EXPERIENCE OF ACOUSTIC EMISSION METHOD APPLICATION AT EQUIPMENT DIAGNOSTICS

Evgeniy Nefedjev, Central Boiler and Turbine Institute (CKTI), Saint-Petersburg, Russia
Alexander Sudakov, Central Boiler and Turbine Institute (CKTI), Saint-Petersburg, Russia

KEY WORDS

Acoustic emission, crack, microcrack, statical destruction, fatigue destruction, corrosion cracking, amplitude distribution.

ABSTRACT

In given work acoustic emission (AE) method of evaluation of steel facilities reliability is described. This method allows to define destruction phase measuring statistical parameters of amplitude AE signals distribution. Cases of statical destruction, fatigue failure and corrosion cracking are examined. Both samples tests examples and elements of real constructions tests examples are given.

INTRODUCTION

In this article we would like to make you acquainted with some fragments of our experiment, concerning the development of AE diagnostics for pressure vessel, pipelines and other important technical equipment.

The problem of method elaboration, aimed at individual estimation of work capacity for these expensive constructions has come to the fore today.

Traditional methods of nondestructive test (NDT) allow to control only separate elements, for example, welded seams and do not allow to estimate work capacity of the whole facility. Besides, application of traditional methods requires more time spending and a considerable spade-work to be done. AE method is the most appropriate among other well-known methods of nondestructive control when testing or controlling constructions destruction process during exploitation [1]. However, the existing criteria for destruction phase estimation using AE method do not fully reflect the physical essence of controlled process. This problem can be solved in case different destruction mechanisms are thoroughly analyzed. Concepts concerning the fact that macroscopic destruction follows the process of micro cracks appearance, their enlargement and on this basis the formation of site breakdown, the development of which accomplishes the whole destruction process serve methodological basis for this task solution [2]. We will consider three basic and most dangerous destruction mechanisms: statical destruction, cyclical destruction and crack producing corrosion.

STATICAL DESTRUCTION

On the basis of kinetic description of destruction process and two-stage character of its time passing a model of constructional steel destruction and a procedure for defining prognostic sign of site of breakdown beginning of macroscopic destruction was worked out.

Our investigations [3] showed that microcracks are the signal source of acoustic emission in constructional steels. In order to evaluate constructions state with the help of AE signal analysis thorough quantitative metallographic investigations were carried out.

It is shown that during the first destruction phase only single microcracks appear, the size of which is defined by the size of the structural elements of the steel. At the same time the function of frequency distribution of single microcracks is determined by size distribution of structural elements and can be described logarithmically with normal dependency.

The second stage is connected with primary microcracks merging and leads to the formation of the site of breakdown. Microcracks merging results in their size deviation from logarithmically normal distribution. This in its turn is followed by dispersion increase (or normal distribution) of microcracks distribution in sizes. That is why the moment of time during which dispersion increase of microcracks distribution in sizes occurs, can be determined as the beginning of site of breakdown formation, i.e. as the precursor of macroscopic material destruction.

The connection between microcracks sizes and AE signal amplitude in constructional steel is thoroughly and in detail investigated in the work [4] using mechanical examination methods, quantitative metallographic, acoustical emission and mathematical statistics. Correspondence between amplitude of registered AE signals and microcracks size was looked for in the form of integral equation. The size of minimally registered microcrack with AE method achieved 45 micron. Calculation of prototypal for the integral allowed to find functional dependency between amplitude and microcrack length in the form of power equation with the power being 1.5.

$$A=k*L^{1.5}+A_0, \text{ where } k \text{ and } A_0 - \text{constant} \qquad (1)$$

This is to testify that the energy, evolved by the microcrack, which is the square of amplitude, is proportionate to the destructed capacity, in which it was stored. Obtained in such a way functional dependency between microcrack size and amplitude of its generated signal makes it possible to control the size of microcracks and to determine the mode of failure.

Judging by the fact that material destruction, as mentioned above, bears multiple character and sizes of resulting microcracks can be controlled using AE method parameters, a model of constructional steel destruction was introduced and its prognostical sign was found.

From the proposed model follows that the appearance of the merging cracks increases standard deviation of the resulting microcracks distribution (S_c). This can be estimated when measuring standard deviation of amplitude AE signal deviation (S_A). Observing S_A of amplitude deviation we can against a background of statistical dispersion of this parameter at some moment of time t* see its significant increase. That is why this very moment of time t* can be considered as the moment of the site of breakdown formation, what is an evidence to the second localized stage transition and is the precursor of the final destruction.

It is to be mentioned that the proposed criterion of the beginning of the site of breakdown formation has nothing in common with the size of the zone radiating AE and within large limits is not related to the steel grade, from which it was produced. This allows to apply it both when studying samples destruction and controlling the state of steel constructions. Received results were used in studies concerning the rules of the site of breakdown formation in following types of constructional steel: 22K, 08GDNFL, 25H1MF, 25HN3MF and others. Work capability of the proposed criterion is confirmed.

CYCLICAL DESTRUCTION

Application of this approach in cyclical destruction of cracked samples turned to be very successful.

We have conducted series of investigations aimed at studying parameters of AE signals with the speed of growth of fatigue cracks on samples. The thickness of samples varied from 10mm to 150mm. Linear dependency was achieved between the value of standard deviation of amplitude distribution AE signals (S_A) and the speed of fatigue crack growth (V) on the linear zone of cyclical destruction diagram.

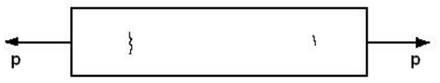
$$V=m*S_A+V_0 , \quad \text{where m and } V_0 \text{ – constant} \qquad (2)$$

Besides in given experiments the correctness of obtained earlier dependency (1) between microcrack size and AE signal amplitude was confirmed. For that on different stages of fatigue crack promotion samples for fractographical investigations were cut out.

Applicability of this possibility to define the speed of growth of fatigue crack using parameters of amplitude distribution of AE signals when studying fatigue destruction of an example, containing two natural cracks, can be demonstratively illustrated (Illustration 1).

In the illustration the structure of the sample, having nature slag defects, is shown. Maximal size of the first surface defect totaled 5mm, the second - 3mm. The sample was exposed to cyclical loading with asymmetry ratio being 0.1 and frequency 1 Hertz. In given case defect growth was simulated in rotor discs of steam turbines when moving on railway.

1.a



1.b

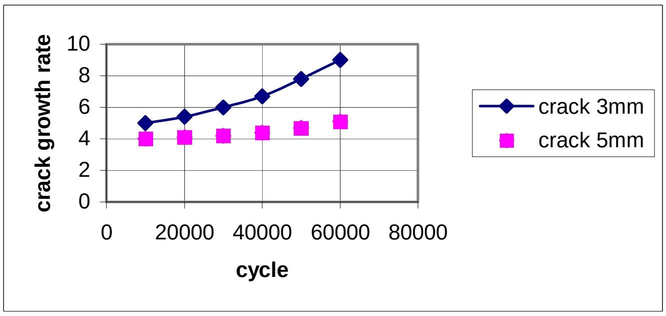


Illustration 1. Scheme of real defects disposition on top of the sample and comparative speed of growth of these effects during repeated loading calculated using AE data

Density of distribution of AE signals along the length of the sample shows that with the help of AE method position data of two defects are clearly localized. At the same time it is worth mentioning that the first defect larger in size while loading radiates approximately two times less signals than the second. Hence we can surmise its lower potential danger. This can be confirmed by Illustration 1.b, where comparative speed of growth of these defects during cyclical loading, calculated using AE data with the help of formula (2) is shown.

From this illustration we can clearly see that during 60000 loading cycles the speed of growth of the first defect has grown from 4 to 5 relative numbers. During this time the second defect has developed with higher speed and its speed has grown from 5 to 9 relative numbers. This helps to conclude that AE method can reveal real defects development in steel and predicts danger caused by the second effect in two ways. This is an evidence of higher stress intensity at the top of smaller crack.

After 60 thousand cycles of fatigue experiment given sample was destroyed statically. As we surmised, the sample was destroyed along 3-millimeter crack. It is worth stressing that the cracks in given experiment were not of artificial, but of natural origin. That is why given results do not deny fundamentals of destruction mechanics but are the evidence of the fact that natural cracks may differ by the degree of delicacy of concentrator. This example stresses the advantages of AE method compared to traditional NDT methods, which help to define only geometrical defect parameters, but not the level of its real danger.

Dealing not only with work capacity checking of our method, we have checked up work capacity using full-scale collector model of Larger Power Canal Reactor (LPCR).

Illustration 2. Experiments of full-scale T-joint connection model (DU 1000)

T-joint model had 800 mm in diameter, wall thickness 60 mm, maximal length 3000 mm. In its most intensive place -fillet- an incision was made. During cyclical loading with the help of intrinsic pressure in a given place fatigue crack was grown. This very crack development was controlled using multi-channel AE system, which helped to localize the spring of destruction and to calculate the speed of its development. After destroying the model the real speed of crack growth was calculated by the spurs of the stop which the crack left on its surface. These data is shown by Illustration 3.

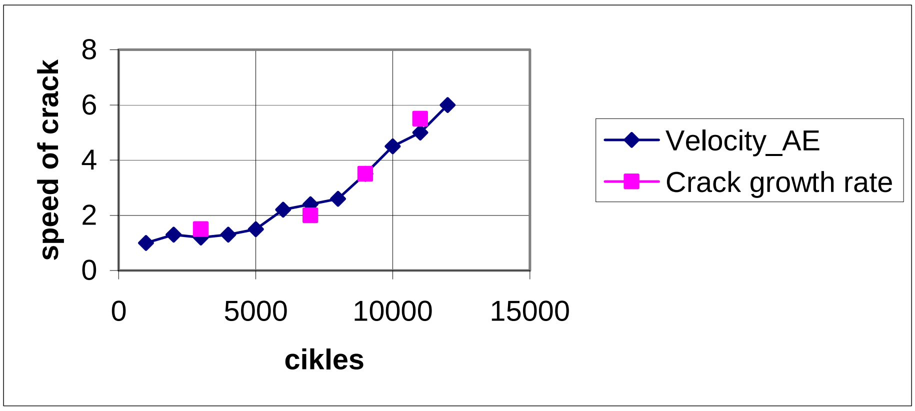


Illustration 3. The speed of crack growth in a T-joint fillet

As it follows from Illustration 3, AE data corresponds to the real speed of development of the given crack. That is why given method can be applied for diagnostic of different pipeline, T-joint connections and other units.

Further we used this method in our AE system for monitoring the state of stand, with the rolling mill 5000 at Izhora Works - the largest rolling mill in Europe.

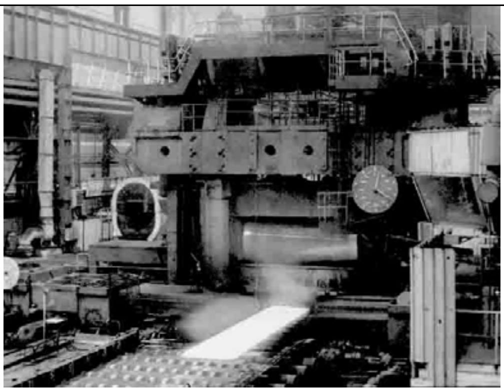
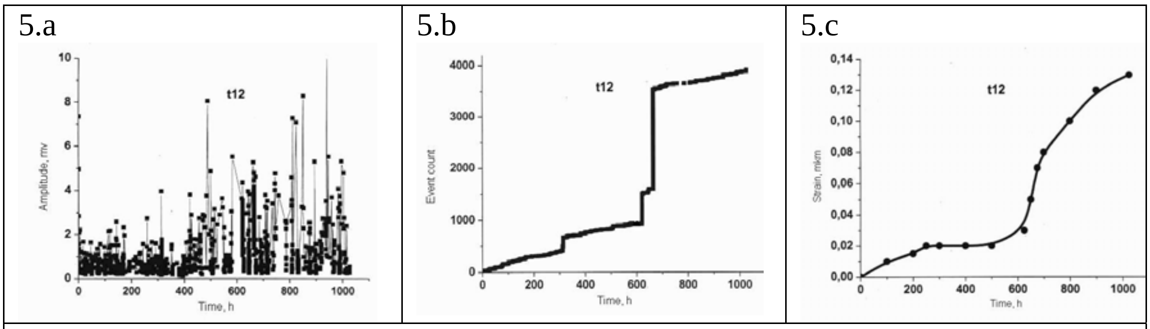


Illustration 4. The rolling mill “5000”

We defined the safe effort by which cracks did not develop. But sheet cogging was not possible. That is why using this method during 8 years we have looked after ring shakes development with the length of 1.5m and depth up to 40mm and in time warned about spasmodic speed increase of cracks growth.

CORROSION CRACKING

Corrosion cracking turns out to be the other dangerous destruction mechanism of steel. For the investigation of corrosion cracking resistance of the basic metal tests of welded samples were conducted, as corrosion resistant materials are prone to this effect when used in welded elements. As the subject of inquiry stainless steel 08H18N10T was chosen. Nowadays great experience of using this steel for atomic electricity power stations (AES) equipment production is accumulated and particularly for pipe system of steam generator. Steel trials for corrosion cracking or corrosion long-time durability were conducted in a solution containing chlorine ions and oxygen with the temperature 300^0 C. Let us consider time dependence of deformation, AE signal accumulation and AE signal amplitudes (Illustration 5).



5.a 5.b 5.c

Illustration 5. The results of sample tests

After 500-hours period (Illustration 5.a) amplitudes of AE signals are increasing 2-4 times, which is an evidence of qualitative changes in microdestruction - transition from single cracks formation to double cracks formation, which in its turn is an evidence of transition from delocalized destruction to localization of destruction and the site of breakdown formation.

After 600-hours period growth in AE activity registered, which is an evidence of destruction process acceleration (Illustration 5.b).

At 650-hours period we can see the previous factors development on macroscopical deformation (Illustration 5.c). It is growing rapidly, which is followed by macrodestruction after 1000-hours period of experiment.

To the given result of the test using a sample 12 mm in diameter correspond the results of full-scale welded connection 320 mm in diameter, tested in similar conditions. Thus rapid work conditions of pipeline at AES were modeled with reactor blocks RLPC. The aim of investigations was to display defects in the form of cracks, which appear in welded seams under corrosion under pressure.

To control the process of corrosion cracking a system of AE control was applied. Sensors were fixed on waveguides. AE system recorded amplitude and coordinate dispersion of signals. Besides, during observation period a number of signals were registered, by which the activity of AE was measured.

Coordinate distribution of signals sources shows that the process of corrosion cracking was localized in the zone of welded seams. This character remained steady during the whole test.

The result of AE test is shown by Illustration 6.

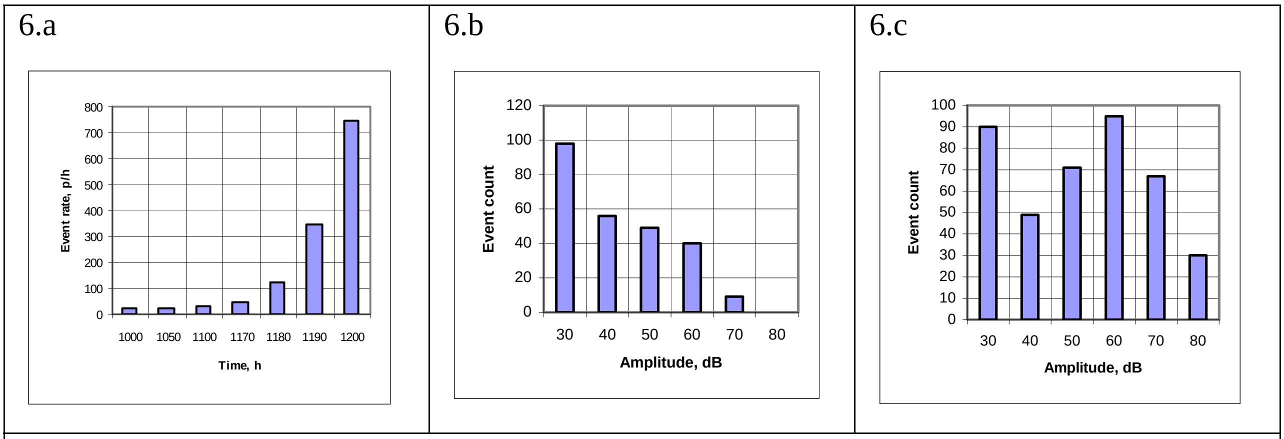


Illustration 6.

6.a Pipeline corrosion under pressure. AE activity diagram,

6.b Amplitude distribution of AE signals during the first 1100 hours,

6.c Amplitude distribution of AE signals after 1100-hours period

During the period between 500 and 900 hours AE activity remained constant. After 1150-hours period activity began to increase drastically and totaled 750 pulse/hour (Illustration 6.a), which is an evidence of drastic speed growth in corrosion destruction. Analysis of amplitude spectrum signals also points it out. It shows that up to 900-hours period inclusively the character of amplitude distribution remained steady (Illustration 6.b). At the final stage of amplitude distribution the peak of high-amplitude appeared (Illustration 6.c), what corresponds to crack appearance of large sizes.

CONCLUSIONS

Given tests show that three important cases of destruction: statical destruction, cyclical destruction and crack producing corrosion under pressure can be analyzed using AE method within the framework of two-stage destruction model. The main patterns are explained by microcrack formation under the influence of pressures. The size of cracks is connected with the size of structural elements - granules. AE signal amplitudes are directly connected with the size of forming cracks. Using standard dispersion value of amplitude AE signals distribution we can calculate the rate of increase of fatigue crack and thus to estimate the level of danger of different defects in steel constructions.

The given methodical elaboration allowed carrying out the control of 500 pipes of SPP-750 at Ignalinsk NPP (Lithuania), several drums and pipelines at Leningrad NPP and also pipelines of the second circuit of the 5th and 6th units of “Kozloduj” NPP (Bulgaria).

Besides the abovementioned objects of nuclear power engineering several hundreds of pressure vessels and pipelines in other sectors of industries were tested.

BIBLIOGRAPHY

1. ASTM E569-85 Standard recomended practice for acoustic emission monitoring of structures during controlled stimulation.
2. Nefedjev E.Y. Destruction forecasting of steel and constructions elements using acoustical emission method, L., PTI AS USSR, 1986, Abstract from Ph.D. thesis in Physics and Mathematics.
3. Nefedjev E.Y., Saveljev V.N., Ljashkov A.I. Showing up regularity of the site of breakdown formation in steel using acoustical emission method. In publ.: Report thesis for the II All-Union Conference on Acoustical Emission. Kishinev, 1987. p.85
4. Nefedjev E.Y., Volkov V.A., Kudrjashov S.V., Ljashkov A.I, Saveljev V.N. Connection between microcrack sizes, acoustical emission parameters and the structure of strained rotor steel. - Defectoscopy, 1986, N 3 p.41-44.
5. Nefedjev E.Y., Volkov V.A., Ljashkov A.I, Saveljev V.N. Fatigue crack growth monitoring in cast steel using acoustical emission method. - Problems of durability, 1987, N 1, p.41-44.