INFORMATION-DIAGNOSTIC SYSTEMS

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METHODS FOR LOCATING STRUCTURAL DEFECT SPOTS BY ACOUSTIC EMISSION SIGNALS

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A review of methods and algorithms for detecting spots of structural defects developing in products under load is given. These methods and algorithms are used in acoustic emission systems designed for locating the sources of acoustic radiation.

The coordinates of the spot of a developing defect are very important in themselves for condition estimation of the product under control. Localization of defects developing in a loaded material – which uses the phenomena of acoustic emission (AE) – is based on the principles of the passive location of acoustic emission sources. Referring to [1], when a structural defect develops (a crack, for example), an elastic displacement pulse is formed which propagates in the material (fig. 1, *a*). As soon as the pulse gets to the piezoceramic transducers installed on the surface of the product, it transforms into an electric one (fig. 1, *b*), whose parameters are then processed by an electronic arrangement. If two or more transducers are installed on the surface of the product, the time of this signal appearance at the transducers is used for determining the spot of a developing defect.

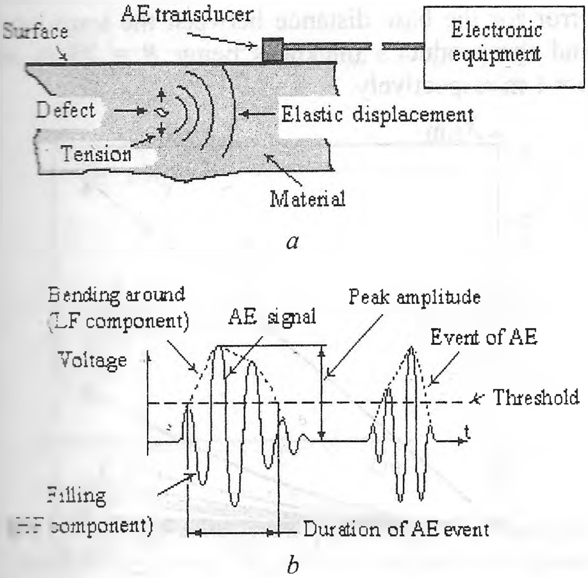


Fig. 1. AE signal radiation:
a – detection of elastic displacement appearing when structural defects of the material develop under the influence of mechanical tensions; *b* – AE signal parameters under processing

A general approach to solving the problem of determining the defect coordinates with the use of the difference in the time of the signal arrival at the transducers is considered in [2; 3]. As this takes place, using two transducers makes it possible to carry out the linear location of emission sources spots, while increasing the number of transducers gives us the possibility of performing their spatial location. If the latter is the case, it is possible to perform location on the surface either within the plane between the AE transducers or on the plane beyond the internal surface between the AE transducers.

As in the majority of cases the thickness of a product is much less than its other dimensions, the problem of locating the source of emission is considered to be linear (a plane). As this takes place, the number of receiving transponders is not less than two. If the source of emission has coordinates X_1, X_2 on a plane, these coordinates are in the system of equations [4]:

$$(X_1 - X_{1\,i})^2 + (X_1 - X_{2\,i})^2 = (r_k + c r_{ik})^2, \qquad (1)$$

where X_{1i}, X_{2i} – coordinates of the Ith receiving transducer; c – the sound velocity in the material; r_k – distance from the source of AE signal radiation to the Kth receiving transducer; $r_{ik} = t_I - t_k$ – difference in the time of the signal arrival at the ith and kth transducers.

The solution of equation (1) is cumbersome, which impacts the promptness in determining the coordinates of the acoustic radiation source spot. The equation may be simplified through the peculiarities of the product's geometry, through the peculiarities of the transducers arrangement, and through the use of simple algorithms for coordinates calculation.

For a product with simple geometry, one dimension of which is much less than the other (a pipe-line, for example), the spots of appearance and development of structural defects may lie in the same straight line. Then the use of two receiving transducers lying in this straight line is possible. As this takes place, the task reduces to a simple linear problem. If the distance between the two transducers equals $2B$, i.e. the base is $2B$ (fig. 2), the origin of the coordinates is placed in the middle of this base, and the source of AE signal radiation lies on the line of this base (fig. 2, point *1*) then the measuring of the delay τ in the signal's arrival at one of the transducers with respect to the other makes it possible to find the coordinate of the source:

$$X_1 = 0,5\, c\tau, \qquad (2)$$

where c – the signal propagation velocity.

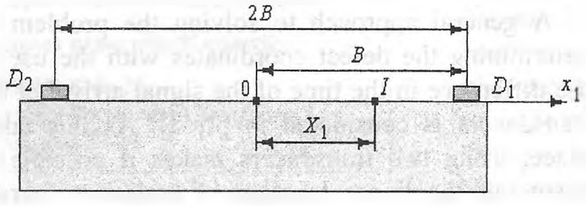


Fig. 2. A diagram of determining the linear coordinates of a source of AE signal radiation:
D_1, D_2 – AE transducers; $2B$ – distance between the transducers (base); *1* – the spot of the source of radiation; X_1 – distance from the origin of the coordinates to the source of radiation

The value of τ is positive if transducer D_1 actuates earlier than transducer D_2, and negative otherwise. Determining the time τ of delay only within the range $\tau‹2(B/c)$ allows to do spatial selection, i.e. to find a source of emission with coordinates $X_1 \geq B$ and $X_1 \leq B$.

If the source of emission is inside the product at a specified depth X_2 (fig. 3), the projection point of the source onto the base is considered (in the linear setting of the problem) to be the spot of the source of emission. This point has the coordinate X_1 (fig. 3, point *1*). But there is a methodological error when calculating in accordance with (2):

$$\Delta X_1 = X_1 - 0,5\cdot[\sqrt{(B+X_1)^2+X_2^2}-\sqrt{(B-X_1)^2+X_2^2}, \qquad (3)$$

where X_2 – the depth of the source of emission with respect to the surface of the product.

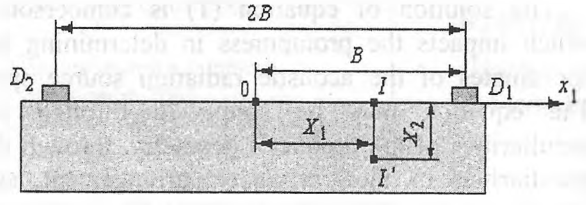


Fig. 3. A source of radiation is situated inside the product:
D_1, D_2 – AE transducers; $2B$ – distance between the transducers (base); I' – the spot of the source of radiation; I – projection of the spot of radiation onto the plane; X_1 – distance to the spot of radiation; X_2 – depth of the spot of radiation with respect to the surface of the product

It follows from (3) that this error is equal to zero when

$$\Delta X_1 = \begin{cases} if X_1 = 0 \ (X_2 \text{ can take any value}); \\ if X_2 = 0. \end{cases}$$

If the values of X_1 and X_2 increase, the error increases too. To lower the error, it is necessary to introduce a correction. To put it another way, the true coordinate of the source of emission is determined as an approximate value of the coordinate to the source of radiation with respect to the origin of the coordinates when the correction for the coordinate is allowed for

$$X = X_p + X_m, \qquad (4)$$

where X_p, X_m are the approximate value and the correction due to the methodological error respectively.

For a fixed arrangement of the transducers the value X_m can be calculated for each value X_p and described by the required function. The true value is then calculated as

$$X^* = X_p + X^*_m,$$

where X^*_m corresponds to an approximating function and has a smaller error.

At the same time it is possible to allow for the maximum error defined by the dimensions of the product. In this case it is necessary to use expression (3) when the maximum value of coordinate X_2 is known. This value is equal to the size of the product or to its thickness, that is the calculated coordinate must equal $X_1 \pm \Delta X_1$.

In fig. 4 are presented the results of calculations of the absolute value of the coordinate determination error for the base distance between the transducers and the product's thickness being B = 25 m and h = 1 m respectively.

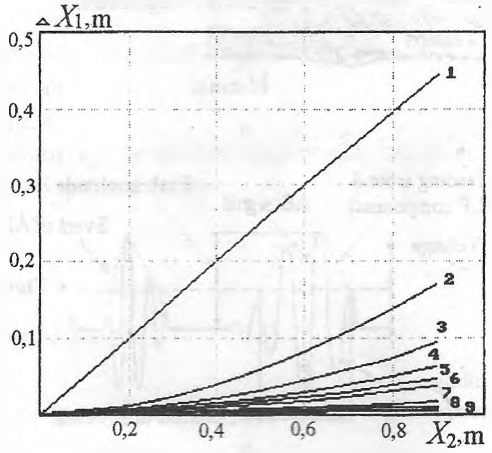
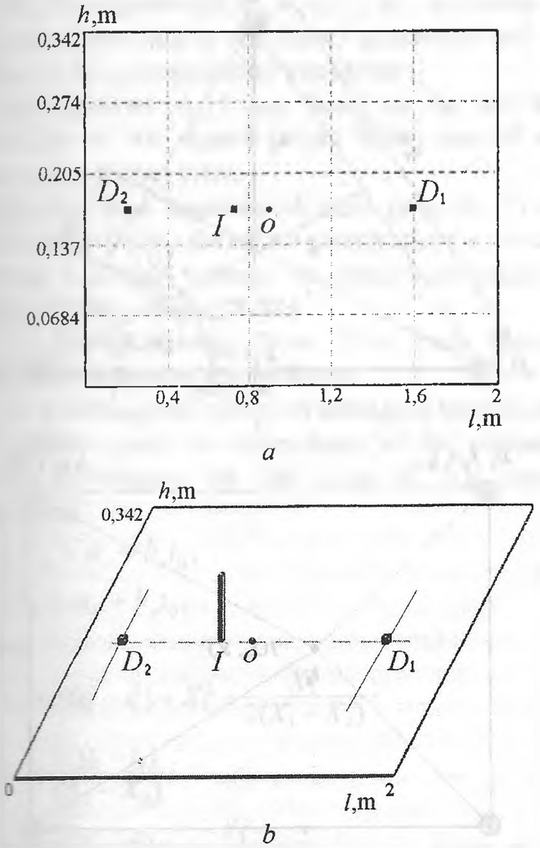


Fig. 4. Relationships showing the variation of the absolute value of the coordinate X_1 determination error as the function of the depth of the source of emission:
1 – 25 m; *2* – 24 m; *3* – 23 m; *4* – 22 m; *5* – 21 m; *6* – 20 m; *7* – 15 m; *8* – 10 m; *9* – 5 m

It is seen from fig. 4 that with decreasing coordinate *X*, the absolute value of the error decreases as a function of the depth of the source of emission. It is important to note that, potentially, the source of emission cannot lie on the line of the transducers' arrangement, because the distance from the source to the origin of the coordinates will exceed the base size, and hence, it will be rejected in the course of selection. It means that curve *1* in fig. 4 will not exist.

Calculations show that with the base equaling dozens of meters and with (X_2/B)<0,25, the absolute value of the coordinate determination error does not exceed several centimeters. With increasing the ratio (X_2/B)>0,25 the coordinate determination error increases. That is why to decrease the error it is necessary to construct an alignment chart for the absolute value of the error with the reference to the thickness of the product for the specified distance to the source of AE signal radiation (fig. 4).

In fig. 5 are shown the results of the linear location of the source of AE signals radiation in two- and three-dimensional representation for the case of the linear location of a graphite rod destruction spot.



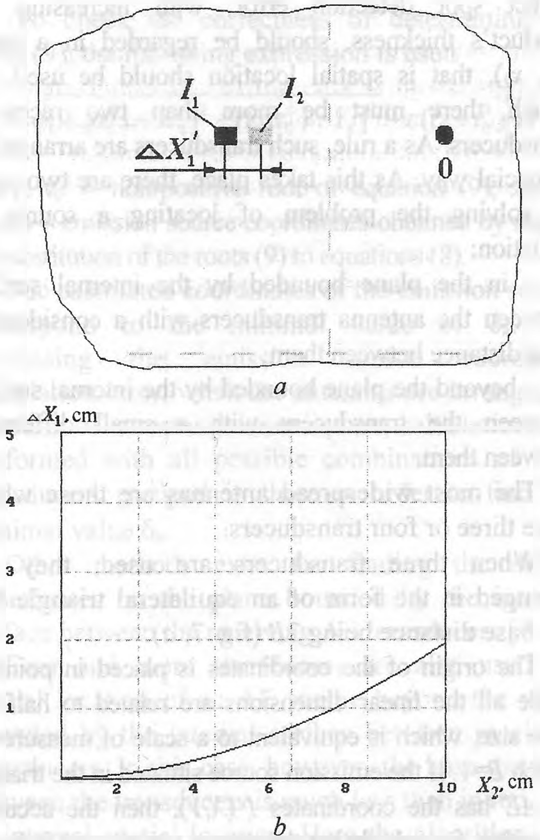
a

b

Fig. 5. Distribution diagrams for the spot of a source of emission throughout the pipe development when linear location with they use of So Nilsson's source takes place:
a – a two – dimensional representation; *b* – a three-dimensional representation;
D_1, D_2 – receiving transducers spaced at 1,4 m; *o* – the origin of the coordinates; *I* – the source of emission

The rod is 0,5 mm in diameter (So Nilsson's source). The research including calculations of coordinates of the source of emission showed that the absolute value of the error after processing 50 detected AE signals, lied within 0,003 m; that is with the distance between the transducers being 1,4 m and the distance from the source of emission to the origin of the coordinates being 0,18 m, the coordinate determination error did not exceed 2 %.

When the graphite rod is being destroyed, a deviation of the calculated coordinate (fig. 6, *a*, I_2) from the true spot of the source of emission (fig. 6, *a*, I_1) is observed on the outer side of the pipe with respect to the transducers arrangement line.



a

b

Fig. 6. A distribution diagram for the spot of a source of emission throughout the pipe development when linear location with the use of So Nilsson's source takes place (*a*), and the dependence of the error absolute value on the product's thickness (*b*):
O – the origin of the coordinates; I_1, I_2 – the emission source which is being destroyed on the transducers arrangement line and on the opposite side of this line respectively; ΔX_1 – the deviation of the emission source calculated coordinate

After 50 detected AE signals had been processed, this deviation was $\Delta X_1 = 1{,}85$ cm, or 10,3%, the distance between the transducers being 1,4 m and the distance from the origin of the coordinates being 0,18 m.

Calculations of the coordinate determination error were done and an alignment chart of its absolute value variation as a function as a function of the depth of the source of emission was constructed.

The calculations and the chart showed that the error maximum value was $\Delta X_1 = 1{,}7\,\text{cm}$. If the error absolute value is allowed for in accordance with the alignment chart, the deviation of the calculated coordinate from the true one will be 0,15 cm, or ~ 1%.

It is obvious that with increasing the distance between the transducers (the thickness of the product being constant), the absolute value of the source coordinate determination error will decrease.

At the same time, the problem of decreasing the defect spot detection error, with increasing the product's thickness, should be regarded in a plane (x_1, x_2), that is spatial location should be used, for which there must be more than two receiving transducers. As a rule, such transducers are arranged in a special way. As this takes place, there are two ways of solving the problem of locating a source of radiation:

– in the plane bounded by the internal surface between the antenna transducers with a considerable base distance between them;

– beyond the plane bounded by the internal surface between the transducers with a small difference between them.

The most widespread antennas are those which have three or four transducers.

When three transducers are used, they are arranged in the form of an equilateral triangle [4], the base distance being $2B$ (fig. 7, *a*).

The origin of the coordinates is placed in point *A*, while all the linear dimensions are related to half the base size, which is equivalent to a scale of measures at which B=1. If the emission source situated in the triangle D_1 *AE* has the coordinates I (X,Y), then the accurate algorithm for calculating the source coordinates is based on finding the point where the corresponding hyperbolas cross (*1–2* and *1–3*).

For the given zone of emission source arrangement the time of the signal arrival at the transducers is $t_1 < t_2 < t_3$, i. e. the difference in the time of the signal arrival at the transducers is $\tau_{21} < \tau_{31};\ \tau_{21} > 0;\ \tau_{31} > 0$.

In order to simplify the algorithm, we replace the intersection of hyperbolas by that of straight lines which are parallel to the directrixes and pass through the vertices of the hyperbolas, i.e. the position of the source is replaced by its approximate position I' (X', Y'), hence a methodological error appears.

The approximate values of the emission source coordinates are found from the expressions:

$$\begin{cases} X' = \dfrac{1}{2}\, c\, \tau_{21}; \\ Y' = \dfrac{1}{\sqrt{3}}\left[1 - c\left(\tau_{31} - 0{,}5\tau_{21}\right)\right], \end{cases} \tag{5}$$

where c – the sound velocity; τ_{21}, τ_{31} – differences in the time of signal arrival at the corresponding transducers.

The refined value of the emission coordinates in view of the correction considering the substitution of the intersection of straight lines for that of hyperbolas is found similarly to (4). These coordinates look as follows:

$$\begin{cases} X' = X'\left(1 + 0{,}173Y'\right); \\ Y^{*} = Y' - 0{,}805\left(1 - X'\right)\left(0{,}578 - Y'\right)^2, \end{cases} \tag{6}$$

where X' and Y' are found from (5).

The coefficients in (6) are chosen to provide the minimum absolute values of deviations of the refined emission coordinates from the true ones. At the same time it should be noted that the absolute value of the coordinate calculation error depends on the size of base B (fig. 7, *a*).

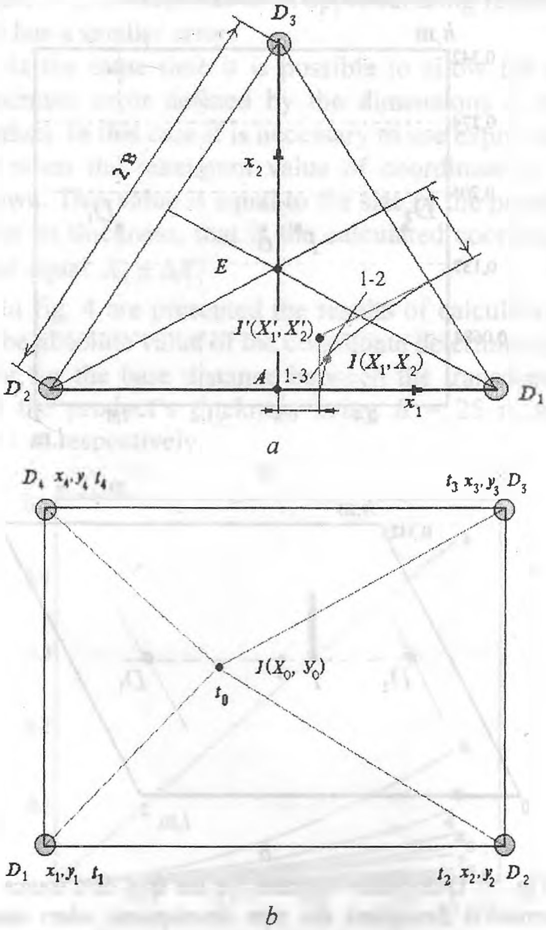


Fig. 7. Diagrams of arrangement of three (*a*) and four (*b*) transducers for the case of spatial location on the plane bounded by the internal surface between the transducers

Expressions similar to (5) and (6) are also obtained for other zones of the emission source arrangement which are bounded by triangles such as D_1AE and for which the time of AE signal arrival at the transducers is defined by the relationships:

$t_1 < t_3 < t_2$; $t_3 < t_1 < t_2$; $t_2 < t_3 < t_1$; $t_2 < t_1 < t_3$.

For these cases there will be different combination of τ in expressions (5) and (6).

When four transducers are used, they are arranged in the form of a square or a rectangular with arbitrary sizes (fig. 7, *b*).

When they are placed on an object under control, the problem of calculating the emission source coordinates X_0, Y_0 (fig. 7, *b*) reduces to solving the system of equations [5; 6]:

$$\begin{cases}(t_1-t_0)c=\sqrt{(X_1-X_0)^2+(Y_1-Y_0)^2};\\ (t_2-t_0)c=\sqrt{(X_2-X_0)^2+(Y_2-Y_0)^2};\\ (t_3-t_0)c=\sqrt{(X_3-X_0)^2+(Y_3-Y_0)^2};\\ (t_4-t_0)c=\sqrt{(X_4-X_0)^2+(Y_4-Y_0)^2},\end{cases} \qquad (7)$$

where X_0, Y_0 – emission source coordinates; X_1, Y_1, X_2, Y_2, X_3, Y_3, X_4, Y_4 – coordinates of transducers D_1, D_2, D_3, D_4 respectively; t_0, t_1, t_2, t_3, t_4 – moments of time corresponding to AE signal generation and its arrival at the corresponding transducers.

The equations in (7) are based on the fact that generation of AE signals occurs before any of the transducers receives them.

Besides, three equations of those given in (7) are sufficient for finding the source coordinates; i. e. we can consider a surface between the transducers which is bounded by the triangle.

The fourth equation from (7) is used then to verify the solution of the problem.

For a rectangular system of arranging transducers the solution gives the dependence of the emission source coordinates on the time of AE signal generation.

$$\begin{cases}X_0=a_x+b_xt_0;\\ Y_0=a_y+b_yt_0,\end{cases} \qquad (8)$$

where

$$a_x=c^2(t_2^2-t_1^2)+X_1^2-\frac{X_2^2}{2(X_1-X_2)};$$

$$b_x=\frac{c^2(t_1-t_2)}{(X_1-X_2)};$$

$$a_y=c^2(t_3^2-t_2^2)+\frac{Y_3^2}{2(Y_2-Y_3)};$$

$$b_y=\frac{c^2(t_2-t_3)}{(Y_2-Y_3)}.$$

The time of generation t_0 in view of (8) and (7) is obtained by solving the quadratic equation:

$$a_tt_0^2+b_tt_0+d_t=0,$$

where

$$a_t=c^2-b_x^2-b_y^2;$$

$$b_t=-2c^2t_1^2+2(X_1-a_x)b_x+2(Y_1-a_y)b_y;$$

$$d_t=c^2t_1^2-(X_1-a_x)^2+(Y_1-a_y)^2.$$

This equation has two roots:

$$\begin{cases}t_0'=-b_t+\sqrt{\dfrac{K}{2a_t}};\\ t_0''=-b_t-\sqrt{\dfrac{K}{2a_t}},\end{cases} \qquad (9)$$

where $K=b_t^2-2\,a_tb_t$.

To check the correctness of determining the roots (9), the following expression is used

$$\delta_k=\left|\sqrt{[X_0(t_0^k)-X_4]^2+[Y_0(t_0^k)-Y_4]^2}-c(t_4-t_0^k)\right|, \qquad (10)$$

where t_0^k – non-positive root of equation (9); $X_0(t_0^k)$, $Y_0(t_0^k)$ – emission source coordinates obtained by means of substitution of the roots (9) to equations (8).

The calculated coordinates of the emission source correspond to the minimal value of δ_k. For decreasing the emission source coordinate calculation error, when the antennas are arranged in the form of a rectangular or square, calculations are performed with all possible combinations of the transducers grouped in three in order to find the minimal value δ_k.

Other methods exist for finding the defect coordinates on the plane bounded by the internal surface between the receiving AE transducers [7; 8].

Four and more transducers are also used for spatial location of an AE source beyond the plane bounded by the internal surface between receiving transducers. In this case, however, the base distance between the transducers is much less than in the case of internal spatial location. Here the algorithms for the calculation of emission source coordinates are simplified due to redundancy of the information obtained and to the defined symmetry in arranging the transducers [2; 4; 9].

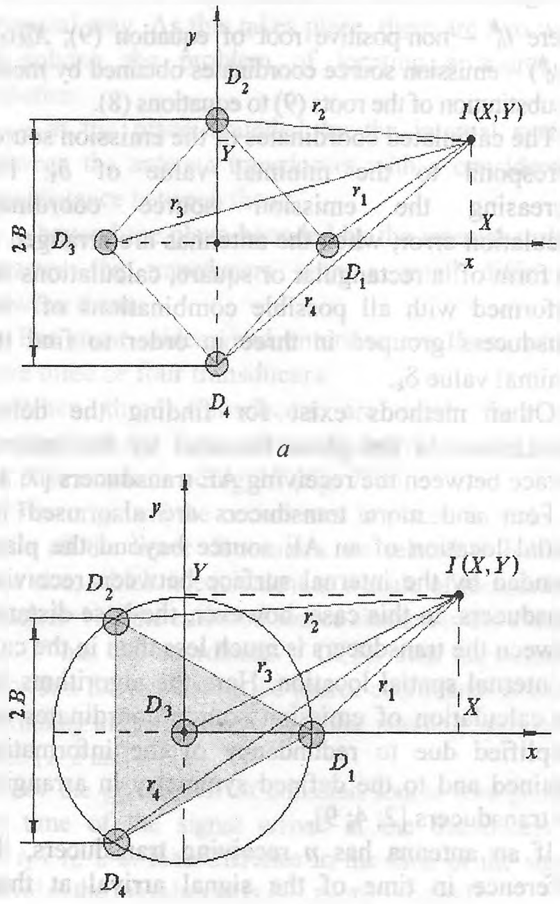
If an antenna has n receiving transducers, the difference in time of the signal arrival at them ($\tau_{ik}=t_i-t_{ik}$) has the following properties:

$$\begin{cases}\tau_{ik}=-\tau_{ki};\\ \tau_{ik}-\tau_{jk}=\tau_{ij};\\ \tau_{ik}+\tau_{kj}=\tau_{ij};\\ \sum\limits_{i=1}^{n}\sum\limits_{k=1}^{n}\tau_{ik}=0.\end{cases} \qquad (11)$$

If transducers are arranged in the form of a square with a base distance between them being 2B, and the emission source is beyond the plane bounded by the plane of the antenna, and the source coordinates are $I\,(X,Y)$ (fig. 8, *a*), then the solution of equation (1) in view of (11) makes it possible to determine the emission source coordinates from the expressions:

$$\begin{cases} X = \dfrac{c^2}{4B}\tau_{31}\dfrac{\tau_{21}\tau_{23}+\tau_{41}\tau_{43}}{\tau_{32}-\tau_{41}}; \\ Y = \dfrac{c^2}{4B}\tau_{42}\dfrac{\tau_{31}(\tau_{23}+\tau_{41})-2\tau_{21}\tau_{41}}{\tau_{34}-\tau_{21}}, \end{cases} \qquad (12)$$

where c – the speed velocity; τ_{21}, τ_{31}, – the difference in the time of the signal arrival at the 2nd and 1st, the 3rd and 1st receiving transducers respectively; B – the base distance between the transducers.



a

b

Fig. 8. Diagrams of arrangement of three (*a*) and four (*b*) transducers for the case of spatial location beyond the plane bounded by the internal surface between the transducers

If transducers are arranged so that they form a centered triangle with a base distance being 2B, and the emission source is beyond the plane bounded by the plane of the antenna, and the source coordinates are $I\,(X,Y)$ (fig. 8, *b*), then the solution of equation (1) in view of (11) makes it possible to determine the emission source coordinates from the expressions :

$$\begin{cases} X = \dfrac{B}{\sqrt{3}} + \dfrac{\sqrt{3}}{2B}c^2\tau_{31}\dfrac{\tau_{41}\tau_{43}+\tau_{21}\tau_{23}-4\dfrac{B^2}{c^2}}{3\tau_{31}-\tau_{41}-\tau_{21}}; \\ Y = \dfrac{c^2}{4B}\tau_{42}\dfrac{3\tau_{31}(\tau_{23}+\tau_{41})-2\tau_{21}\tau_{41}-4\dfrac{B^2}{c^2}}{3\tau_{31}-\tau_{41}-\tau_{21}}. \end{cases} \qquad (13)$$

Here, for decreasing the emission source coordinates calculation error, the minimal base size of the antenna (the base distance between the transducers) in chosen on the basis of the relative density ($2\overline{B}_{\min}$) of transducers arrangement, or on the basis of the minimal relative size of the antenna

$$2\overline{B}_{\min} = \frac{2B_{\min}}{S_n},$$

where S_n – the diameter of the antenna.

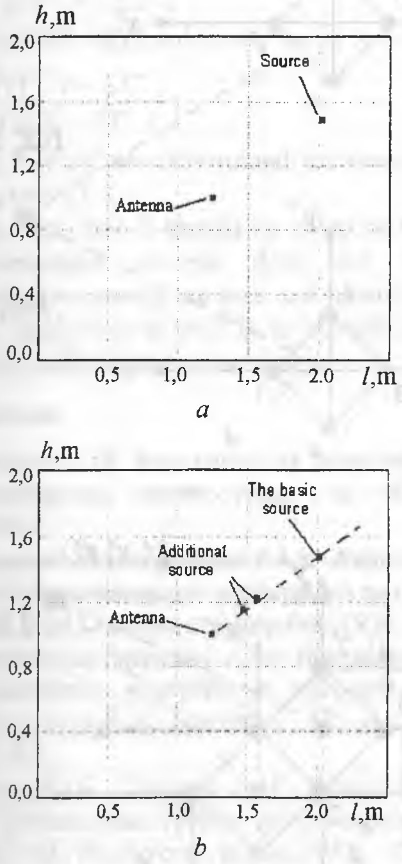
For a square-shaped antenna the value $2\overline{B}_{\min}$ equals 1,414, for a triangle-shaped antenna $2\overline{B}_{\min}$ = = 1,732. It should be noted, however, that with decreasing the base size of the antenna, the difference in the time of the signal arrival at the transducers decreases. This complicates the calculation of this difference and makes requirement on the accuracy of their measuring more rigid.

At the some time, the calculation of the emission source coordinates is influenced by a variety of waves appearing as a result of relaxation processes which occur in the course of AE signal propagation. This causes the problem of detecting the reaction of the transducers at the appearance of one and the same signal [10; 11]. We may use for it AE signal selection or filtration on the basis of some characteristics. These characteristic may be: range of the minimal and maximal delays of different-in-time-of-arrival signals at the transducers: range of the total minimal and maximal delays of different-in-time-of-arrival signals; sound velocity range; range of the amplitudes of signals received by the transducers for the given base distance between them.

Research was carried out when testing a spatial location system with an antenna having the form of a square with band-pass and wide-band transducers in a plane beyond the antenna. The research showed that when rigid parameters of filtration are introduced, the source coordinates become fixed in accordance with the coordinates of the emission source under testing (fig. 9, *a*). Test signal was processed when determining the emission source coordinates for a square-shaped antenna with a base B = 0,22 m (fig. 9, *a*), an emission simulator being installed at a distance X = 1,0 m, Y = 0,75 m from the antenna.

The results obtained showed that the coordinate calculation error did not exceed 0,8 % [12].

However, the experimental results show that when the range of filtration parameter values expands, or when wide-band transducers are used, additional emission sources (apart from the main one) appear on the source distribution diagram (fig. 9, *b*).



a

b

Fig. 9. Emission sources on the development of the object under control:
a – the range of values of filtration parameters is limited ($N = 130$) ; *b* – the range of values of filtration parameters is expanded ($N = 551$)

These additional sources always lie in the straight line connecting the antenna and the main source of AE signals. The most influential factor here is the expanding of the velocity range. The wider this range, the more additional emission sources appear, which is in agreement with the existence of different kinds of waves emerging when an AE signal is propagating.

In order to lower the number of additional fixed emission sources one can use either transducers with a narrow transmission band or resonant transducers. At the same time, it is necessary to find a transmission band for every product (material), i.e. individual selection of transducers is necessary, which is a very complicated problem to be realized in practice.

On the other hand, the existence of additional emission sources on the straight line between the antenna and the main source may be regarded as additional information for determining the source coordinates. This allows us to find the direction to the emission source.

This direction is determined by the slope of the straight line which proceeds from the origin of the coordinates and ends at the source coordinates (X, Y) for the given antenna orientation on the plane of the object:

$$\alpha = \mathrm{arctg}\left(\frac{X}{Y}\right), \qquad (14)$$

where α – the slope of the line connecting the origin of the coordinates (antenna) with the AE signals source; X, Y – the source coordinates determined according to (12) for a square-shaped antenna and according to (13) for an antenna having the form of a centered triangle.

If we have n emission sources, then the average direction to the source is determined from:

$$\alpha = \sum_{i=1}^{n} \alpha_i,$$

where n – number of the sources detected; α_i – the slope for the ith detected emission sourceaccording to (14).

Thus, when performing spatial location, we may use two antennas arranged at a certain distance from each other and having a definite spatial orientation; each of the two antennas is helpful in determining the direction to the emission source, (fig. 10, *a*), (A and A'). This allows us to increase the reliability of determining the emission source coordinates. Here the filtration parameters are the same for both antennas, whereas each of them works independently and determines coordinates with relation to its base and orientation: $I\ (X, Y)$ for antenna A; $I\ (X', Y')$ for antenna A'. When there are additional emission sources, the direction to the source is found (the slope of straight lines) and the coordinates of the point of intersection of the straight lines corresponding to these directions are determined. The obtained coordinates correspond to the spot of the emission source [13].

Let us consider two equally oriented antennas, the first of which is the base one, while the second antenna has its origin of the coordinates shifted along the axis y over a certain distance L (fig. 10, *a*).

When performing the spatial location, the emission source coordinates with relation to the base antenna A are (X, Y), and with relation to the second antenna A' – (X', Y'). For the defined coordinates, the equations of the straight lines connecting the source with the antennas are the following:

$$\begin{cases} y = a_1 x; \\ y' = a_2 x'; \end{cases} \qquad (15)$$

where coefficients: $a_1 = X/Y$; $a_2 = X'/Y'$.

Allowing for the second antenna's shift (L) and taking into account that $x = x'$, equation (15) may be written as

$$\begin{cases} y = a_1 x; \\ y = a_2 x - L. \end{cases} \qquad (16)$$

After solving (16) we will obtain the emission source coordinates in the form:

$$\begin{cases} X_I = \dfrac{L}{Y' - Y}; \\ Y_I = \dfrac{LX^2}{Y(Y' - Y)}, \end{cases} \qquad (17)$$

where $X=X'$, Y, Y' are determined for each antenna according (12).

When we use an antenna having the form of a centred triangle (fig. 8, *b*), the emission source coordinates are found from expressions (16), (17) with allowance made for (13).

The use of two antennas increases the reliability of determining the emission source coordinates. However, it leads to increasing the amount of information registered, makes the electronic equipment greater in size, and complicates the software algorithms. This influences, first of all, the speed of information processing. The problem becomes much simpler when we use a compound antenna consisting of six rigidly arranged transducers and having a rigid size of the base (fig. 10, *b*). The main antenna *A* consists of transducers *1–4*, and the additional antenna has transducers *1'–4'*. As this takes place, transducers *2* and *3* of the antenna *A* are incorporated into antenna *A'* which has its own numeration (*1'* and *4'* respectively). When the compound antenna is installed on the object under control, the orientation of its components has always the same direction. Due to a negligible "base" size of the antenna, the delays of signals' arrival at the transducers are comparable, which decreases sharply the speed of information processing in the computation channels.

Generally, the relationships (12) for calculating the emission source coordinates remain unchanged. The calculations may be carried out either for the common base or for each of the compound antenna's components independently. In the first case the coordinates are specified with respect to the antenna *A* operating in the normal condition. Here the source coordinates are calculated by expressions (12). For the antenna *A'* the spot of the source is determined with allowance made for the shift of its base coordinates with relation to antenna *A*. In the second case the base coordinates for each of the compound antenna's components are introduced, and the emission source coordinates are calculated independently in accordance with (12). A compound antenna operates similarly to two independent antennas and allows us to determine the direction to the source and its coordinates.

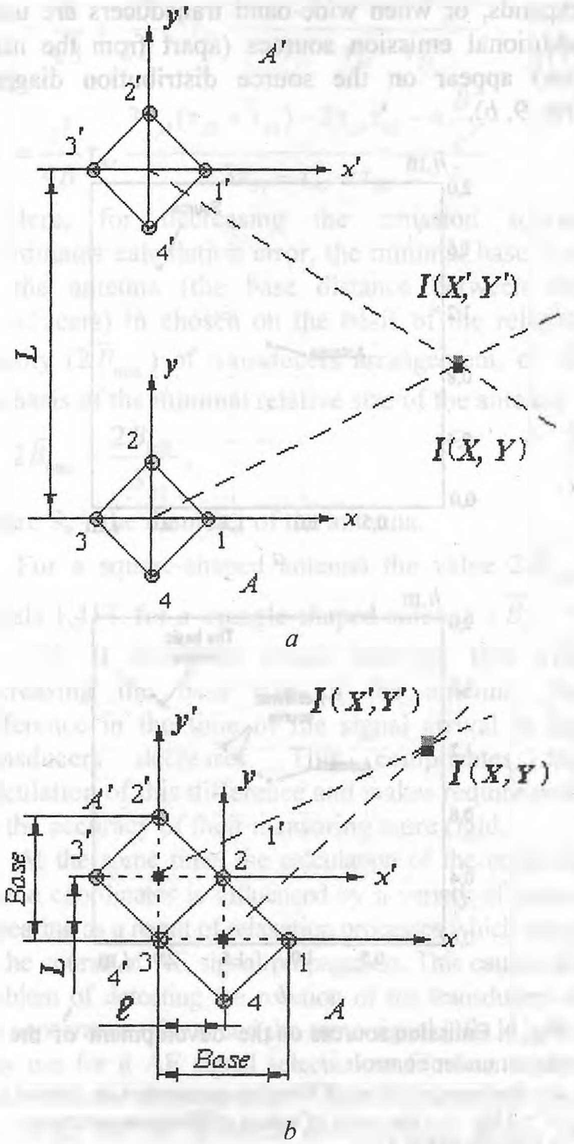


Fig. 10. Determining of the direction to the emission source:
a – when two independent antennas are used; *b* – when a compound antenna is used

Let us consider a compound antenna with a single orientation of its components, one of which is the base antenna, the other has its origin of the coordinates shifted along the axis *y* at a certain distance *L* and along the axis *x* at a distance *ℓ* (fig. 10, *b*). When performing the spatial location, the emission source coordinates are (*X*, *Y*) with relation to the base antenna *A* and (*X'*, *Y'*) with relation to the antenna *A'*. For the defined coordinates, the equations for the straight lines, connecting the emission source with the antennas (the origin of their coordinates), fit the expression

(15). Allowing for the second antenna's shift ($L,\ \ell$), the equations (15) will have the form:

$$\begin{cases} y = a_1 x\,; \\ y = a_2 x - d\,, \end{cases} \qquad (18)$$

where $d = a_2 \ell - L$; a_1, a_2 are found according to (12).

After solving (18) we will obtain the emission source coordinates:

$$\begin{cases} X_i = \dfrac{X(Y'\ \ell - LX')}{(Y'X - YX')}\,; \\ Y_i = \dfrac{Y(Y'\ \ell - LX')}{(Y'X - YX')}\,; \end{cases}$$

where X, Y, X', Y' are determined for each antenna according to (12).

At the same time it should be noted that the use of a compound antenna does not lead to considerably increasing the size and quantity of the electronic equipment as well as to sharply reducing the speed of information processing.

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Методи локації місцезнаходження дефектів структури за сигналами акустичної емісії

Наведено огляд методів та алгоритмів визначення місцезнаходження дефектів структури, що розвиваються у виробах при їх навантаженні, які використовуються в акустоемісійних системах локації джерел акустичного випромінювання.

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Методы локации местонахождения дефектов структуры по сигналам акустической эмиссии

Приведен обзор методов и алгоритмов определения местонахождения дефектов структуры, развивающихся в изделиях при их нагружении, которые применяются в акустико-эмиссионных системах локации источников акустического излучения.