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Development of a technology for continuous acoustic emission monitoring of in-service damageability of metal in safety-related NPP equipment

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Abstract

Safe operation of the NPP main equipment whose design life has expired requires the development of new approaches to integrity diagnosis and monitoring due to high level of metal ageing.

These approaches should be based on nondestructive testing methods which make it possible to inspect equipment not only during the period of repair, but also in conditions of operation when dangerous defects are initiating and growing. One of highly efficient present-day techniques for nondestructive testing suitable for use in the process of operation is acoustic emission method. The paper presents the results of the activities to develop a multi-parameter system for acoustic emission monitoring of the nuclear plant equipment damageability in the process of the unit operation with specific features of the NPP control taken into account. The stages of the activities are described with all factors of impacts on the developed system assessed and taken into account, namely the need for keeping the system serviceable during long-term operation in high-temperature conditions, a complicated geometry of the monitored item, and an increased level of noise, as well as the acquisition and transmission of monitoring data via intranet systems for being processed and displayed online. A series of system tuning experiments conducted in laboratory conditions to refine and validate the selected monitoring techniques are described.

Keywords: Nuclear plant; Acoustic emission; Defect; Cluster; Location; Monitoring; Steam generator; Damageability; Transducer; Weld; Operation.

Traditionally, the integrity of the nuclear power (NPP) components and pipelines is analyzed largely by nondestructive ultrasonic testing of the component and pipeline metal. This approach does not enable the defect nucleation time to be detected and is based on an assumption that the defect will be timely located when the reactor unit is shut down for scheduled repair and the dynamics of its development will not give the defect to grow rapidly to an inadmissible level when it rapidly progresses into a through-the-thickness flaw leading to a loss of coolant. The preferred option would be to monitor the integrity status in the process of the plant operation exactly when defects are nucleating and developing. Acoustic emission method, one the most well-known nondestructive test techniques, suits ideally the monitoring task [1–3]. As compared to other NDT techniques, acoustic emission (EM) has a number of advantages:

- it is possible to carry out in-service monitoring and to detect progressing defects immediately in the process of operation and, thus, the most dangerous defects in the greatest stressed reactor components;
- it is possible to locate defects (cracks, plastic strain areas, leaks and so on) quite at a distance from the receiving transducers;
- it is possible to carry out real-time monitoring and, consequently, to detect timely the coolant leak from pressurized vessels and pipelines at the reactor facility's difficult-of-access points during the accident development;
- AE method is compatible to other NDT techniques, which makes it possible to improve the reliability of monitoring through using a number of independent methods;

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- it is possible to carry out remote automated monitoring in unattended radiation-hazardous rooms of the nuclear plant.

Despite these obvious advantages, practice shows that acoustic emission method is used on a small scale in conditions of Russian nuclear plants. One exception is probably only the introduction of AE for the VVER NPP primary circuit pipe leak detection as part of the LBB (leak-before-break) concept [4–6].

We believe that such obvious underestimation of AE as an NDT method is explained by the absence of commonly accepted correlations between the parameters of AE signals and different types of the NPP metal damage, by complications involved in the identification of useful AE signals against the background of heavy noise from operating equipment; by the absence of standard primary transducers (AE probes) and electronic AE signal selection, amplification and conversion units capable to operate for a long time without losing their service properties in conditions of high temperature and ionizing radiation fields, and by the absence of durable high-temperature lubricating couplants to ensure the transducer's acoustic contact with the tested item.

It should be noted that the experience in adapting different NDT methods shows that the most efficient way is to update and perfect the monitoring methodology and equipment.

In our case, we would like to apply AE method to the inspection of the metal integrity in the region of welded joint No. 111 (WJ 111 hereinafter) between the primary coolant "hot" header and the steam generator's Dn1200 nozzle at unit 5 of Novovoronezh NPP.

The experience of operating the PGV-1000 steam generators shows that service cracks nucleate on a regular scale and tend to grow in the region of WJ 111 (Fig. 1); cracks occasionally penetrate through the 70-mm thickness of the SG vessel wall until the coolant leak starts.

It is required to develop an AE testing system for monitoring online the entire perimeter of WJ 111 throughout one fuel life (for about a year), from the time of the unit startup to the unit outage for preventive maintenance (RM). The system will be responsible for the collection and storage of data, and for the processing and analysis of same to locate potential defect formation and growth areas. Acoustic data shall be continuously communicated via the intranet network directly to the organization in charge of the nuclear plant scientific and technological support.

As far as WJ 111 is concerned, express processing of monitoring data makes it possible in some cases not only to detect the defect formation time but also to evaluate the cause and effect relations that have led to the crack growth based on analyzing the pre-failure service conditions [8].

The study was divided into four stages.

Stage 1 included the selection and testing of the AE testing equipment. This includes high-temperature AE transducers (probes); devices for the probe attachment to the tested items; acoustic contact stabilizers (couplants and lubricants); model AE signal simulators to check up the diagnostic equipment; electronic AE signal selection, amplification and conversion units; computers for the test data processing and display, including special-purpose software; auxiliary equipment for laboratory investigations with regard for the simulation of service in the NPP conditions (increased temperature, vibration and noise representative of the test item operation).

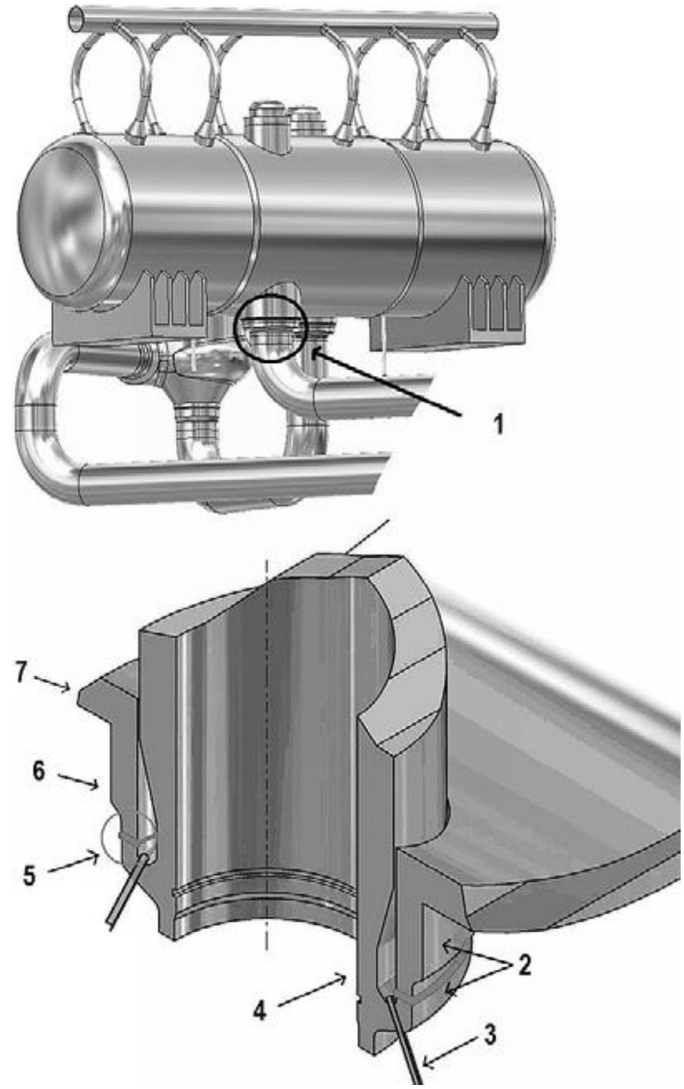

Fig. 1. Welded joint between the primary coolant header and the PGV-1000M SG's Dn1200 nozzle where service defects (cracks) form: 1 – SG WJ 111 region; 2 – locations of AE probes; 3 – Dn80 blowdown nozzle; 4 – header; 5 – WJ 111 failure region; 6 – SG nozzle; 7 – SG vessel.

Stage 2 was devoted to the development of the AE test procedures with regard for the work results on the initial cluster. The following activities were undertaken to develop the procedures.

1. The design and engineering documentation for the equipment to be tested and the SG service conditions and operating modes was reviewed, historical data on the SG status was studied, an expert ultrasonic test of WJ 111's metal was conducted by phased-array method for the detection of vulnerabilities, and the area was detected with a sensitivity to the defect formation because of the existence of an original manufacturing flaw to below the reject level.