EXPERIENCE OF IMPLEMENTING THE METHOD OF ACOUSTIC EMISSION TEST OPERATION OF EQUIPMENT AT THE STATIC FRACTURE, CYCLIC FRACTURE AND STRESS-CORROSION CRACKING

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Introduction

This report represents a part of our practice in developing the method of acoustic emission (AE) test operation of pressure vessels, pipelines and other important technical equipment.

The AE method is considered to be the most acceptable one of all the known nondestructive inspection methods for the realization of control over the process of construction fracture during the exploitation or testing.

However, the existing criteria for the estimation of fracture stage with the help of the AE method do not reflect clearly the physics of the process under control.

We will consider three basic and the most dangerous mechanisms of fracture: static fracture, cyclic fracture and stress-corrosion cracking.

Results

In this article we would like to introduce you to some fragments of our experience in developing the AE method: the acoustic emission testing of pressure vessels, pipelines and other important technical equipment.

One of the main issues in planning and manufacture of pressure vessels and other critical equipment is reliability. However, during planning, manufacture and operation at such facilities no sufficient attention is given to evaluation of their real condition. The solution to this problem appears relevant and of much interest at the present time, which is connected to the fact that the design service life of many industrial facilities that have operated for 20 to 30 years, has run its course. Therefore, the issue of developing methods of individual performance evaluation for such expensive pieces of equipment has now moved to the forefront.

Using the traditional methods of non-destructive inspection (NDI), one is able to perform control tests only on certain singular elements, such as welded seams, and these methods do not allow measuring the performance of an entire facility. Moreover, the usage of traditional methods is quite time-consuming and, beside that, requires a solid amount of preliminary work. Due to the equipment's massive performance, an increase in inspection time is directly connected with a giant escalation in expenses, and these costs can sometimes be measured in the amounts of billions of rubles per day. Therefore, the development of an on-line inspection method that would cover the testing of an entire facility is very much advisable economically. Out of all known methods of non-destructive inspection, the AE method seems the most admissible in monitoring the structure failure process during performance or test running. /1/ However, the existing AE method criteria that are used to evaluate the failure stage do not sufficiently represent the physics of the controlled process. It is only possible to solve this problem through comprehensive examination of various damage mechanisms. The methodological basis for handling the problem is the concept that macroscopic destruction is preceded by appearance of microfractures and their enlargement, followed by formation of fracture nucleus, the development of which concludes the overall failure process. We shall go over the three main and most dangerous damage mechanisms, which are: static failure, cyclic failure and stress-corrosion fracture.

STATIC FAILURE

The basis of kinetic description of the destruction process and its two-stage behavior helped develop a fracture model for sectional steel, as well as a method to define a prognostic for the beginning of the fracture nucleus appearance for macroscopic-scale failures.

Our research /2/ has shown that the main source of acoustic emission signals in section steel is microfractures. In order to use the AE signal analysis to evaluate the structural condition, comprehensive quantitative metallographic observations had been carried out.

It is exhibited that the initial stage of steel failure involves appearance of singular microfractures, the dimensions of which are defined by the size of steel structure elements (steel grains). The density distribution of singular fractures is defined by size distribution of structural elements and can be described logarithmically by normal dependence.

The second stage is linked with aggregation of the initial microfractures and eventually leads to formation and development of the fracture nucleus.

Fracture aggregation leads to deviation from the logarithmically normal size distribution. That causes an increase of dispersion (or standard deviation) in fracture size distribution. Therefore, the moment of initial increase in dispersion of fracture size distribution can be recognized as the beginning of fracture nucleus formation, or in other words, as the precursor of macroscopic destruction of material.

The link between microfracture size and AE signal amplitude in sectional steels is explicitly and consistently covered in the work /3/, with use of mechanical testing, quantitative metallography, acoustic emission and mathematical statistics. Respondency between the registered AE signal amplitude and the size of microfractures was sought in the form of an integral equation. The size of the minimal microfracture registered with the use of AE method constituted 45 microns. Calculation of the integral primitive allowed for determination of a functional link between the amplitude and the length of a microfracture in the form of a polynomial equation with the exponent equal to 1.5.

This serves as a testimony to the fact that the energy produced by a microfracture, which is calculated as the squared amplitude, is proportional to the destroyed volume in which it was accumulated. The functional dependence between the microfracture size and the amplitude of the signal produced by the microfracture allows to remotely control of the size of the appearing microfractures and evaluate the damage behavior.

Due to the fact that failure of materials is multiple in behavior and that the appearing microfracture size can be controlled using the AE signal parameters, it was possible to introduce a sectional steel failure model and find a prognostic for it. It follows from the introduced model that the appearance of aggregating microfractures causes an increase in standard distribution (S_c) of the resulting microfracture distribution. This can also be recorded via measuring the standard deviation of amplitude distribution of AE signals (S_A). By monitoring the S_A of the amplitude distribution, with the underlying statistical dispersion of this parameter we at some point in time t* can observe its significant ascension. Therefore, the moment of time t* can be accepted for the fracture nucleus as the time of its initial formation, which testifies to the transition to the second localized stage of destruction and is the precursor of the final failure.

It should be noted that the introduced criterion for the initial formation of fracture nucleus is not connected with the AE-emissive area dimensions and, to a large extent, the grade of steel it is manufactured from. It allows using it both during the research of sample destruction and the testing of steelwork condition. The acquired results are used in studying the regularities of fracture nucleus formation in sectional steels: 22K, 08ГДНФЛ and others. Working capacity of the introduced criterion is confirmed.

CYCLIC FAILURE

The implementation of the above approach was also quite successful during research of cyclic failure in fractured samples /4/.

We have conducted a series of studies to determine the nature of connection between various parameters of AE signals and fatigue fracture increase rate in samples for eccentric tension of different thickness. The sample thickness varied from 10 mm to 150 mm. A linear relationship was acquired between the value of standard deviation in amplitude AE signal distribution (S_A) and the fatigue fracture growth rate (V) in the Paris range of the cyclic failure diagram.

In addition to the above, the research conducted during these experiments helped confirm the validity of the link acquired before (1), the one between microfracture size and AE signal amplitude. For that on different stages of the fatigue fracture advancement, samples were cut to be used in fractographic investigation. The size distribution of fragile facets on the surface of fatigue fracture (fig.1) identified via raster electron microscope PSEM-500, was compared with the amplitude of the AE signals detected during the advancement of the fatigue fracture front in that particular area.

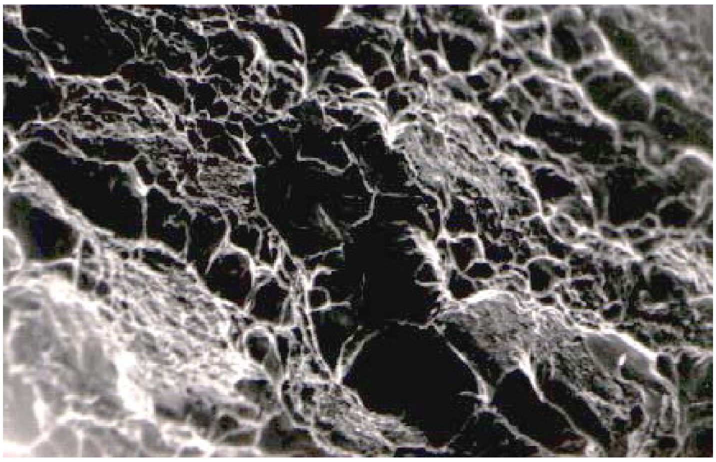

Fig. 1. Facets of brittle split on fatigue crack surface X640.

Not limiting ourselves to testing the working capacity of our method on samples, we checked its working capacity on a full-scale model of a high-power channel-type reactor (HPCTP) collector.

The T-junction model was 800 mm in diameter, had wall thickness of 60 mm and maximum length of about 3000 mm. An incision was made at the most strained spot, that being the T-junction molding. During cyclic load pressure a fatigue fracture was grown at said spot. The fracture development was controlled by a multi-channel AE system that allowed locating the fracture origin and evaluating its rate of development. After destruction of the model the true fracture growth rate was determined via examination of the fracture halt trace on its surface. This data is shown in fig. 2.

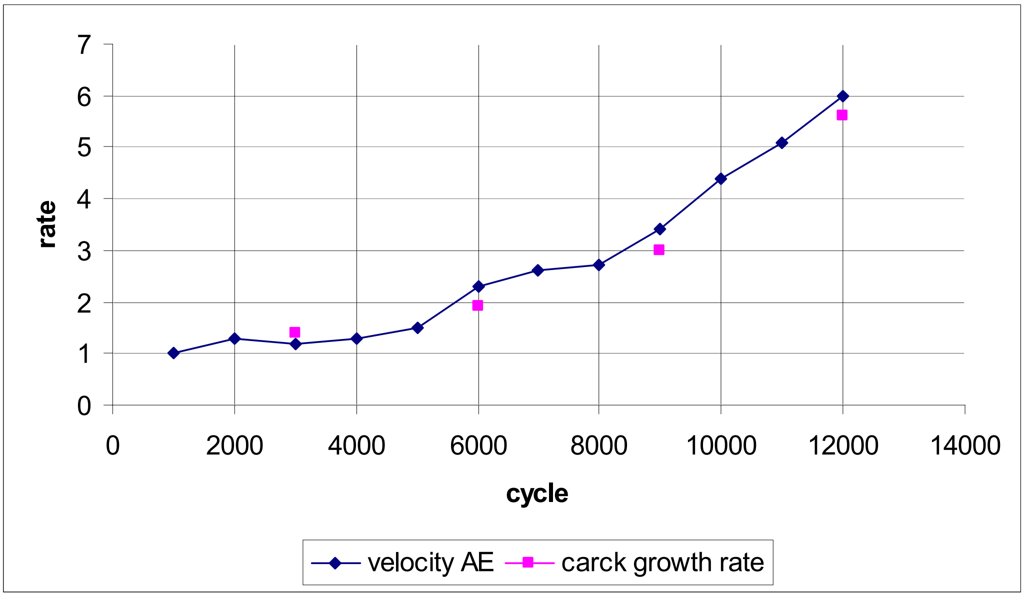

Fig. 2. The speed of crack growth in a T-joint fillet

As it follows from fig. 2, the AE data and the real development rate of the fracture correspond well. Therefore, said method can be used to diagnose various pipelines, T-type junctions and other equipment.

In the following, we used the above method in our system of AE monitoring in foundation slabs of the mill 5000, the biggest rolling mill in Europe (fig. 3).

Fig. 3. The rolling mill "5000"

We have determined a non-destructive strain rate which caused no development in fractures. However, millwork was not possible at that strain rate. For that reason during the following 8 years we used our method to successfully monitor the development of two circumferential fractures, each 1.5 meters long and up to 40 mm deep, which allowed for a timely warning about a spasmodic increase in the development rate of said fractures (fig. 4).

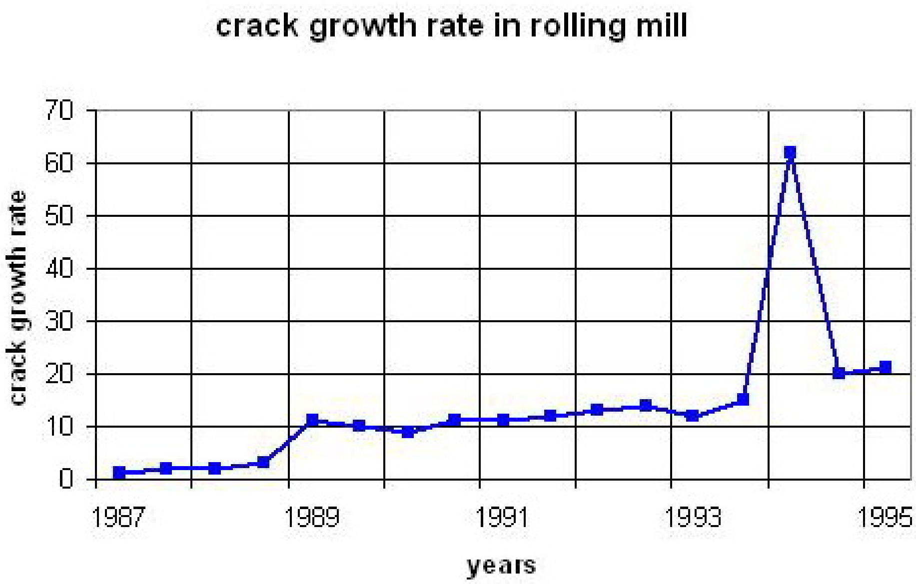

Fig. 4. AE monitoring of the Rolling Mill "5000"

STRESS-CORROSION FRACTURE

Another dangerous steel damage mechanism is stress-corrosion fracture. It is known that at nuclear stations chloride-induced embrittlement occurs as a result of the primary and secondary coolant influence. Caustic embrittlement is possible due to secondary coolant contamination.

To model strained corrosion the pipeline was filled with a NaCl solution heated up to 270°C, strained with internal pressure of 88 atm and, in addition to that, with tensile axial force of 310 ton-forces on a ZZ8000 simulation machine. Through that we modeled the accelerated operating conditions for pipelines at nuclear power stations with a HPCTP reactor block. The research goal was to determine faults in the type of fractures appearing in welded seams under stress corrosion.

To control the process of stress-corrosion fracture we used the system of AE monitoring. The sensing elements were placed on pipes. The AE system was used to register amplitude and coordinate distribution of AE signals. Additionally we registered the amount of signals appearing during monitoring, which were then used to evaluate the AE activity. The coordinate distribution of AE signals shows that the stress-corrosion fracture process is located in the welded seam area. That behavior persisted during the entire testing period.

In the period from 500 to 900 hours the AE activity remained permanent. From hour 1150 the activity began to skyrocket and reached the level of 750 impulses per hour (fig. 5), which proves the significant increase in corrosion damage rate.

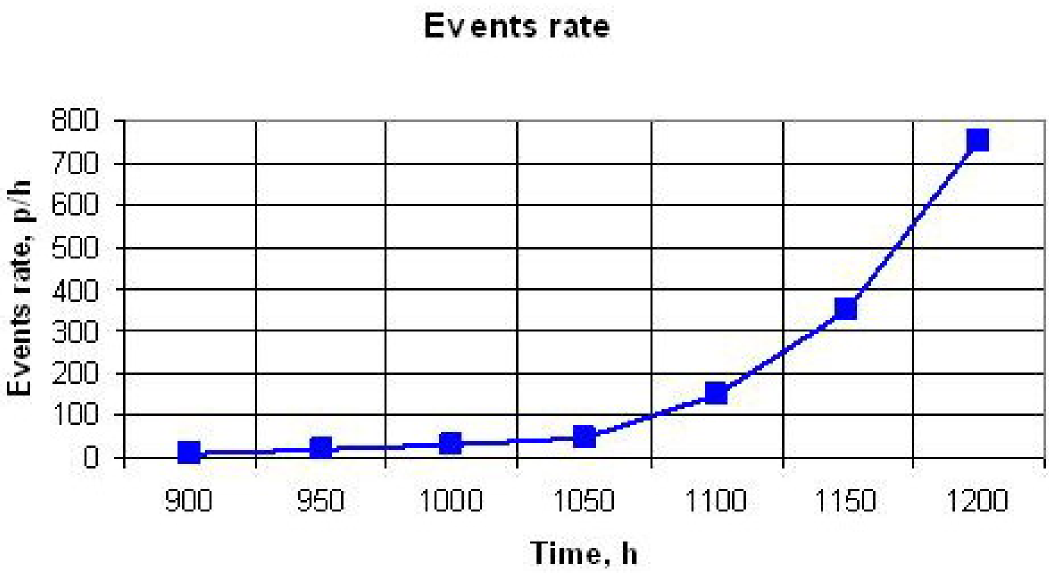

Fig. 5 Corrosion cracking test of 320 mm full-scale welded connection. AE activity

The analysis of amplitude spectrums for AE signals denotes the same. It shows that up to 900 hours inclusive the amplitude distribution behavior remained virtually permanent (fig. 6).

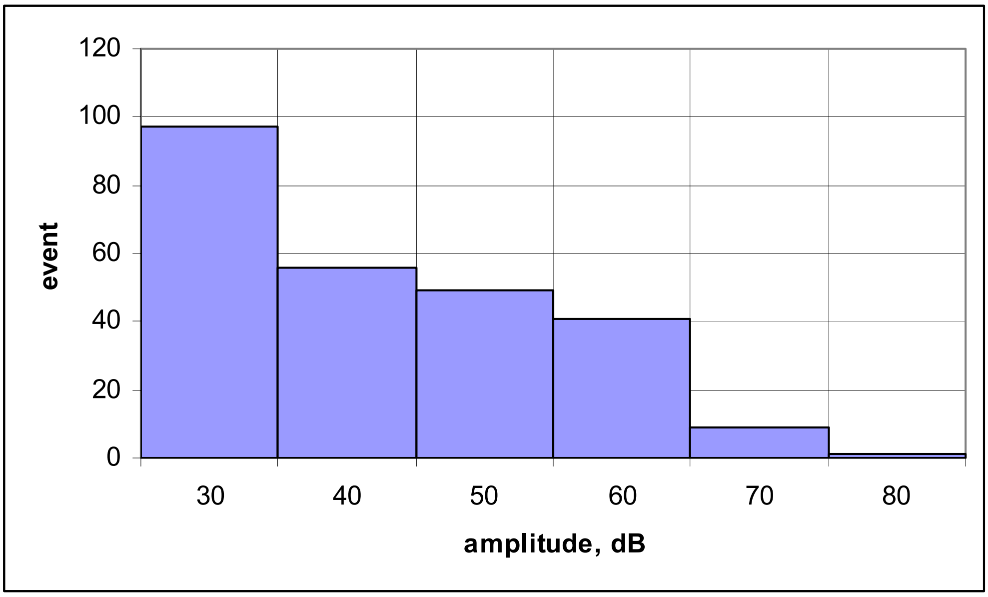

Fig. 6. Amplitude distribution of AE before 1000 h..

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The final stage displayed a peak in high-amplitude signal activity (fig. 7), denoting the appearance of ample-sized fractures.

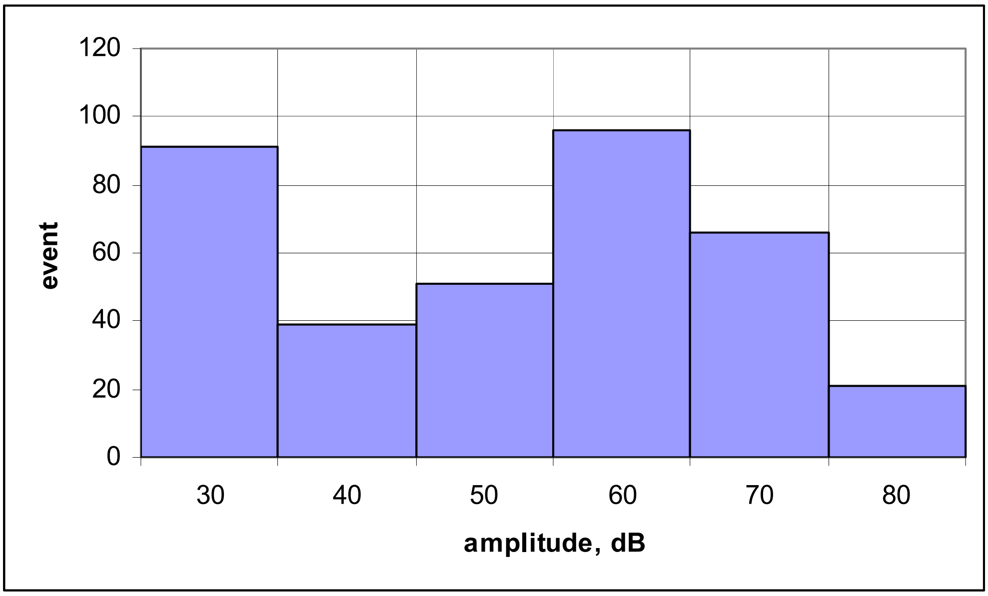

Fig. 7. Amplitude distribution of AE after 1000 h.

Conclusions

The present research shows that three of the most critical instances of failure: the static, the cyclic and the stress-corrosion fracture can all be analyzed using the AE method within the framework of a two-stage failure model. The main trends are explained by appearance of strain-induced microfractures. Their size is connected with the size of the structural elements, the grains. AE signal amplitudes are directly connected with the size of appearing microfractures. Using the standard deviation value in the amplitude distribution of AE signals one can calculate the fatigue fracture increase rate and, with that, evaluate the hazard level of various faults in steel structures.

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