Estimation of residual resource of hydro technical structures using the acoustic emission method

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**SUMMARY**

Acoustic emission occurs during the local dynamic restructuring of the material structure, which is irreversible. Such rearrangements include the nucleation of microcracks, plastic deformations, and phase transformations associated with changes in the crystal structure, and others. The sources of such changes can be geological processes that occur over a considerable period of time, and anthropogenic destruction that occurs almost instantly. An actual example of the latter is the damage to hydro technical structures in Ukraine, which occurred as a result of military operations. Research using the acoustic emission method can be aimed at establishing: 1) features of the acoustic emission parameters to choose the optimal measurement conditions during structural tests in industrial conditions; 2) connections of the acoustic emission parameters with the mechanical characteristics of the materials or with the parameters of the processes occurring during loading in the structure of the materials. Therefore, the application of the acoustic emission method makes it possible to determine the optimal parameters for conducting research on the technical conditions of materials constituting hydro technical structures. This makes it possible to evaluate the residual resource of the structures.

*Keywords: microcracks, deformations, acoustic emission, residual resource, hydro technical structures*
Introduction

The acoustic emission (AE-control) method is a unique non-destructive method for detecting microcracks (Rokochinskiy et al., 2023). Because the acoustic emission (AE) method is relatively simple compared to other ultrasonic methods and does not require specific sample limitations, it is widely used in modern non-destructive testing of objects and structures of great value (Onanko et al., 2020). At the same time, a characteristic feature of AE method is its integrality. The entire object could be monitored simultaneously using one or more AE transducers mounted on the surface of the sample. At present, practical experience of AE-control of objects such as tanks, cisterns, reactors, rectification columns, cauldrons, process pipelines, sections of main pipelines in dangerous zones (crossings, karst, and landslide zones) (Ivanik et al., 2022), cranes, bridges, and aircraft device elements has been accumulated (Gomelya et al., 2020). As a result of military operations, a significant number of hydro technical structures in Ukraine have suffered damage and destruction (Ivanik et al., 2022). Therefore, AE-control of their technical condition to determine the residual resource and the need for repair or reconstruction of structures has become an urgent task (Halysh et al., 2020).

Method and Theory

AE signals have a number of features, including a complex nature, low energy level, and wide dynamic range of parameters. Therefore, broadband systems capable of recording AE pulses (with durations in the range of $10^{-8} - 10^{-3}$ seconds) are required for the full registration of AE signals (Onanko et al., 2021). However, in practice, the frequency range is deliberately narrow. Registration in the low-frequency area is limited to industrial noise, which significantly exceeds the level of AE signals. Registration in the high-frequency area by a significant expansion of the frequency range resulted in a significant increase in the level of inherent noise of the equipment. The experimental methods used are the equipment for AE-control, which operates at the frequency $f = 0.200-0.500$ MHz and $\alpha = 68$ dB, as shown in Figure 1 and Figure 2.

![Figure 1. AE-control equipment technique (left) and formed pulse after the peak detector (right).](image1)

![Figure 2. Block-diagram of AE-control registration technique.](image2)

1 – radio pulse generator, 2 – rock, 3 – acoustic emission sensor, 4 – blocking filter, 5 – preamplifier, 6 – acoustic emission signal processing device AF-15, 7 – oscilloscope, 8 – personal computer

Results

The residual resource of hydro technical structures depends on the direct mechanical damage resulting from military operations, age of the structure, and conditions of its operation (Kuzmych& Voropai,
Therefore, an important condition for the objectivity of research is a comprehensive approach to the selection of parameters for the application of AE-control method (Turcheniuk et al., 2022).

Therefore, it is important to establish a relationship between the two AE types (continuous and discrete). These two types of AE are distinguished by the shape of the electrical signal and maximum amplitude of AE energy. A discrete AE implies that two consecutive pulses do not overlap and that the time interval between them is greater than or equal to their decay time. In other words, a discrete AE is a random sequence of AE pulses that appears discretely. Simultaneously, the voltage waves are characterized by a large amplitude, which can vary over a very wide range and reach several volts in the converter. Continuous AE can be defined as a superimposition of pulses characterized by a small amplitude (on the order of a few microvolts), which varies within narrow limits and looks like noise, which greatly exaggerates the noise level of the electronic equipment that registers AE. For continuous AE, the time interval between pulses was smaller than their attenuation. Such emission is the result of the superimposition of a large number of low-amplitude discrete pulses.

Figure 3 shows the signals of the two AE types. In the case of a discrete AE, the condition \((t_{n+1} - t_n) > \tau\) is fulfilled, where \(\tau\) – the decay time of the nth pulse, \(t_{n+1}\) – the time of the end (beginning) of the nth and (n+1)th pulse. The pulse energy was \(10^10…10^{14}\) eV, which is sufficient for the formation of microcracks. For a continuous (low-energy) AE, which occurs when many pulses are superimposed in time, that is, when they overlap, the condition \((t_{n+1} - t_n) < \tau\) is fulfilled. The energy of the pulse was 1…10 eV, which is sufficient for the movement of dislocations.

As a general characteristic, we can consider the effect that bears the name of the German scientist Kaiser, and is associated with the fact that when a sample is repeatedly loaded, AE in the same sample occurs under certain conditions. The effect is that if a specimen is mechanically loaded to a stress \(\sigma\) at which AE is observed and then unloaded at a stress of \(\sigma_2\), then upon repeated loading, AE will only appear when \(\sigma > \sigma_2\). If the sample is loaded cyclically, then in the nth cycle, AE occurs at the load \(\sigma_n > \sigma_{n,i}\), \(\sigma_{n,i}\) – the stress at which the load was removed in the previous cycle.

Figure 4 shows images of AE signals (discrete and continuous) obtained from the experimental studies during thickness fluctuations of the sample. The acoustic radiation that occurs in the sample contains information about the parameters of AE source, that is, the properties of the formed defects, which can be used to study the defect formation processes. A necessary condition for amplitude analysis of AE signals is the presence of a peak detector for isolating the radio pulse envelope. The influence of various external factors on the solid body causes an increase in the level of internal stresses, which reach extreme values in some areas of the sample and lead to the appearance of structural defects. Part of the energy released as a result of the structural rearrangement was transformed into the energy of elastic vibrations, which propagated in the form of acoustic waves in the studied sample.

The occurrence of AE was related to AE source. The presence of active sources of AE is the most important condition for the occurrence of AE. AE source is the area of the material where the dynamic restructuring of the material structure occurs (Onanko et al., 2012). The locality of the source
is one of the necessary conditions for the occurrence of AE because the locality of the influence causes the emergence of a voltage gradient.

Figure 4. Images of AE signals: discrete AE (left) and continuous AE (right)

Based on the measurement of the characteristics of the acoustic wave field, a problem arises when reproducing the physical parameters of the radiation source that it generates. From a dislocation point of view, the formation and development of cracks are determined by the movement of dislocations; therefore, a growing crack must give birth to AE. From a phenomenological perspective, the emission of mechanical waves by a rapidly developing crack can be explained by the dynamic unloading of a part of the material adjacent to the edges of the crack being formed (Romashchenko et al., 2022). The jumpiness in the development of the crack as a whole, which developed slowly, led to a similar effect.

The process of relative volume equalization of the local densities of point and line defects over time competes with the prevailing process of linking point defects and dislocations into clusters – the natural aging of dislocations occurs (Vorobyova et al., 2019). Static aging of dislocations occurs owing to the diffusion of impurity atoms, such as oxygen or nitrogen, and their fixation (so-called pinning), according, to the limitation of their mobility and the growth of "starting" stress. The initial dislocations present in the solid were saturated with impurities owing to static natural aging, whereas Cottrell atmospheres were formed. Thus, during the time \((2.5 \text{ – } 6.3) \times 10^8 \text{ s} \text{ or 8 – 20 years}\), there was a significant decrease in the number of potentially active sources of continuous AE with the simultaneous formation of defect complexes (new AE sources), while two- and three-dimensional structural defects played a significant role. Newly formed AE sources require considerable energy for activation. For more than 30 years, no new large hydro technical structures have been built in Ukraine. Thus, it can be concluded that, for the study of existing large hydro technical structures in Ukraine, it is optimal to use AE-control method with optimal equipment parameters to fix a discrete AE. For hydro technical structures less than eight years old, the study of continuous AE is more relevant.

Conclusions

1. The peculiarities of the parameters of acoustic emission were studied to determine the optimal conditions of measurements during the research of the technical condition of hydro technical structures.

2. Connections of acoustic emission parameters with mechanical characteristics of materials and parameters of processes occurring during loading in the structure of materials have been established.

3. The optimal operating parameters of the equipment for recording acoustic emission were determined for researching the residual resource of hydro technical structures depending on the age of their operation.
References


