Multilevel model of time dependences of acoustic emission parameters as the basis for nanodiagnostics of the state of technical objects

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Abstract. The method of acoustic emission (AE) and the information-kinetic approach to AE diagnostics are identified as the most promising from the point of view of observing the process of growth of damage and optimization of production technologies. Based on a multilevel model of the time dependence of AE parameters, estimation of elastic homogeneous fracture intensity parameters of representative structural elements of a product and universal strength nanoconstants, the approach combines the traditional experimental way of resource estimation and kinetic representations of fracture. This allows to separate the effect of macro- and nano-factors on the AE of the material, variously related to the strength and acoustic emission activity of the material. A multilevel model and an informational-kinetic approach to acoustic emission diagnostics are described, combining nano-, micro- and macro-factors affecting acoustic emission activity, reliability of technical objects and methods for assessing their resource. On the example of a welded pressure vessel, the implementation of the method of its nano-diagnosis is considered. The possibility of effective resource estimation of various technical objects based on the information-kinetic approach to their acoustic emission diagnostics is shown. As a methodological basis, a multilevel model of the time dependences of the AE parameters is taken, which describes their behavior under conditions of strength and metrological heterogeneity.

1. Introduction

The search for the practical use of nano-diagnostics technologies for assessing the state of technical objects [1, 2] distinguishes among others an information-kinetic approach to diagnostics based on a multi-level model of the time dependence $\xi(t)$ of acoustic emission (AE) parameters, estimation of related with a resource of model parameters and universal strength nanoconstants [3, 4], combining traditional [5] and kinetic representations of fracture, allowing one to separate the influence of macro- and nano- on the material properties actors in different ways connected with his toughness and acoustic emission activity.

The approach is ensured by the introduction of the following reducing uncertainty in assessing the resource of innovations in conducting and analyzing the results of traditional strength tests of macroscopic samples:

1. The transition from visual control of the number of cycles to the destruction of standard samples with conditionally identical defects to the automated acoustic emission monitoring of the
destruction time of industrial facility’s representative microelements, which ensured the controllability of the damage accumulation process;

2. The transition from the strength characteristics of the strength of reference macro-samples to the concentration-kinetic indicators of strength and strength heterogeneity of the facility, which ensured the information content of the control.

3. Replacing the spatial-geometric criteria of strength similarity (shapes, sizes, geometric parameters of samples, defects, cracks, etc.) with time (time to failure, parameters of the distribution density functions of the associated strength nanocharacteristics), which made it possible to select AE signals from representative structural elements material through reasonable filtering of the flow of AE signals from the diagnostic object according to kinetic and statistical features;

4. Identification of parameters of material fatigue curves and time dependences of AE parameters, substantiating the choice of stable strength characteristics and provide the possibility of using the fatigue tests results.

2. Methodology
The multilevel model has the form:

$$\xi(t) = k_{AE} C(\gamma, \sigma, T, t),$$

(1)

where \(\xi(t)\) is the time dependence of the AE parameter, \(k_{AE}\) is the acoustic emission coefficient meaning the acoustically active volume (macro level), \(C(\gamma, \sigma, T, t)\) is the time dependence of the concentration of microcracks (micro level) determined by the activation volume \(\gamma\), stresses \(\sigma\) and temperature \(T\) on thermofluctuation decaying atomic-molecular bonds (nano-level).

Multilevel concentration-kinetic AE strength indicators resistant to the influence of destabilizing factors of AE control are the AE characteristics of strength (Table 1). We will consider the practical application of the approach using examples of diagnosing the condition of a transport cryogenic tank and the outer ring of rolling bearing No. 6212. For recording AE signals, the acoustic emission diagnostic system SDAE-16 (2), consisting of the AE information collection and processing unit described in [3, 4].

**Table 1. Multimodel multilevel concentration-kinetic AE-indicators of strength, resistant to the influence of interference and destabilizing factors of AE control**

| AE indicator | Micromodel | Nano model | Macromodel | Dimension |
|--------------|------------|------------|------------|-----------|
| \(X_{AE}\)   | \(d\ln \xi(t)/dt\) | \(\gamma \dot{\sigma}/KT\) | - | S\(^{-1}\) |
| \(Y_{AE}\)   | \(d\ln \xi(t)/d\sigma(t)\) | \(\gamma/ KT\) | \(Y_0=d\ln N_/d\sigma\) | Pa\(^{-1}\) |
| \(kY_{AE}\)  | \(d\ln \xi(t)/dF(t)\) | \(k\gamma/ KT\) | \(d\ln N_/dF\) | N\(^{-1}\) |
| \(W_{AE}\)   | \(d\ln \xi(t)/dK_i(t)\) | \(\omega = \gamma \sigma/ KT\) | \(\ln N_B - \ln N_{work}\) | - |

*Note. \(\xi(t)\) is the time dependence of the AE parameter, \(t\) is the current time, \(\dot{\sigma}\) is the stress growth rate, \(K\) is the Boltzmann constant, \(k = \dot{\sigma}/F\) is the proportionality coefficient between the load \(F\) and the rated voltages, \(\omega\) is the nano parameter, \(K_i\) is the coefficient load (the ratio of the diagnostic load to the working one), \(N_e, N_{work}\) - the number of cycles to failure and their predicted number, \(Y_0, N_B\) - parameters of the material fatigue curve (Fig. 1.a).

\[
\ln N_B = \ln(\tau_0/\tau_{cycle}) + 0.43 U_0/ KT \approx const,
\]

where \(\tau_0, U_0\) are stable nano-parameters, \(\tau_{cycle}\) – is the period of the loading cycle [3].

3. Calculation results
The results of AE registration obtained during pneumatic loading of the inner tank shell with nitrogen vapors formed by passing liquefied nitrogen through an evaporator are shown in Figures 1, 2. The
operating pressure on the passport was 0.35 MPa; the test pressure was 0.38 MPa; the average loading rate is 0.0441 MPa / min with a 5-minute pressure exposure of 0.3 MPa.

Processing the results of recording AE signals allowed us to obtain the values of the concentration-kinetic parameters $Y_{AE} = 0.003 \pm 0.01$ MPa$^{-1}$, $W_{AE} = 2.5 \pm 6$. For example, at a pressure of $P = 1.8$ kgf/cm$^2$ at the 150th second $N_2 = 10$ signals were recorded, at $P = 3$ kgf/cm$^2$ at the 200th second $N_2 = 67$.

$$W_{AE} = d\ln N_2/dK_H = \Delta\ln N_2 \cdot P_{work}/\Delta P = \ln 6,7 \cdot 3,5/(3 - 1,8) = 5,6,$$ (2)

which determined as a critically active source of AE. According to the reference data for the material of the inner case (steel 12X18H10T) we have the parameter of the fatigue curves $N_B \approx 10^{4.5} \pm 10^{6.5}$, the resource at the working pressure:

$$N_C = 10^{5.5}/\exp 5.6 = 1169 \text{ (117 } \div \text{ 11693) cycles.}$$ (3)

Residual Resource:

$$N_{res} = N_C - N_{waste},$$ (4)

where $N_{waste}$ is a waste resource. When $N_{waste} = 126$ (according to the operation department), the minimum probable resource can be exhausted.

![Fatigue curves and results of registration, AE modeling, and estimation of the universal material constant NB of the inner casing of a transport cryogenic tank for liquid oxygen, nitrogen, and argon obtained by its pneumatic loading with nitrogen vapors](image1)

**Figure 1.** Fatigue curves and results of registration, AE modeling, and estimation of the universal material constant NB of the inner casing of a transport cryogenic tank for liquid oxygen, nitrogen, and argon obtained by its pneumatic loading with nitrogen vapors
a) Housing diagram and arrangement of AE converters

b) Low-cycle fatigue curves of steel 12X18H10T 1, 2 - at \( T = 273K \), 3 - at \( T = 673K \). \( \text{dlg} \ N_B \approx 2 \) – metrological spread of the value of \( \text{lg}N_B \).

**Figure 2.** Fatigue curves and results of registration, AE modeling, and estimation of the universal material constant \( N_B \) of the inner casing of a transport cryogenic tank for liquid oxygen, nitrogen, and argon obtained by its pneumatic loading with nitrogen vapors

Low value of the resource indicates the need to reduce the working pressure by 3 times:

\[
W_{AE}/[W_{AE}] = 5.6/1.8 \approx 3, \tag{5}
\]

which will increase the resource by about 20 times.

Here:

\[
[W_{AE}] = [W_R] = YR[\sigma] = 0.018 \text{MPa} - 1 \cdot 100\text{MPa} = 1.8. \tag{6}
\]

The results of AE registration obtained under static loading of a bearing on a bench are shown in Figure 3. For a bearing with a dangerous defect, the 3 * 3 grid according to the AE control data has the number of AE pulses recorded from 145 to 150 seconds equal to 5 and 54th, and the diagnostic load changed during this time by 10,000 N. Then, with a working load on the bearing, \( P_{\text{work}} = 40000 \text{ N} \) we have:

\[
W_{AE} = \text{ln}(54/5)/(1/4) = 9.52. \tag{7}
\]
The time dependence of the number of AE pulses during the period of uniform destruction from 140 to 150th second.

a) Appearance and installation diagram of piezoelectric transducers

b) Graphic illustration of $N_B$ definition

c) The constant $N_B$ is calculated from the bearing fatigue curve converted to an exponential form:

$$(C/P)^n = L_h, \text{ million rpm}$$

The bearing will withstand one revolution at a load of $P = 100\ C$, $ln1=0$.

At a load equal to the dynamic load capacity $P = C$, the number of turns of the bearing $L=10^6$, $ln10^6=13.82$, from the proportions of the exponential fatigue curve:

$$[(100C-C)/C = \ln106/(lnN_B−ln10^6)],$$

We have:

$$lnN_B = ln10^6 (1 + 1/99) = \ 13.82 \cdot 1.01 = 13.953.$$  \hspace{1cm} (10)

Bearing life in revolutions

$L = N_B/\exp W_{AE} = \exp(1.01\ln106)/\exp9.52 = \exp(13,953-9.52) = 82.8\ rev.$

durability is low, the bearing is inoperative, which is true.

4. Conclusion

Thus, this article shows the possibility of technical objects’ effective resource estimation based on the information-kinetic approach to their acoustic emission diagnostics. A multilevel model of the time dependences of the AE parameters is taken as a methodological basis. It describes their behavior under
conditions of strength and metrological heterogeneity. The connection of the model with the results of traditional fatigue tests combine the results of AE control with a wide database of reference data, ensuring a reduction in the uncertainty in assessing the resource of dangerous technical objects.

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