INSTRUMENTS FOR ACOUSTIC EMISSION CONTROL AND DIAGNOSTICS OF WELDED STRUCTURES

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The paper presents materials of testing and investigation of performance of instrumentation for acoustic emission and diagnostics of the new generation, as well as the results of introduction of updated software for the above instrumentation, which offers new technological capabilities for its practical application.

Keywords: *welded structures, diagnostics, acoustic emission control, instruments, material strength*

Experience of expert examination of higher risk facilities is mainly based on modern achievements in the fields of development of theory and efficient methods and instrumentation for control and technical diagnostics. This directly concerns the technologies of diagnostics based on acoustic emission method, the effectiveness of which is confirmed by their wide application in the most critical facilities. PWI conducts a number of developments on technical diagnostics in such high priority directions as software and instrumentation realizing the control technology and including the programs of acquisition, processing and compression of input information, algorithms of destructive process identification based on mathematical statistics, theory of probability, prediction and decision theory; certification of the developed procedures and control equipment; training personnel performing work on control of the condition of structure material, etc.

Four channel acoustic emission (AE) instrument GALS1 upgraded and tested under different operation conditions together with SPC «Prompribor» and laboratory sample of AED instrument for new generation diagnostic systems EMA-3.5 developed together with Hungarian Company «Videoton», were selected as objects of investigation (Figure 1) [1]. Tested instruments are new generation developments in the field of AE technology and have new technological capabilities, namely high resolution, real-time processing of AE signal shape, as well as a large number of adjustment parameters, allowing filtration of false AE signals and efficient processing of the useful ones.

Basic software of EMA-3.5 system was upgraded for new AE systems allowing for the data communication protocols developed by manufacturers. Algorithms of data saving on a hard disc in unchanged format in keeping with the new data communication protocols were realized. Instrument operation under the laboratory conditions and in PWI industrial testing facility was tested. Stability of instrument operation was checked, as well as their acoustic and other indices, and possibility of AE signal location at different configuration of location arrays (location array means a group of AE transducers, which process the data simultaneously, in particular, in order to determine AE source coordinates).

In this study the influence of error of measurement of the time of AE signal arrival to the transducer on their localization using AE diagnostic system EMA-3 was established and obtained data will be taken into account at certification of new and currently developed AE diagnostic systems, as well as preparation of procedural and normative documents.

The effectiveness of the methods of AE source coordinate determination, also under the conditions of simulation of various sources in the industrial testing facility and during actual mechanical testing was con-

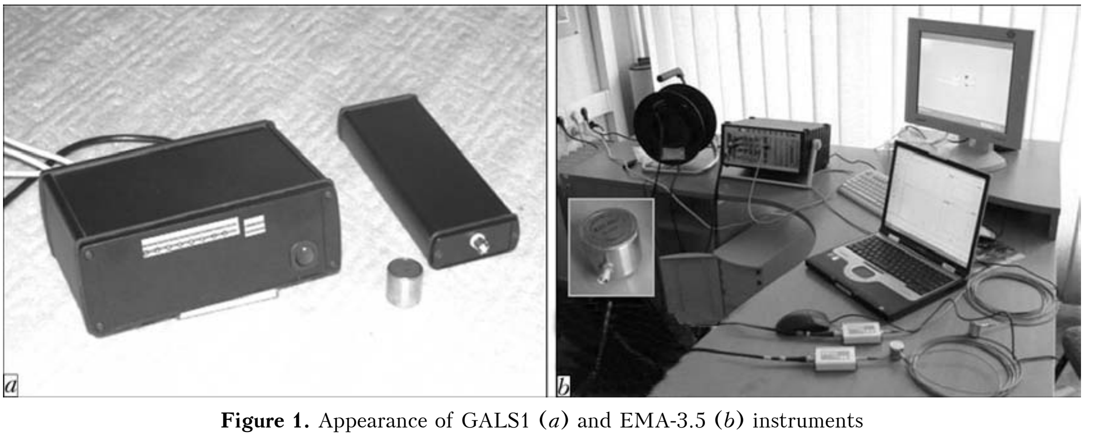

Figure 1. Appearance of GALS1 (*a*) and EMA-3.5 (*b*) instruments

firmed, using GALS1, AED instruments and EMA-3 software.

Signals were simulated using transducer-simulators and at breaking of a pencil lead. The quadrant was divided by a net, in the nodes of which AE sources were simulated (Figure 2). As is seen from the Figure, there are certain deviations in location of AE signals, coming from concrete points. Visually determined deviations are minor, real value of the error does not exceed 3 % of the distance between AE transducers. A conclusion can be made that for a reliable adjustment of AE instrumentation it is necessary to apply common simulation means, for instance, electronic simulator with adjustable signal parameters or breaking of a pencil lead.

To assess the errors of determination of AE source coordinates, a special schematic (Figure 3) was developed, according to which the zones of the object of control with the same level of coordinate calculation error, are represented by the same colour. Error of determination of AE source coordinates is calculated for several different methods, in particular, for accurate and approximate mathematical formulas and directed search method (a variant of Monte-Carlo method).

Testing of AE instruments was performed during testing of samples for static cutting and control of some industrial facilities. In addition, the instruments were tested for serviceability in long-term operation mode. Testing showed satisfactory operation of AE instruments. Obtained results are indicative of a real possibility of bringing the instruments to a level allowing performance of their metrological certification, and recommending them for introduction.

EMA type software was developed so as to ensure hardware independence. This means that with the same or similar basic principles of organization of AE instrumentation from various manufacturers, a uniform system of data acquisition, their preprocessing and high-level analysis algorithms can be achieved, allowing an automated decision to be taken as regards the condition of control objects.

Considering the incompatibility of the types of data obtained from different instrumentation, a special mechanism of matching these data on a high level, using so-called polymorphous classes, is introduced into EMA-3.5 software.

A modification of EMA-3.5 instrument was applied at testing by internal pressure of three pipes from steel 20 of 600 mm diameter with 10 mm wall thickness. A hydraulic pump was used as the loading system, water being the working medium. During loading of the control object, a stop and unloading were performed, and then it was loaded up to fracture.

The objective of the research was to demonstrate the effectiveness of application of AE means to determine fracture site coordinates. EMA-3.5 diagnostic system was used in the same mode as EMA-3. AE

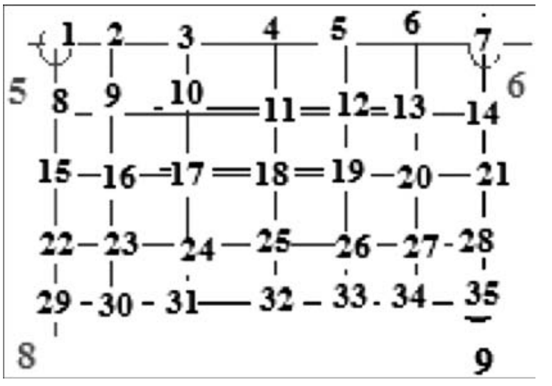

Figure 2. Coordinates of AE sources at simulation

signals were recorded during loading, and data on pressure variation were entered into the logbook and after testing they were entered into EMA-3.5 system.

Testing of pipe 1 was conducted at an extremely rapid pressure rise (test duration was 206 s) directly up to fracture without intermediate stops. Fracture occurred at the pressure of 13.8 MPa. EMA-3.5 system showed preliminary coordinates of fracture site at about 2.6 m distance from transducer 1.

Testing of pipe 2 was conducted in three stages: pressure rise up to 100 MPa; unloading and pressure rise up to 110 MPa; unloading and pressure rise up to fracture (fracture ran at the pressure of 14.2 MPa). EMA-3.5 system gave preliminary indication of fracture site coordinates. A feature of testing consisted in that the crack was of a rather large size outlined by AE clusters.

Testing of pipe 3 was also conducted in three stages: pressure rise up to 10 MPa; unloading and pressure rise up to 110 MPa; unloading and pressure rise up to fracture (fracture occurred at the pressure of 12.5 MPa). EMA-3.5 system gave preliminary indication of fracture site coordinates in the pipe central part, between transducers 3 and 4.

Let us give as an example of successful application of developed AE systems in industry, the results of testing by AE method the drums of BKZ 75/39 boilers, conducted together with specialists of technical diagnostics laboratory of «Nikolaev Alumina Plant» Ltd. using EMA-3.5 system [2].

Testing was conducted in keeping with DSTU 4227–2003 «Guidelines on conducting acoustic emis-

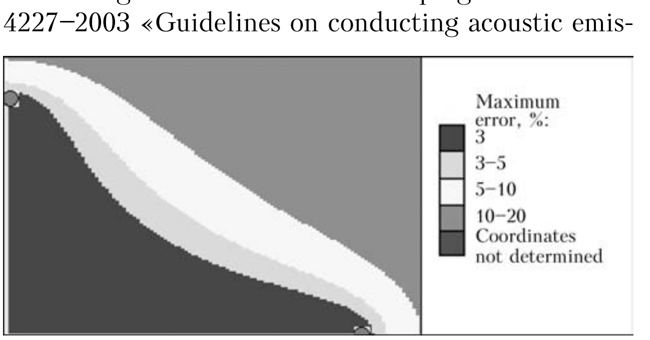

Figure 3. Example of application of schematic of representation of error of calculation of AE source coordinates (location by an accurate formula; error of calculation of AE source coordinates within a flat zone outlined by transducers is not more than 3 % of array base)

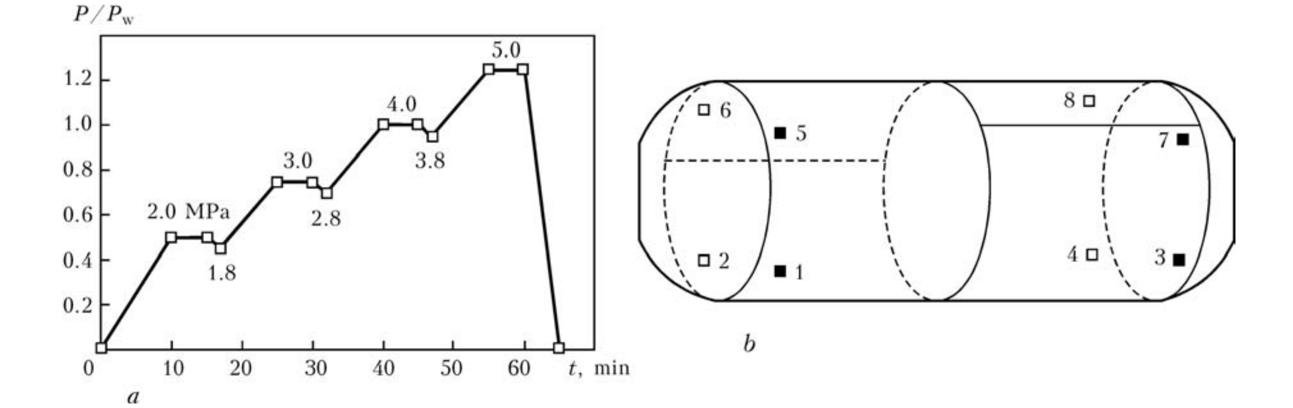

Figure 4. Graph of the program of loading (a) and arrangement of transducers of AE measuring instrument on the surface of drum of BK3 boiler: 1–8 — transducer numbers; ■, ❐ — visible and invisible points of AE sensor mounting; t — testing time

sion diagnostics of higher risk objects». «Technological map of AE monitoring of drum of BKZ 75/39 boiler» was made before the start of testing.

During testing internal pressure P in boiler drums was raised up to 1.25 of working pressure, namely from 0 up to 5 MPa with five minute soaking at the load of 0.4, 0.6, 0.8 and 1.0 of the maximum one and its lowering by 0.2 MPa after soaking.

AE parameters were recorded during testing. Then values of breaking load for drums of BKZ 75/39 boilers were calculated in the mode of computer rerun of testing.

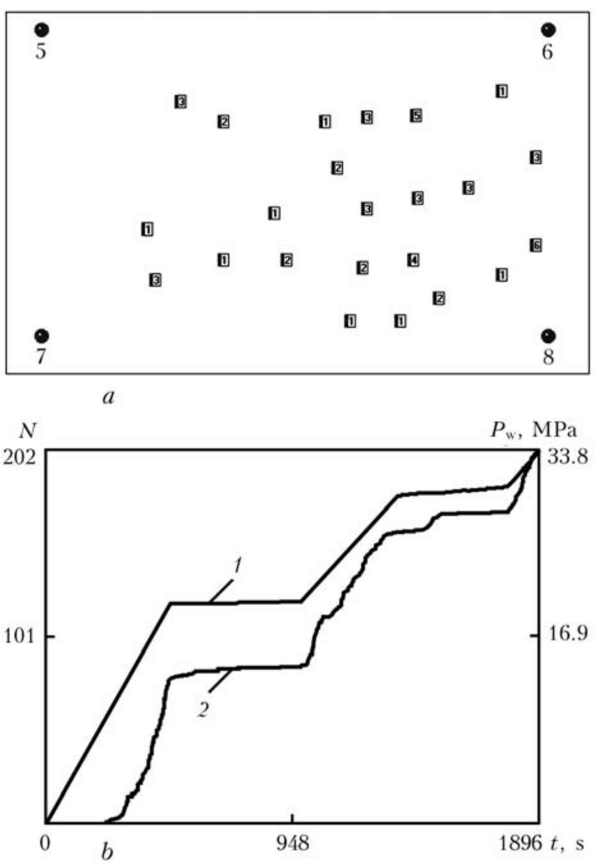

Figure 5. Results of testing the drum of boiler A (array 2): *a* — localizing AE events after performance of cluster analysis of the data (❐ — clusters with indication of the number of AE events; ● — location of transducers 5–8); *b* — curves of load P_w (*1*) and accumulation of AE events N (*2*) during testing

Assessment results were the basis for issuing recommendations on subsequent operation of control objects, and treatment of boilers marked A and B. Drums of boilers from steel 20k have the operating life period of 25 years, and are operating at working pressure P_w = 3.9 MPa. Operating medium (steam) temperature was equal to 450 °C.

By the data of operating enterprise, AE testing was preceded by nondestructive testing of boiler drum walls, including thickness measurement and ultrasonic testing (UT), which did not reveal any defects.

Testing of the drum of boiler A showed that at loading and soaking (Figure 5, *a*) numerous AE signals were recorded practically over the entire surface being controlled, both for the measuring location array 1 (from transducers 1–4) and for measuring location array 2 (from transducers 5–8).

Main sections of concentration of numerous AE signals are located in the central right part of the drum (Figure 4, *b*) controlled by array 2 (transducers 5–8). Figure 5 gives the data provided by EMA-3.5 program on initial test results (by AE data and load values).

Processing and cluster analysis of test results given in Figure 4, revealed the presence of hazardous defects in the material of the object of control, which, however, do not create any emergency situation during monitoring. Data of cluster analysis graphically presented in the program, are indicative not only of the presence of a large number of dispersed damage, but also of absence of defects propagating in a critical manner.

Graphs of EMA-3 program (Figure 5) are indicative of the change of number N of AE events and P_w, depending on the time from the start of the test up to its completion. As is seen from the Figure, testing included two soaking periods with subsequent pressure rise.

A sufficiently high noise level was recorded, which rises together with the load, which is indicative of the presence of dispersed damage in the boiler drum material [3].

Considering the detected sites of acoustic activity [4], the possibility of boiler drum material damage as a result not of disturbance of the condition of strength, but formation of local cracks should be considered.

During testing of the drum of boiler B the total number of AE events was recorded, which is much smaller than during testing of the drum of boiler A. An important essential difference of this test is the fact that the noise level remains unchanged practically during the entire loading time. On the whole, the material of the drum of boiler B is less damaged than the drum of boiler A. In the last two soaking periods, AE signals are absent at all, unlike the results of testing the drum of boiler A.

In terms of strength characteristics, the material satisfies the applied service requirements. However, presence of AE sources scattered over the surface material, requires allowing for the possibility of gradual damage of boiler drum material as a result of defect localization and microcrack formation.

Proceeding from test results, the following recommendations were issued for further operation of the drum of boiler A:

- perform additional UT of the surface of drum of boiler A in the sites of initiation of acoustic activity, using cluster data;
- take the decision on the modes and terms of further operation of drum of boiler A after performing additional UT.

Technical diagnostics laboratory of «Nikolaev Alumina Plant» performed UT, which revealed in the wall of boiler A defects of the type of cavities and mcirocracks, corresponding by their location to clusters 2 and 3 of array 1 and clusters 3, 7, 10, 12 of array 2. Laboratory staff performed evaluation of criticality of the defects, in keeping with factory standards. Detected defects by their characteristics were regarded as admissible for this type of products under normal operation conditions. A decision was taken to perform object control by AE method with the frequency of once every 6 months.

As regards further operation of the drum of boiler B, the following recommendations were issued:

- repeat AE monitoring of the surface of drum of boiler B and additional monitoring of the surface of drum of boiler B after 6 months;
- take the decision on the modes and terms of further operation of the drum of boiler B after repeated AE monitoring.

In keeping with the above recommendations, technical diagnostics laboratory of «Nikolaev Alumina Plant» performed repeated control of drum of boiler B, and after 6 months — another additional control. Considering a similar situation at testing and no deterioration of its condition after 6 months, the laboratory took a decision on extension of operation of drum of boiler B in the working mode and performing AE monitoring every 6 months.

Thus, after performance of control not requiring dismantling or other serious expenditure, the term of operation of drums of boilers A and B was extended. Control covered 100 % of materials of drum surface and took about 2 h together with mounting of the measuring instrument and system deployment. As a result of testing all the information required for taking the decision on boiler condition was obtained, which provides grounds for stating serious advantages of this procedure of AE control of industrial facilities.

CONCLUSIONS

1. Retrofitting of the developed instrumentation for AE control was performed. Changes in data communications protocol were made, and program interfaces for data storage and transfer were developed. Data processing capabilities were expanded, and first of all, frequency analysis and filtration.

2. Analysis of different methods of calculation of AE source coordinates was performed. Level of error at application of the above methods was assessed. Method of direct search was selected, which gives the smallest error. A method to evaluate the error of calculation of AE source coordinates using a colour scheme was developed.

3. AE instruments were tested during control of some real industrial facilities, their performance was verified in long-term operation mode. It is determined that the instruments can be applied in the future as mobile AE systems with a small number of channels.

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