Approximate relationship between parameters of AE event mechanism and selected parameters of detected AE signal.

M.Přibáň, P.Hora, ÚFY & ÚT AV ČR Plzeň

ABSTRACT

Exact description of AE event mechanism based on detection of undistorted surface displacements (as it is known from laboratories) is unrealistic or impractical in industrial AE testing. On the other hand some effective approximate relationship between absolute parameters of AE event mechanism and selected relative parameters of detected AE signal shall exist in industrial AE testing as well (at least estimation for detectability criteria). The scheme of creation and assessment of selected approximation is described. The described approximation is based on calculation of surface displacements of plates as response to the selected models of mechanisms of AE event acting in or on plates and on calibration of selected characteristics of typical resonant AE sensor. The results are discussed from the point of view of applicability of the approximation in industrial AE testing.

BASIC THESES

One of the most important condition to improve evidence/reduce unreliability of evaluation of AE testing in practice is the introduction of effective procedure to assess absolute parameters of AE source mechanism (i.e. not only parameters of detected AE signal). Let us use the analogy. Ultrasonic testing introduces equivalent defect size - the procedure to assess absolute defect parameter (size of defect). The procedure generally accepted is effective approximation that is based on some equivalent model/ simplification of physical reality. This approximation is based on some presumption and according to agreement with the assumption the resulted equivalent size corresponds to the reality. Similar approximate procedures should exist in AE testing as well.

„Complete“ exact assessment of a set of AE source/mechanism parameters (deconvolution) is unrealistic and impractical. Even in the case of precise laboratory experiments we typically come from some presumption/ model of an AE source mechanism and the AE transfer function (wave propagation function with respect to geometry of the body, source and sensor location, together with and sensor transfer function). Based on this presumption we get some expected relationship between selected parameters of AE source and detected AE signal [1,2]. Deduction of AE source parameters from detected AE signal is not based on deconvolution but on comparison with the pattern of expected AE signal.

The identification of AE source mechanism and deduction of its parameters is based on some simplification of reality - on some approximation. The degree of simplification can be different.

In above-mentioned precise laboratory testing the degree of simplification is low. The general time evolution of dipole force tensor approximation is a very good approximation of reality. The knowledge of elastodynamic Green function and application of special AE sensor enable precise complex assessment of parameters of AE source mechanism. But even this approximation did not cover the problem completely (for instance radiation pattern of the infinitesimal crack jump cannot be described through dipole force tensor [1]).

On the other hand assessment of absolute parameters of AE source based on the number of AE events detected per surface of growing crack (mm^2) represent approximation with high simplification of reality.

A consideration of effectiveness of an approximation (degree of simplification)

depends on requirements and criteria for the particular application of AE testing.
Nevertheless there are at least two criteria that the selected approximation shall satisfy:

a) the approximation shall be widely accepted equivalent, („common denominator“) for comparison and transfer of results among various AE testing

b) the approximation shall provide acceptable degree of unreliability of assessed AE source parameters, (acceptable scatter of assessed value with respect to given application).

The task, we made our aim, is to contribute to the solution of the above problem through realisation of the scheme at fig.1.

The aims are in particular:

1) to compare and consider effectiveness of the selected variants of approximation („*equivalent parameters of AE source*“) from the point of view of increasing reliability and information scope provided by AE method - against simplification and price reduction of the AE evaluation in industrial practice *.
2) to prepare the effective exact basis for the evaluation of AE testing results at planned fracture tests of bodies in approximation of thick walled plate. (Ductile-Brittle Fracture, and Fatigue Induced Hydrogen Assisted Cracking).

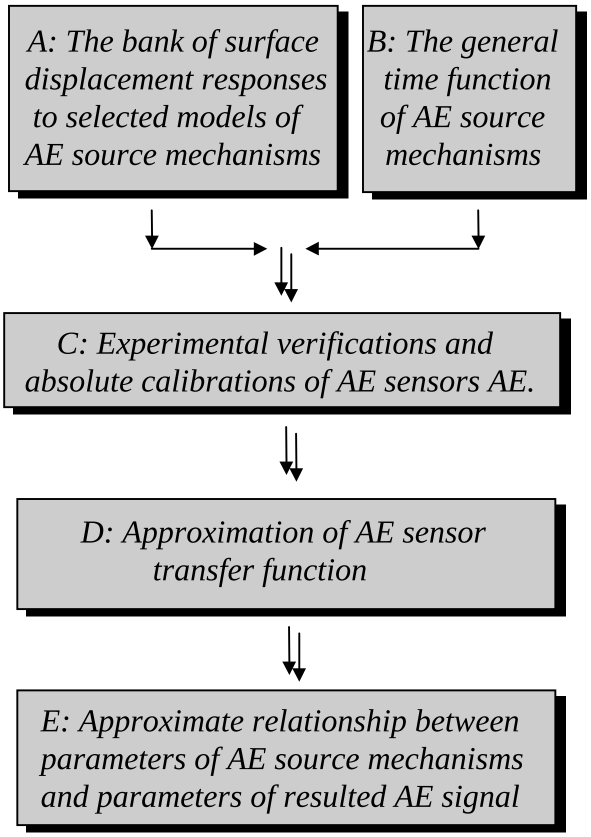

Fig.1: The scheme of testing the selected approximation between parameters of AE source mechanisms and parameters of resulted AE signal.

***Note *:** AE testing at thick walled pressure vessels and pipes (low alloy steel) in power and chemical plants).*

In the next part we put forward some comments to the items depicted at fig.1.

DESCRIPTION OF THE SCHEME

A: The bank of responses to selected model of AE source mechanisms.

The bank contains the calculated time response of radial $u_r(t)$ and vertical $u_z(t)$ surface displacement at any ($\boldsymbol{R} \leq 12\boldsymbol{t}$) surface points (inner or outer) in the approximation of thick walled plates [3,4], fig.2. The mechanisms of AE source are modelled by point force and point dipole force step function (Heaviside) located at depth ***h*** of wall thickness. (the bank shall be extended by the calculation of thick walled plates with water (half space approximation) at inner surface and thin walled plates this year.

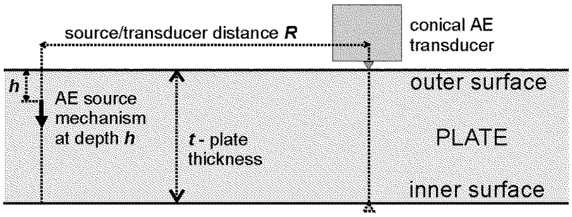

Fig.2: Drawing of the position of model of AE source and the position of calculated displacement response or sensor placing.

In fig.3 you can see the calculated vertical displacement as response to outer surface force point step function (force 1N) at $\boldsymbol{t}$=50mm and $\boldsymbol{R}$=150mm. In fig.6 you can see $u_z(t)$ at the same situation but for R=50mm.

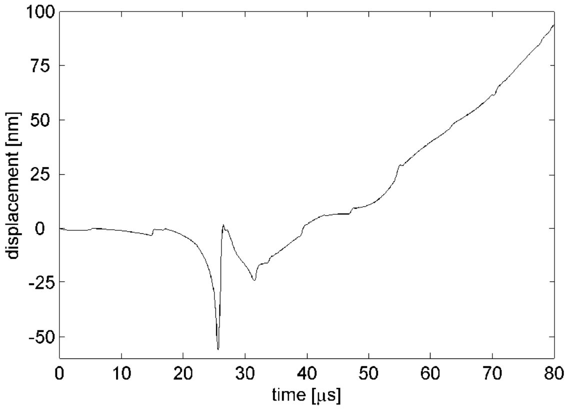

Fig.3: Computed displacements $u_z(t)$ as response to point force step function (1N) - $\boldsymbol{t}$=50mm, $\boldsymbol{R}$=150mm, $\boldsymbol{h}$=0.

B: Generalised time function of the acting AE source mechanism.

The generalisation of stepwise function of the calculated response for various time function/evolution model of the selected AE source mechanism can be simply added through convolution of response of stepwise function (Heaviside) and derivation of time function of AE source. There are considered two interesting cases, at first the influences of multiple repeated stepwise time function and at second influences of „slow down“ effect of stepwise function on resulting surface displacements. As results of the first two items A), B) we are able to calculate surface displacements $u_z(t)$ of large variety of modelled mechanisms and geometry configurations (source/detection location).

C: Experimental verification and absolute calibration of AE transducers.

The calculated surface displacements $u_z(t)$ can be experimentally verified for the cases of surface point force source induced by capillary break by the known force. As reference transducer for verification of calculation we used calibrated conical sensor with relatively flat frequency response (from 30kHz to 800kHz ±3dB). The performed experiments showed very good agreement between theoretical and experimental results, for every configuration at outer ($\boldsymbol{R}$=1,2... ÷ 12$\boldsymbol{t}$) and inner ($\boldsymbol{R}$=0,1...÷12$\boldsymbol{t}$) surface. From these results we imply, that other calculated responses (calculated by the same theory) [3,4] give us the properly estimated displacement responses.

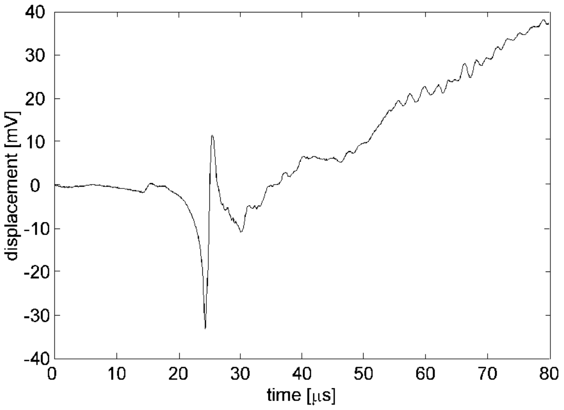

Fig.4: Measured response of conical sensor with respect to the surface displacement $u_z(t)$ depicted at fig.3.

Based on these results we introduce some simplified procedure for absolute calibration of AE sensors - we mean the simplification with respect to standard procedure [5], see next chapter.

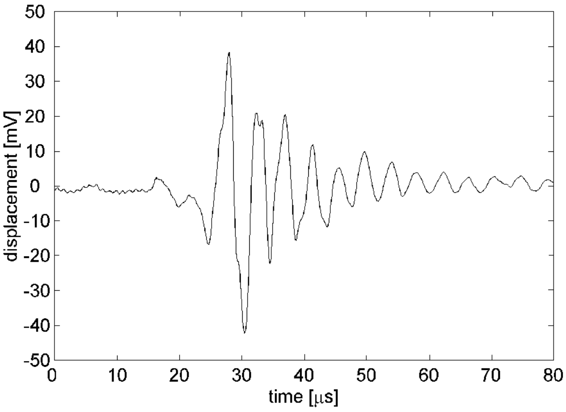

Fig.5: Measured response of typical resonant AE sensor with respect to the surface displacement $u_z(t)$ depicted at fig.3.

D: Approximation of AE sensor transfer function.

The objective of this item is to introduce a creation procedure of sensor transfer function f(t) for calculation of resulted electrical AE signal as

$$V(t)=\text{convolution}[u_z(t)*f(t)].$$

Complete description of AE sensor transfer function can be represented as amplitude and phase frequency spectra with respect to input (displacements $u_z(t)$) and output (electrical output signal V(t)). But the situation is more complex. At first the input is given not only by displacement $u_z(t)$ but $u_r(t)$ as well. The results depend on viscosity of coupling media and force applied on AE sensor. At second typical resonant AE sensor is not 1-dimensional object, it has some contact surface and it is 3-dimensional object. This is principal reason why the transfer frequency characteristics resulting from relationship between V(t) and $u_z(t)$ are similar but not equal for different ***R*** (the greater differences appear at phase spectra). Moreover there are some problems if we try to create desirable transfer function in time domain from frequency spectra by deconvolution, e.g. transfer function f(t) as response to $\delta(t)$ pulse (V(t)=convolution[f(t)*$u_z(t)$)].

From the application point of view in industrial practice we need not have complete complex AE transfer function. So we tried to create and then tested some simple transfer functions with the objective to identify only several parameters of a suitable dynamic model/transfer function of sensor. The results did not satisfy us.

Finally we have concluded that we can obtain good results if we consider transfer function f(t) , as the response of sensor output V(t) to the displacement $u_z(t)$ depicted on fig.6, see next chapter.

E: Approximate relationships between absolute parameters of AE mechanisms and parameters of resulted AE signal.

Above items A to D describe the procedure of computation of the resulted signal at transducer output V(t) with respect to large variety of selected locations, and mechanisms of AE sources. We have a set of mechanisms of AE sources and set of electrical AE sensor output signals V(t). The objective is to select and to test some useful and effective relationships between mechanisms and locations of AE sources and

a) displacement function $u_z(t)$
b) signal at the sensor output V(t)

ABSOLUTE CALIBRATION OF AN AE SENSORS AND ELECTRICAL PATH OF AE SIGNAL.

In this chapter we present the procedure of effective absolute calibration of AE sensors (its installation, and electrical path of detected signal). This procedure is applicable in laboratory and in industrial application as well (if the region near the installed AE sensor or waveguide/sensor can be approximated as thick wall plate).

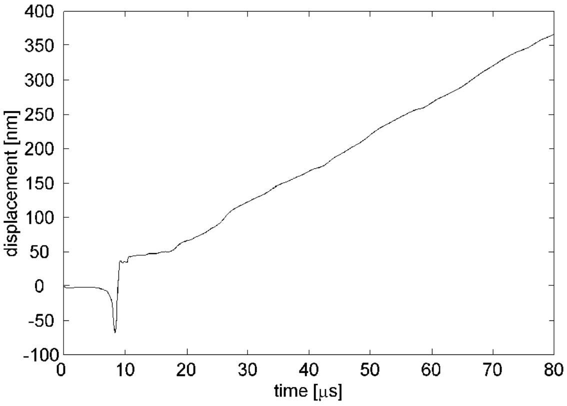

Fig.6: Computed displacements $u_z(t)$ as response to point force step function (1N) - ***t***=50mm, ***R***=50mm, ***h***=0

In fig.6 there are depicted vertical displacements $u_z(t)$ assigned as $u_{z0}(t)$ at the position ***R***=***t*** as response to point force step function (1Newton) at the outer surface.

The $u_{z0}(t)$ in fig.6 start at the time t=0 that represent arrivals of the 1st reflected dilatation P waves. The magnitude of $u_{z0}(t)$ step at t=0 is 2.5nm. At about t=8μs coincide the arrival of 1st reflected shear S waves and Rayleigh surface wave. Other reflected modes are much weaker to the above mentioned modes. The $u_{z0}(t)$ at the position ***R*****=*****t*** represent approximation of δ(t) input displacement function. So the sensor output $V_0(t)$ approximates absolute sensor transfer function $f_0(t) \approx V_0(t)$*.

Note *: *It is suitable to add some slow changing (low frequency) function so that the signal begins and ends at zero and to eliminate slow growing of $u_{z0}(t)$ after peak displacement.*

The testing of these transfer function $f_0(t)$ was based on comparison of theoretically computed $V_t(t)$=convolution$[u_z(t)*f_0(t)]$ with experimentally measured sensor output signal for various $u_z(t)$ at different configurations of the detection position and position of point force step source (capillary break) at inner and outer surface. These testing provided good agreement between $V_t(t)$ and $V_m(t)$.

Based on these results we have suggested a procedure for approximate absolute calibration of AE sensor and/or electrical path of signal. The calibration block is penny shaped 50mm thick plate - diameter 300÷400mm. The source - capillary or pencil lead break is placed at the centre of upper side of the block. The reference conical sensor and tested resonant AE sensors are placed in 50mm distance from the source.

The displacements $u_{z0}(t)$ for ***R*****=*****t*** for ***t***≠50mm is similar to that depicted in fig.6 and can be normalised with respect to plate thickness ***t***. The advantages of the procedure are:

1) possibility of reaching the approximate δ(t) displacement input function on the body with relatively small dimensions (with respect to block recommended in [5] and obtain good approximation of absolute sensor transfer function.

2) the surface displacements are known for many other surface positions, so we are able to test obtained approximate sensor transfer function $f_0(t)$.

3) the procedure is analogous to calibration of AE sensor in industrial practice where the calibration configuration is often analogous to thick plate geometry.

CONCLUSION

In this paper we described the first step (items A) to D) of scheme depicted in fig.1). We present a procedure of creation and computation sensor output signal (and/or electrical path of signal) as response to large variety of models of AE source mechanism in approximation of thick wall plate.

This procedure provide good basis for the item E), see fig.1, i.e. searching and testing effective approximate relationship between the parameters of models of AE source mechanism and the parameters of resulted AE signal.

Some useful approximations as results of item E) will be presented at conference.

Acknowledgement: We would like to express special thanks to support of Grant Agency of the Czech Republic - Grant No.101/97/1074.

LITERATURE

[1] Wadley H.N.G, Scruby C.B.:
Int..Jour.of Fracture 19(1983), p.111-128
[2] Scruby C.B, Baldwin G.R., Stacey K.A.:
Int.Jour.of Fracture 28(1985), p.201-222
[3] Achenbach J.D.:
Wave propagation in Elastic Solids.
North-Holland Publ., Amsterdam (1973)
[4] Pao Y.H., Ceranoglu A.:
J.Appl.Mech. 48(1977), p.125-147
[5] ASTM E 1106-86
Standard Method for Primary Calibration of Acoustic Emission Sensors