segment boundary.

Massive segment itself should be a three-convex body.

A typical case of liquid content consideration is presented by models of vertical cylindrical tanks.

1.6 Waveguide Properties

Waveguide properties consist of the sound speed and attenuation functions defined separately for different types of waves.

Attenuation function is given in the form of pairs of values "distance from the source" - "the attenuation in dB."

References to waveguide properties are contained in flat facets and massive segments.

2. Modelling of Acoustic Waves

2.1 Events in Source Vertices

Several sample events are simulated in each source vertex characterized by different magnitude (energy) of the initial impulse. Magnitude of the initial impulses is selected based on specific conditions; for example, it may be a value from 50 to 150 dB in 10 dB step. Each initial impulse forms, in general, several waves of different types, representing different modes (longitudinal wave, shear wave, Rayleigh wave, Lamb wave, etc.). There is, respectively, specific sound speed and attenuation function for each wave type in waveguide characteristics attributed to graph edges.

Calculations of paths for impulses having the same source could be combined to speed up the processing.

2.2 Wave Propagation

Modeling of wave propagation is performed by "in-breadth" search algorithm. Each wave (primary wave or reflection wave) moves independently, forming a wave front.

The information about the arrival time, amplitude and full distance from the source is supported in reached vertices for each of the independently considered waves. The wave can reach vertex only if it was not there before or if it reaches vertex by a new path with less arrival time than before (in such case time of arrival and amplitude are respectively replaced by new values).

Possible ways of further propagation from the vertex include:

- Directions to all other vertices of given facet.
- Directions to all vertices of other facets belonging to the same massive segment.

At moving of the impulse from vertex to vertex the travelling time and new amplitude value are determined by waveguide characteristics associated with this edge.

If the wave amplitude is less than the minimum sensitivity of all sensors in antenna, the further spread of the wave is not taken into account.

3. Location

3.1 Search for Events

Search task is formulated as follows. The set of sample events was obtained as a result of modeling and simulation. Each sample event is characterized by a set of expected sensor responses:

$$E_m = [(c_o, 0, A_o),\ (c_1, t_1, A_1),\ \dots,\ (c_n, t_n, A_n)]$$

where:

$c_o, c_1, \dots, c_n$ – channel identification numbers for first, second etc. signal in event;

$t_1, t_2, \dots, t_n$ – time delays relative to first signal in event for the second, third etc. signals (sec);

$A_o, A_1, \dots, A_n$- amplitude of first, second etc. signals in event (dB).

On the other hand, similar in structure sets of combinations (E_f) are present in actually registered data. The task is to find entries of sample responses E_m in the set of actual combinations E_f, taking into account specified matching criteria.

3.2 Detection of Sample Response in Actual Combination

First the initial screening is carried out by following conditions:

1) All channels $c_o, c_1, \dots, c_n$ from sample combination E_m should be present in actual combination E_f.
2) The first channel in actual event should be a channel, but not necessary the first one, from sample combination E_m. This condition takes into account the situation when there is little time delay between first and second signals and they could be swapped because of the model inaccuracy.

Then the search by single channel responses is performed by following steps:

1) Take next i-th single response (c_i, t_i, A_i) from sample response E_m with time delay and amplitude t_m and A_m, respectively.

2) Find actual response for this channel in actual combination E_f with time delay and amplitude t_f and A_f, respectively. If there are multiple responses for this channel c_i in this actual combination E_f, then the closest response by time delay is considered.
3) Perform check for the discrepancy between delays:

$$\Delta_t = |t_f - t_m| \leq \Delta_t^{max}$$

where Δ_t^{max} – maximum allowable time delay discrepancy.

4) Perform check for the discrepancy between amplitudes:

$$\Delta_A^{(+)} = A^f - A^m \leq \Delta_A^{(+)max}$$

and

$$\Delta_A^{(-)} = A^m - A^f \leq \Delta_A^{(-)max}$$

where $\Delta_A^{(+)max}$ and $\Delta_A^{(-)max}$ – maximum allowable deviation of the actual amplitude from sample amplitude by greater and smaller side, respectively.

5) Go to next single response in sample response E_m, i.e. i = i + 1, and return to item 1.

3.3 Location in Incoming Signals Stream

The search is done in sorted by time signals stream actually registered by sensors. All possible sequential combinations of signals with overlapping are considered.

The algorithm of formation of actual combinations (signal groups) E_f is following:

1) Take the next signal from actual stream (with N index) for the initial signal in combination.
2) Include into combination also all signals that came after initial signal during Δt_w time. The duration of time window Δt_w is taken to be equal to the longest sample event duration.
3) Go to next signal by time, i.e. N = N + 1, and return to item 1.

3.4. Location with Pre-grouping

In contrast to the location in the input stream, wherein the binding source signals occurs on-line, at pre-grouping procedure the formation of actual responses and their evaluation are separated from the location.

Preliminary grouping starts with picking out the stable combinations of actual signals, evaluates their significance, and only after this the attempt to find source location is undertaken. Attempt to locate the group, however, may end in vain; in this case the refinement of the model is performed, or the location is done manually, i.e. in the expert manner.

4. Location Result Analysis

4.1 Overall Results

The overall result is the set of actual entries of sample events. Actual entries of different sample events can overlap, i.e. include the same actual signals.

Sample events are grouped by source vertices.

Location results analysis is carried out in order to evaluate the activity and potential hazard for AE sources, for this purpose different empirical criteria are used, e.g. power and historic indices etc.

4.2 The Problem of "Not Found" Events

No matter how perfect is the model, it can not fully reproduce the real process, so there will always be signals that can not be located, i.e. can not be attributed to definite source.
The smaller is the number of these signals, the better and more accurate is the location. However, there are noises that could be located only by zone, and false events appear because of superposition of random noise.

4.3 Refinement of Model

When location results are unsatisfactory or it is necessary to increase the accuracy the model could be refined by adding vertices on the boundaries of facet and increasing the number of source vertices. Importantly, this can be done exceptionally in areas where the presence of active source has been detected.

Conclusion

The technique of location has been developed, the benefits of which are:

- No restrictions on the shape of the object.
- Detailed consideration of the structure of the object, in particular, welds.
- The possibility of combining in one model all parts of the object, including those that have different waveguide properties.
- Consideration of the properties of registering equipment.
- Visibility and proximity to the engineering drawings.
- Easy software implementation.

Disadvantages of the technique are:

- Discrete character.
- Relatively high amount of time to build the model.

Nevertheless, despite its shortcomings, the considered method, in our opinion, is a promising tool, especially in cases when long-term observation of the same object is performed, which takes place in monitoring systems.

References

[1] A.Samokhvalov, V.Shemyakin. "3D Model Based on Regular Cubic Cell Mesh for AE Sources Location on Complex Industrial Structures", 30th European Conference on Acoustic Emission Testing, 7th International Conference on Acoustic Emission, Granada 12-15 September 2012, Proceedings. – pp. 846-854.
[2] G. Prasanna, M. R. Bhat, C. R. L. Murthy. "Acoustic Emission Source Location on an Arbitrary Surface by Geodesic Curve Evolution". - Journal of Acoustic Emission. Vol.25, 2007. – pp. 224-230.
[3] X. Li and L. Dong, "An efficient closed-form solution for acoustic emission source location in three-dimensional structures". - AIP Advances, vol. 4, no. 2, - p. 027110, 2014.
[4] Viktorov, I. A. "Rayleigh and Lamb Waves: Physical Theory and Applications". – Plenum Press, New York, 1967.