ACCELERATORS FOR NON-DESTRUCTIVE INSPECTION OF THE NUCLEAR REACTOR EQUIPMENT

M.F. Vorogushin, Yu.N. Gavrish
FSUE “D.V. Efremov Scientific Research Institute of Electrophysical Apparatus”, Russia

Abstract

In compliance with the requirements of IAEA and GosAtomNadzor of the Russian Federation, when manufacturing the equipment of nuclear reactors, a thorough inspection of the weld seams of the 1st category should be provided.

The potentialities of the accelerators for non-destructive inspection designed and manufactured in NIIEFA are described in the paper. The accelerators allow the radiographic and radioscopic inspection to be performed in compliance with the ASTM-1-1T standard in the range 20-600 mm for steel.

In compliance with the requirements of IAEA and GosAtomNadzor of the Russian Federation, when manufacturing the equipment of nuclear reactors, a thorough inspection of the weld seams of the 1st category should be provided. As the maximum thickness of the weld seams in the equipment of atomic power plants can be 500-600 mm (for steel), the quality control required can be realized only by using charged particle accelerators.

FSUE “D.V. Efremov Scientific Research Institute of Electrophysical Apparatus” (NIIEFA) is the leader in Russia among the designers and manufactures of charged particle linear accelerators for various applications. Professional skills of the staff allow us the complete manufacturing process to be implemented, starting from the designing of new models to their full-scale production. We use our Quality Management System based on the International Standard ISO 9001.

We perform on-site installation of the equipment delivered, training of customers’ specialists, provide warranty and after-warranty service, offer supervision services through the whole operating lifetime of the equipment.

The accelerators designed and manufactured in NIIEFA are successfully operated in Russia and abroad. High quality of our machines makes them competitive with international analogs.

Linear electron accelerators for non-destructive testing are exclusive products of the D.V. Efremov Institute, and systems for radiography, radioscopy and tomography have been designed on the basis of these machines.

A series of accelerators for processing, UEL-W-D, with an energy of accelerated electrons from 2 MeV to 16 MeV and a dose rate 1 m from target from 3 Gy/min to 160 Gy/min has been designed to serve as a source of X-ray radiation.

Figure 1 shows the irradiator of the UEL-15-D accelerator of weight 950 kg and the size: 204×88×92 sm^3. The irradiator is mounted on a special yoke enabling changes of its location relative to an object under inspection (figure 2).

Figure 1: The irradiator of the UEL-15-D accelerator for radiography.

Figure 2: The irradiator yoke.

In radiography, the X-ray beam passed through an object inspected is recorded on the X-ray film. An advantage of the radiographic method is the possibility for inspection of objects of thickness up to 600 mm for steel.

Nowadays, such innovative methods of non-destructive inspection as radioscopy and tomography are implemented.

In radioscopy, an object is scanned layer-by-layer with a fan-shaped X-ray beam. A line of scintillation detectors is used instead of the X-ray film. The shadow image of defect is observed on the monitor of the operator workstation.

As compared with the radiographic inspection, the radioscopic method offers higher efficiency, lower operating costs and less time for data processing**.**

When applied to radioscopy, a standard set of the linear accelerator equipment is supplemented with:

- beam collimation system;
- detection system;
- system for positioning an object under inspection;
- operator workstation with a software.

The collimation system is intended for beam forming. It consists of three collimators: the primary collimator installed on the radiation source (figure 3), the secondary collimator placed in front of an object inspected and a collimator placed in front of the detector line (figure 4).

Figure 3: The primary collimator and the radiation source.

Figure 4: The collimation system.

The system for positioning an object under inspection is intended to ensure linear travel of an object perpendicular to the axis of the fan-shaped beam. To change the angle, the object is rotated in the beam plane. The parameters of the positioning system are set by using an automated control system.

The measuring element of the detection system is the detector line placed behind the last collimator. The detector line transforms the recorded photons into electrical signals transmitted to the operator workstation after preliminary processing.

There is special software for data processing and visualization, which ensures preliminary processing of data and their digitization, data correction, image filtration, pseudo-colorization of images.

The computer workstation allows reconstructing the shadow image of the object with a subsequent analysis of the defects detected. On detecting a defect, an operator can localize and zoom up a necessary fragment to have better opportunities for the defect sizing and spotting. High operator qualification is not a must due to special features of the software.

In the radioscopic systems developed in NIIEFA, the latest advances in the linear accelerator engineering, electronics and computer technology were applied, that made it possible to attain high spatial resolution in compliance with the 1-1T level of the ASTM standard when testing objects of thickness up to 420 mm for steel. Today this result is the best achievement in the word.

Two-dimensional image obtained under radiographic scanning is easily interpreted when an object inspected is of simple internal structure. However, in some cases the problem of unambiguous identification of structure can be solved only by applying computerized tomography.

Under tomographic inspection, every object section is scanned under continuous or discrete rotation of the object in the plane of the fan-shaped beam formed by the irradiator and beam collimation system.

The data obtained as a result of angular scanning are written in file in the digital form and processed with mathematical reconstruction methods. This makes it possible to find two-dimensional density distribution in the cross-section inspected. The application of the procedure described to a consequence of cross-sections allows one a complete image of the three-dimensional density distribution in an object under inspection to be obtained.

The set of tomographic system equipment is similar to that of radioscopic system with some modifications in the design of positioning system and software. Under tomographic inspection, the rotation of object ensures angular scanning of its cross-section, and linear motion is used for cross-section positioning. More stringent requirements are imposed on the angular positioning system and accuracy of detectors' installation.

The software of tomographic system is supplemented with special methods of mathematical reconstruction.

Figure 5 shows an inspected object and the tomographic reconstruction of its section.

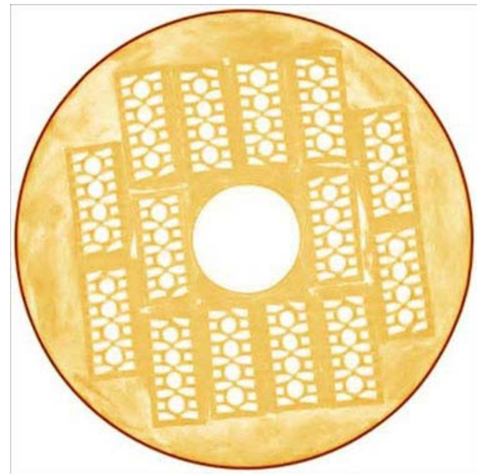

Figure 5: An inspected object and the tomographic reconstruction of its section.

It is hoped and it could be expected that achievements of NIIEFA in the field of non-destructive testing of the large-scale equipment of atomic power plants will be in demand for inspecting weld seams of the nuclear reactor equipment.