THE PRIME PROBLEMS OF ACOUSTIC-EMIISSION DIAGNOSTICS OF TECHNICAL DEVICES AND CONSTRUCTIONS.

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Abstract: The method of acoustic emission has started for industrial inspection of engineering objects without a deep penetrations into physical and fracture mechanics bases. Then there was some promotion. Now there has come time for deeper substantiation of application of the given method.

Introduction: AE method in industrial application

The method of acoustic emission (AE) which in the industry is applied already more than 30 years, has appeared rather useful as a method of not destructive testing (NDT). Method AE as method NDT now it became a routine method widely enough used in the industry. However potential opportunities of method AE allow to carry it to methods of technical diagnosing (TD) in modern understanding of this term, i.e. definition of a real technical condition of object with the purpose of definition of its safety (through an estimation of risk) and forecasting of a resource.

Method AE apparently potentially the most powerful method NDT and TD. However now its opportunities are used no more, than on 10-15 %. Therefore in most cases for an estimation of a degree of danger of found out sources AE use in addition other (traditional) methods NDT which have norms of rejection. These norms contain the sizes of defects and their quantity.

The main advantage of method AE is ability to estimate a degree of danger of defect for object without definition of the sizes of defects. Intuitive utility of method AE promoted fast and wide use of its in the industry. However method AE now is used, basically, as an auxiliary method. I.e. in most cases after use of a method AE apply other methods NDT to identification of defects and decision-making.

It is known, that in most cases failure of designs occurs as a result of growth of defects (as a rule, cracks) up to critical size. Objects can be in following conditions:

1. Macroscopical defects are absent. Objects can contain heterogeneity of a material, the zones containing design features - concentrators of stress. And also to contain micro and meso defects. Similar defects can exist in object its all life and not lead to destruction. This usual condition of each object in performance, it the most probable condition.
2. Objects which besides the set forth above features, contain meso-defects which in due course growth of crack and can reach the critical sizes (limiting conditions) during service life.
3. The object contains macro-defect which can at test loading to lead to destruction.
4. The object containing macro-defect which at working loading can already lead to destruction.

That method AE became a method of TD and monitoring to the full, it is necessary, that under indication AE critical decisions concerning destiny of object were accepted. Unfortunately, now method AE develops in a greater degree in breadth, instead of deep into.

Problems and Tasks of AE Method

To understand the reason of a suspension of AE method development, it is necessary to consider in details all elements and problems of a method, to estimate a degree of the decision of these problems and to plan directions to which it is necessary to concentrate efforts on the further development. For consideration of problems and tasks in AE method we shall look at a picture presented on Fig.1. [1].

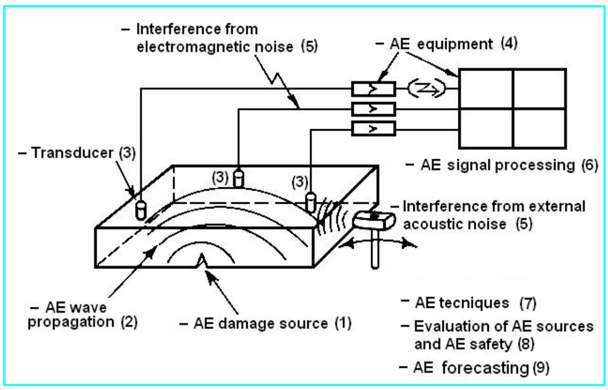

Fig. 1. Problems and tasks of AE method: AE

source models (1), Propagation of AE signals (2), AE transducers (3), AE instrumentation (4), Noise and interference (5), AE signal processing (6), AE techniques (7), Assessment of AE sources (8), Forecasting with AE (9).
Listed above a problem are solved in that volume which allows to use now method AE with the fundamental advantage for the testing of industrial objects and research of deformation and fracture processes. However there is a wide open space for the further development. In table 1 it is presented expert estimations to "Degree of the decision of a problem" and "Urgency of a problem". The urgency is connected with an opportunity of reception of an end result, i.e. an estimation of a degree of danger of AE source for a design.

Table 1

№	Problem	Urgency of a problem (range: 0,0 -1,0)	Degree of the decision of a problem, (%)
1	AE sources (models)	0,2 ÷ 0,4	70 ÷ 80
2	AE channel	0,4 ÷ 0,6	60 ÷ 80
3	Transducers AE (TAE)	0,8 ÷ 1,0	50 ÷ 70
4	AE instrumentation	0,4 ÷ 0,6	90 ÷ 97
5	Noise and interference	0,3 ÷ 0,5	80 ÷ 90
6	AE signal processing	0,8 ÷ 1,0	10 ÷ 30
7	AE techniques	0,3 ÷ 0,5	90 ÷ 97
8	Assessment of sources, AE safety	0,8 ÷ 1,0	10 ÷ 30
9	Forecasting with AE (prognosis)	0,8 ÷ 1,0	0 ÷ 10

Naturally, the figures resulted in the table, are expert estimations. Each expert has the opinion which differs from another. It is necessary to admit, that by preparation of this report the author repeatedly (though and it is insignificant) changed figures in table 1.
Problems of AE method can be subdivided into 4 levels (on a degree of importance for industrial application).

1. Fundamental (prime) problems (5, 8, 9 of Table 1).
2. Basic problems (1, 6).
3. Actual problems (2, 3,).
4. Current, technical problems (4, 7).

Depending on potential and the purpose of the researcher the choice of a subject of researches and development any of the specified problems can be made. It is necessary to emphasize once again, that specified above estimation reflect current (for the present) opinion of the author and, probably, are not indisputable.
Let's begin the brief review of the specified problems.

Sources AE and degradation of signals (Problems 1, 2).

If to consider the fundamental physics and mechanics of AE source it is rather complex. And complexity of processes depends on a necessary level of consideration. For practice of model of the AE-source can be simplified and signal AE near to a source (crack) can be presented in the form of step function (Fig.2) which parameters to contain key parameters of a crack jump, including size Δa [2].
There is a question: what information is kept in a signal 3 from a signal 1 (Fig.2c). And it is. Generally it is kept in energy and in amplitude [2]. Besides in a signal 3 there is an information on the channel of a signal propagation and on a site of source AE. Scales on a time base $t_{1,2}$ (for signals 1, 2) and t_3 (for a signal 3) differ in 10 ÷ 100 time.
The high level calculations of acoustic signals performed under direction of Y.H. Pao and presented in several papers, for example in [3], have shown, that rather "simple" signals under the form near to a source turn to stochastic signals of absolutely uncertain form far from a source. It is on distance (10÷20) d (d - thickness of a wall of object). The task of AE source reconstruction at

the accepted signal is incorrect in essence and hardly it will be possible it decently enough regularized.

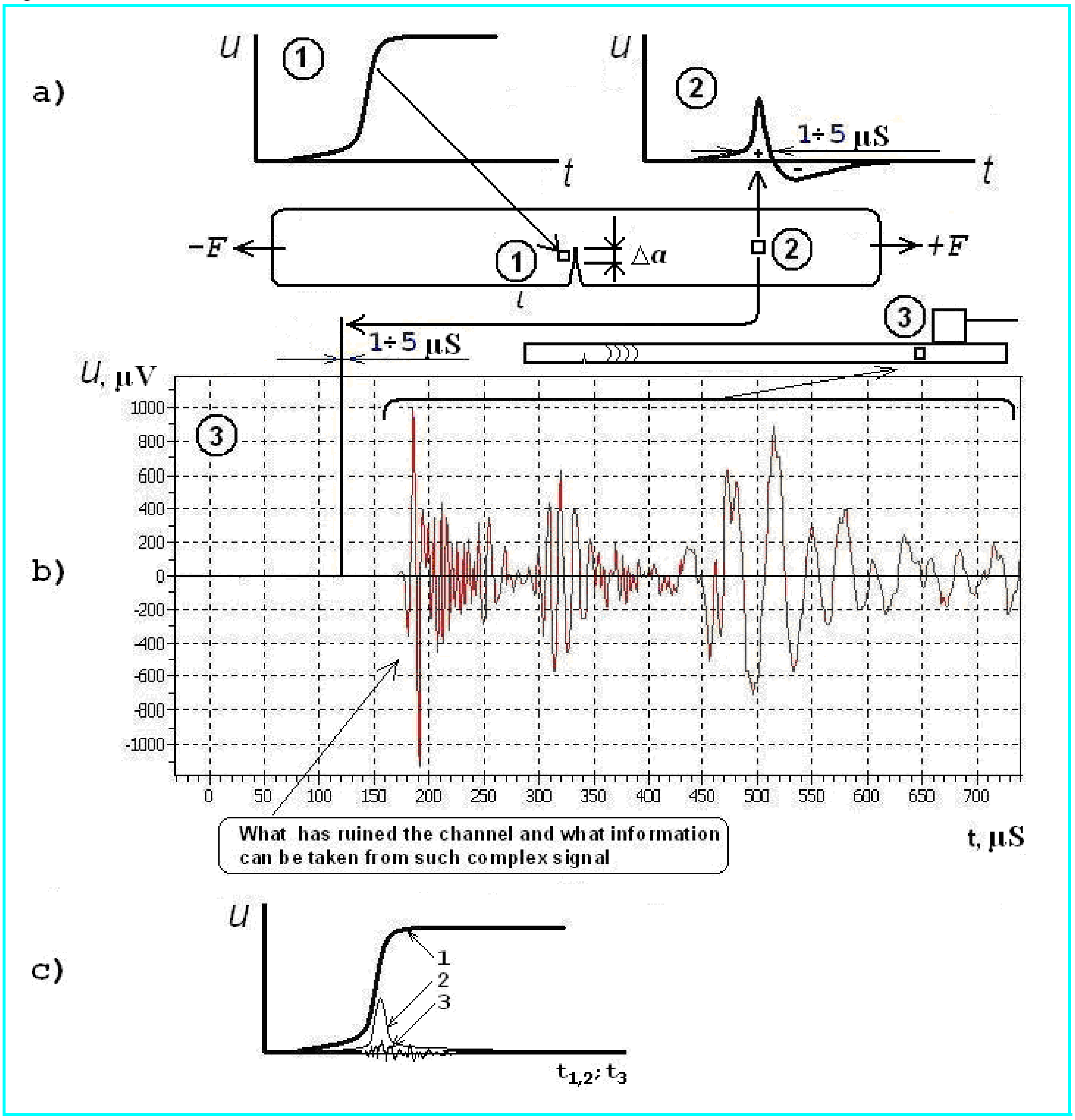

Fig.2. Signals AE from individual jump of a crack on different distances from a source: a-1) - an acoustic signal in immediate proximity from source AE; a-2) - it is not so far ($10a \div 20a$) from source AE; b) electric signal on output AE Transducer (TAE) after travel through the acoustic channel, c) conditional matching acoustic and electric signals.

What the channel has distorted and what information can be take from such complex form (a signal 3)? For the skilled and knowing expert even in a signal 3 a lot of information contains. However, hardly it is expedient to spend exact calculations of AE signal transfer through AE channel. Apparently, the analysis of parameters degradation by experimental statistical estimations is necessary.

AE Transducer. AE Equipment. (Problems 3, 4).

Requirements to AE Transducer (TAE) are concentrated, basically, in two areas: 1) factor of transformation and 2) Amplitude-Frequency (essentially without the Phase-Frequency) response. The factor of transformation depends on a used transducer material, and frequency characteristics - from a design. As it is impossible to measure phase-frequency characteristics in solid, for the description of the TAE it is necessary to use pulse response. Requirements to the transducers used for industrial testing would be rather actual, if the signal coming on TAE would not be so strongly deformed by the acoustic channel [2, 3].

To experts in the field of AE, working in the beginning of XXI century, has carried that progress in the field of IT has reached in this area of transcendental (almost metaphysical) heights. Further art of creation of the equipment depends only on literacy technical specifications.

Problems of interference and noise. Processing of AE signals. (Problems 5, 6).

The greatest restrictions in AE method are connected with its small Noise Resistibility. It is caused by that AE signal is pulse stochastic process which parameters to us are unknown. Therefore we cannot while to take advantage of achievements of a radar theory in the field useful signal/noise recognizing. Basically, we can work more or less confidently at the signal/noise ratio not less than 6 ÷ 12 dB (on amplitude). Therefore the problem is simple (and at the same time is complex) - it is necessary deeply to study AE signals [2.]. And only after that it will be gradually possible to leave on a worthy level.

If the equipment, owing to development of processors and digital circuits does not represent vital problems, the methodical approaches connected with recognizing of signals from noise remain, basically, at a level of "Stone Age".

AE Techniques. Assessment of sources, AE safety and forecasting. (Problems 7, 8, 9).

Construction of techniques AE depends on properties and a design of concrete testing object. Techniques should contain two basic parts: 1) concrete technological receptions of monitoring procedure and 2) an estimation of results of the testing. Judgment about presence and degrees of danger of defect are formed at the analysis of AE parameters. AE signals bear the information on sources, and it displays processes of deformation and destruction. Classes of informative parameters of AE signals are presented in Table 2.

Table 2. Classes of informative parameters of AE signals:

The parameters of AE signals used for an estimation of results		
Totally, Time-dependent	Amplitude, energy	Complex
$N, \acute{N}, N_\Sigma, \acute{N}_\Sigma, \ldots$	$A\ (U_m)$, E	Complex Par = $F(A, E, N, \acute{N}, N_\Sigma, \acute{N}_\Sigma)$

Totally - Time-dependent parameters bear the information mainly about growth of deformation and destruction processes, Amplitude - energy parameters bear the information mainly about parameters of individual jumps of cracks.

Totally - Time-dependent parameters are used often during hydro-pneumo tests. At test of object in the first stage loading (the stage 1 on Fig.3), is registered, as a rule, big number of AE signals. It is connected with plastic deformation of a "fresh" material in places of stress and strain concentration. Thus can be formed as well microcracks which do not render essential influence on static strength of object. The probability of fracture at a stage 1 makes $P = 10^{-5} \ldots 10^{-6}$ for objects of high reliability. Accordingly, for the given stage at detection of sources AE it is possible «over rejecting». However, in case of presence at object of defect of the critical size, it will be found out with probability not less than 0,8 - 0,9 [2]. At detection of sharp increase of total emission direct transition of a stage 1 (corresponds to critically active source AE) in a stage 5 (corresponds to catastrophically active source AE) on Fig.3d takes place. Dependence $N(\Pi)$ possesses predictive force. At stages 1-4 reliability of a prediction is less, than at a stage 5.

At stages 2, 3, 4 AE signals are connected with formation and development of macrodefects. At the given stages it is possible as "over rejecting" (a situation resulted on fig.3b and stage 1, 3-α), and loss of defect (a situation resulted on Fig.3, stages 2 and 4-β). The probability of object fracture at stages 2, 3, 4 can lay in a range $10^{-2} \ldots 10^{-5}$. From Fig.3 it is visible, that method AE has the certain potential opportunities of the forecast of fracture. Now the given potential is as much as possible realized while at a stage of 5 works of object.

Whether but it is possible at stages 1, 2, 3, 4 (where α - critically active source, β - passive source) to predict catastrophic moment × (the end of a stage 5 = the end of a life of object). Hardly probable, at least, today. It is possible to make it with this or that probability (risk) at approach of a stage 5. The important problem - correctly to identify approach of accident.

Stage of a object life	Probability of destruction, *P*
1	$10^{-4}…10^{-5}$
2	$10^{-3}…10^{-4}$
3	$10^{-2}…10^{-3}$
4	$10^{-1}…10^{-2}$
5	$1…10^{-1}$

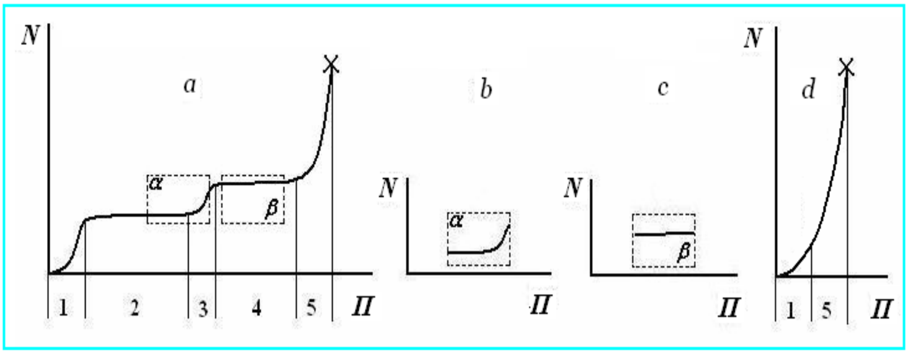

Fig.3. The generalized dependence of total AE N as a function of loading parameter $П$. Item 1 … 5 - stages of a life of object. *a* - full cycle of a object life, *b*- stage 2α, *c* - stage 3β, d - object with critical defect (a stage 1 → 5 - catastrophic).

As criteria of an estimation of an AE source the exponent *n* can serve:

$$N = aП^{n}, \tag{1}$$

I name this dependence Dunegan formula [4]. As loading parameter $П$ there can be a force, pressure, stress intensity factor, strain intensity factor etc. With use of this formula classification of sources AE has been made [2]:

I	-	$n < 1$	- passive source AE;
I I	-	$n \approx 1$	- active source AE;
I I I	-	$1 < n < 6$	- critically active source AE;
IY	-	$n > 6$	- catastrophically active source AE.

Except for dependences of parameters AE on loading (or time which we name Total-Time-dependent), resulted on Fig.3, amplitude or energy and complex parameters (Table 2) are used also. Amplitude parameters are represented, as a rule, in the form distribution of impulse peak. For a 15X2NMFA (steel for atomic vessels) prismatic specimen with a crack peak distribution looks like, presented on Fig.4.

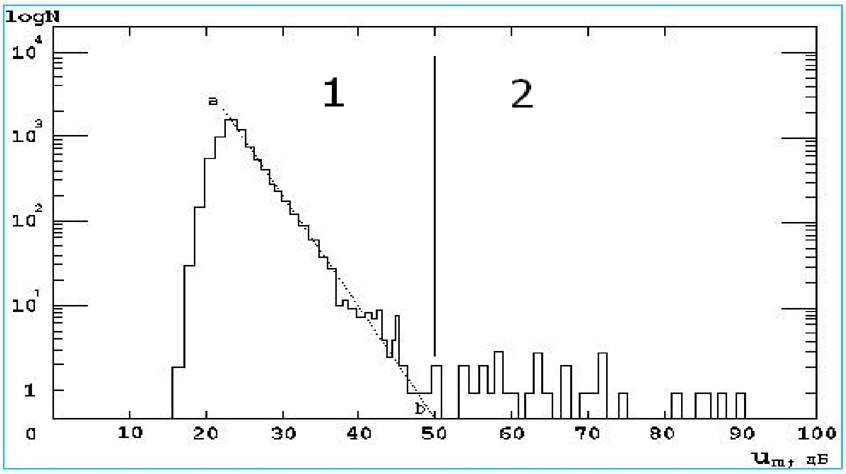

Fig..4. Amplitude distribution of AE impulses.

The area of 1 (20 … 50 дБ) distribution of amplitudes is connected with plastic deformation and formation of micro-cracks. The area of 2 (50 … 100 дБ) amplitudes is connected with formation of a macro-cracks and development of the main crack.

Amplitude or energy parameters are more preferable for using at the testing of objects over rather fragile materials. A class I sources (insignificant sources) and class I I (serious sources) can be carried to area 1 on Fig.4, a class I I I sources (critical) and class I Y (catastrophic sources) can be carried to area 2.

For the testing of more viscous materials it is more preferable to use time-depended parameters and their combinations. But then important to have a binding to a stage of an object life (Fig.3).

Thus, method AE as the method of technical diagnosing possesses an unconditional opportunity of definition of a technical condition of object, allows estimating adequately a degree of safety of object, to estimate real danger of defects. At use of method AE terms «over rejecting» and «defect miss» find a real basis. Revealing critically and catastrophically active sources which inform on the accelerated development of the main crack and approach of its size to the critical size for the given design is certainly useful.
The prediction of rare events represents a challenge. There is no theory of rare events. However use of AE method under the scheme of monitoring allows defining a true condition of object in real time. Scheme of AE monitoring should take in the near future a worthy place in task of a maintenance safety of industrial objects.

Conclusion

Method AE can be carried to one of the most powerful methods NDT and TD. The AE method of possesses the maximal potential concerning detection of the defects leading failures. At full realization of potential of a method we should define safety, a resource and likelihood estimations of these parameters, i.e. risk. The huge potential of method AE should be to the full realized in the further in the field of monitoring.
To potential of method AE, which else it is necessary to realize, it is possible to carry:
- An opportunity of definition of the size of defect (though it for method AE, probably, it also is not necessary).
- An opportunity of an estimation of a real degree of danger of defect.
- An opportunity of forecasting of a condition of object.

Referens

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