A JOINT APPROACH FOR PWR CORE BARREL BOLT AND WELD INSPECTION

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ABSTRACT

The outer circumference of the core internals is formed by a cylinder-shaped shell, the core barrel, which are welded together.

The enclosed horizontal former plates are connected to the core barrel via support and/or clamping ripples and the support plates. Bolts connections are used to fasten the support plates.

In case the integrity of the barrel welds and of the barrel former bolts is not guaranteed, the entire structure of the core barrel would be jeopardized by the external forces which occur according to design and operation loads.

It is, therefore, of importance to inspect the barrel former bolts and barrel welds with a non-destructive inspection method and to replace them in case of a failure. Because of the high radiation in this area, all work has to be done by remote controlled manipulators.

The first inspection of core barrel bolts and welds was successfully conducted by the joint efforts of Kansai, MHI and ABB Reaktor. This result demonstrated the ability to inspect the core barrel bolts and welds using manipulator system and UT technique.

INTRODUCTION

In order to assure the reliability of the nuclear power plants during operation and to avoid unplanned shut-downs, it becomes more and more necessary to inspect periodically all plant components including the components of the core internals.

The core barrel (Figure 1) represents the outer shell of the core internals. It is composed from cylindrical-shaped plates which are welded together. The horizontal former plates are connected to the core barrel by bolts. These bolts are surrounded with thermal shield or neutron panel depending on plant type. Core barrel is designed to be encircled fully by thermal shield or partly by neutron panel.

Figure 1 Barrel with segmented thermal shield

Broken bolts in US plants started the study and development by utilities and vendors of the inspection system for the barrel welds and bolts.

The challenge is to detect cracks accurately in a relatively inaccessible area of the thermal shield type design: the gap between barrel and thermal shield is only 20 to 50 mm depending from the plant type. Additionally the high radiation dose up to 10^4 Rads limits the choice of materials for the construction of manipulator and probes.

Considering the experience of US NPP, The Kansai Electric Power Co. Inc. (Kansai) planned to inspect barrel welds and barrel former bolts to confirm the integrity of it's NPPs. Kansai and Mitsubishi Heavy Industries, Ltd. (MH) studied to determine the requirements for inspection method, area to be inspected and specifications of inspection systems. MHI was requested to conduct inspection and ABB Reaktor was also requested to design and manufacture the inspection systems jointly with MHI's technical support.

Based on the experience gained by developing inspection systems for the reactor vessel head penetrations, ABB Reaktor has designed and manufactured a sophisticated manipulator system able to insert and to drive the inspection probes into and within the narrow gap between barrel and thermal shield. A number of techniques to perform non-destructive examinations for this technically challenging environment have been developed and qualified within a remarkably short time.

INSPECTION METHOD

The main inspection method for the integrity of the barrel welds and former bolts is an automatic ultrasonic testing (UT) based on the pulse-echo technique. The transducer installed in the single UT probe transmits ultrasonic waves which propagate in the weld or in the bolt shaft. If the ultrasonic wave hits a discontinuity, i.e. a crack, the sonic wave will be reflected partially and can be detected by the ultrasonic transducer. Depending on the size of the crack, only a part of the ultrasonic wave reaches the shaft end. Amplitude and time of flight of this reflected part will be used to evaluate the integrity of the welds and of the bolts.

For the inspection of the barrel welds an eddy current (EC) probe is used primarily for the identification of the weld seam location. Additionally this probe can be used for the detection of surface cracks.

By the inspection of the barrel bolts a radiation resistant fiber optic probe serves the purpose of positioning the UT probe and of visual examination.

INSPECTION EQUIPMENT

The inspection system consists of a manipulator system including the probe holder, the video as well as the UT and EC equipment.

The total system including the ultrasonic and eddy current equipment, video monitor and video control can be operated from the main control unit.

Manipulator System

The inspection manipulator Figure 2 consists of a revolving carriage which is mounted and guided on top of the core barrel flange. By means of the revolving carriage, the test positions (welds and bolts) are approached in circumferential direction.

The probe guiding system is mounted to the revolving carriage and moves the probe holder in vertical direction by means of a chain “tramway”. This chain “tramway” is placed through the guide rail into the gap between thermal shield and the core barrel. During manipulator movements, the guide rail moves in circumferential direction on the core barrel flange cone with the support of a special rolling device. At the end of the guide rail two standards are placed for the calibration of the ultrasonic and eddy current probes.

For the inspection of the barrel welds the probe holder is a plate which carries the eight UT probes and the EC probe. Once, the weld position is identified by means of the EC probe, the weld is scanned in meander path.

For the inspection of the barrel bolts a sophisticated probe holder carries the fiber optic probe and the UT probe. Positioning of the UT probe is performed visually. The fiber optic probe is aligned exactly on the bolt to be inspected by a hairline target of a visual lens. By means of a stroke the UT probe will be driven in horizontal direction with a disalignment distance which corresponds to the distance: fiber optic probe to test head on the UT probe. By this motion the ultrasonic test head is positioned exactly in front of the bolt to be inspected.

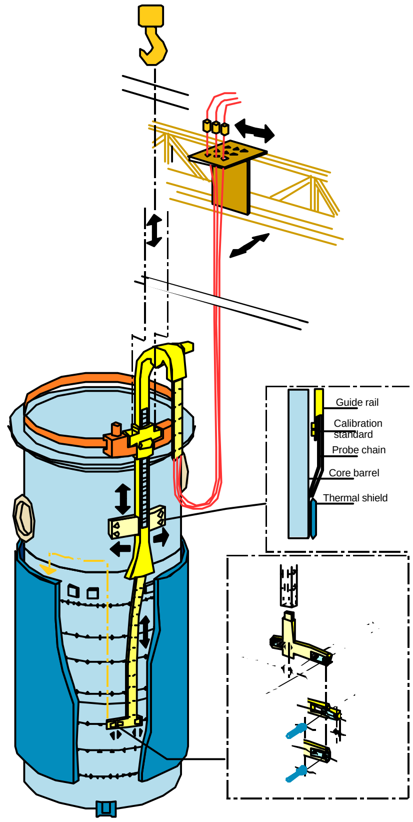

Figure 2 Overview of the barrel inspection system

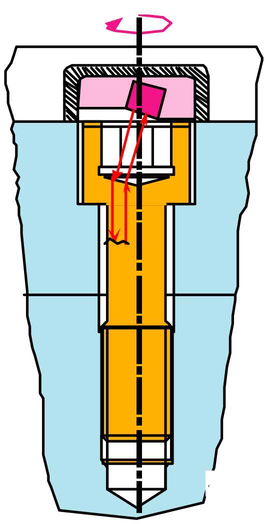

Figure 3 Inspection technique for the hexagonal socket bolts

UT Probes for the Bolt Inspection

Two different types of probes have been developed for the inspection of the hexagonal socket bolts and for the slit pin bolts.

The immersion technique was chosen for the inspection of the hexagonal socket bolts (Figure 3). The probe is operated with a frequency of 10 MHZ by a water path of about 19 mm. The ultrasonic pulse emitted from the transducer meets the conus in the head of the bolt at an angle of about 16°. This angle was chosen such that the refracted ultrasonic wave in the bolt will propagate axially through the bolt. When inspecting a bolt without a defect the ultrasonic wave will be partially reflected by the bolt head (entrance echo), a part of the refracted ultrasonic wave is reflected at the threat and the rest at the bottom face of the bolt. If a defect is present in the bolt the refracted ultrasonic wave will be mainly reflected at the defect and the echo of the bottom face of the bolt will be reduced in amplitude. In order to inspect the whole bolt, the UT probe will be rotated in 360°.

The inspection of the slit pin bolts is done by using the contact technique (Figure 4). The UT probe consists of two transducers operating at a frequency of 10 MHz in pulse echo technique. The ultrasonic wave emitted by the transducer is propagated in the axial direction of the bolt. Small portions of the ultrasonic wave are reflected at the thread area, the main part is reflected at the bottom face of the bolt. If a defect is present the ultrasonic wave is reflected at the defect and the echo of the bottom face will be reduced in amplitude.

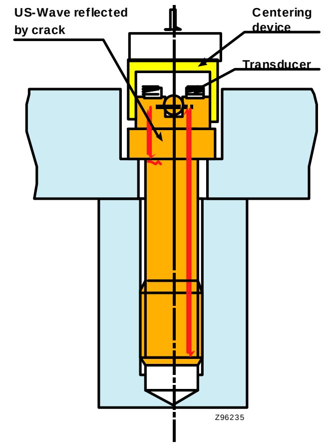

Figure 4 Inspection technique for the slit pin bolts

UT Probes for Weld Inspection

In order to detect cracks in the longitudinal and transverse directions of the welds on the outer as well as the inner surface of the barrel, 8 UT probes (Figure 5) are used:

- 4 probes SEK 3 (creeping wave probes) for detection of cracks on the outer surface.
- 4 probes 55 EL (longitudinal wave probes) for detection of cracks on the inner surface.

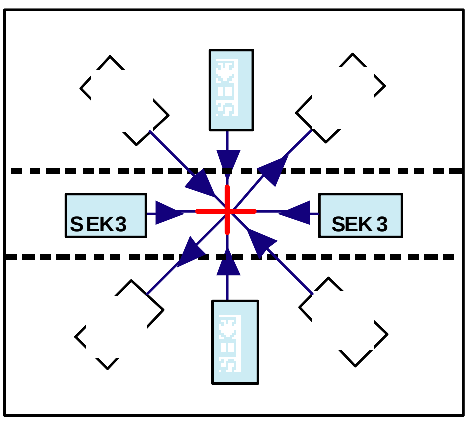

Figure 5 Probe arrangement for barrel welds inspection

A symmetrical arrangement of the UT probes was chosen to avoid additional handling by the inspection of the longitudinal and circumferential welds of the barrel. The ultrasonic pulse propagation is similar to that one described above.

EC Probe

The EC probe consists of two coils which are crossed in a special arrangement. The probe can be operated in absolute and differential mode. In absolute mode the probe is very sensitive to material changes so that the weld seam can be easily located. In differential mode the disturbing signal of the weld will be minimized and the probe can be used for crack detection.

PERFORMANCE DEMONSTRATIONS

For both cases, inspection of the barrel welds and the bolts, the performance of inspection techniques has been demonstrated. Full-scale mockup prepared with ID and OD transverse and longitudinal defects (for the welds) and defects of different positions on the shaft of the bolts were utilized for these tests. All defects were EDM notches.

The complete performance demonstration was obtained in different steps. First, the performance was determined in the laboratory under the best possible conditions. The performance demonstration tests were conducted using the inspection tool on full-scale mockups installed in site-realistic conditions, to demonstrate that the target performances were achieved.

The main NDE performances determined are:

- detection sensitivity
- location and length accuracy
- measurement reproducibility.

For the inspection of bolts, overheads 6 and 7 show typical UT signals of notches located on the shank, shaft and thread of the hexagonal socket bolts and of the slit pin bolts respectively. The detection level of defects in the field is estimated not larger than 3 mm on the shank, shaft and thread of the bolts in depth.

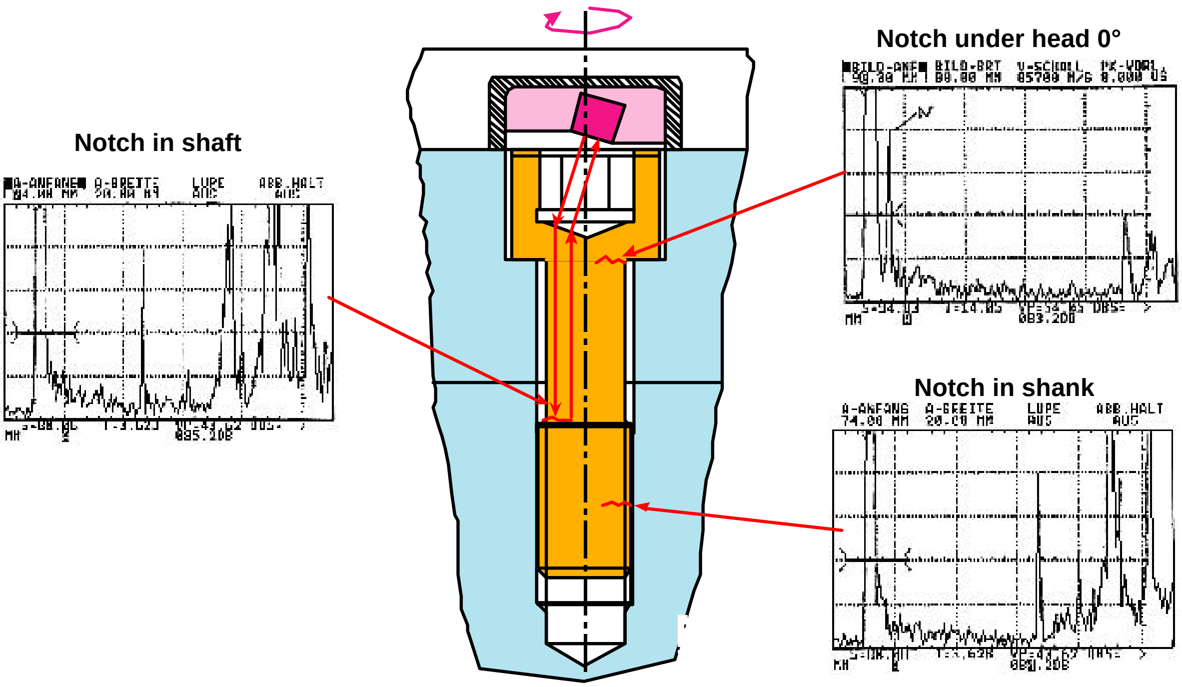

Figure 6 : Immersion testing technique

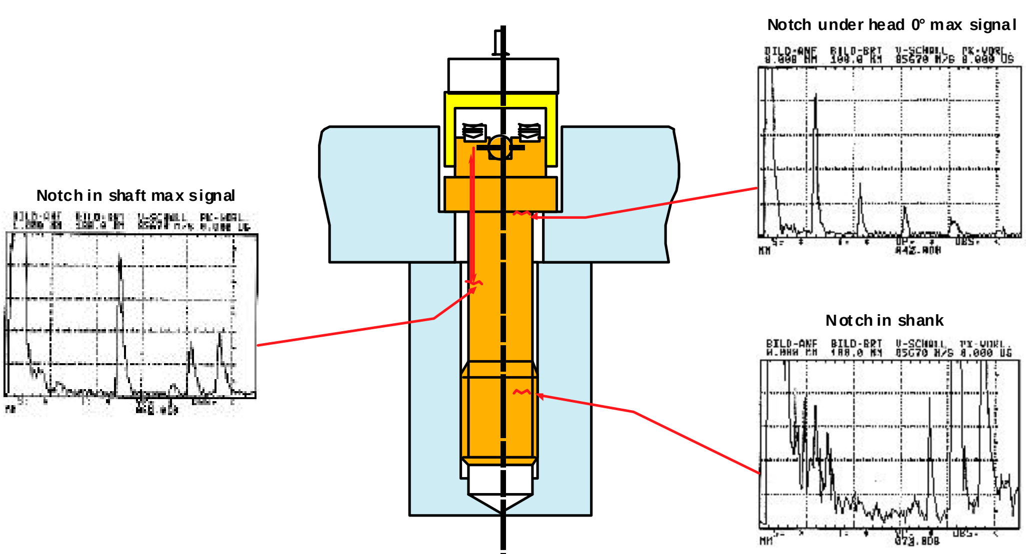

Figure 7 : Contact testing technique

Figure 8 shows the detection capability of the inspection technique for defects near and inside the barrel welds. Both ID and OD transverse and longitudinal defects larger than 5 mm in depth can be detected with sufficient accuracy.

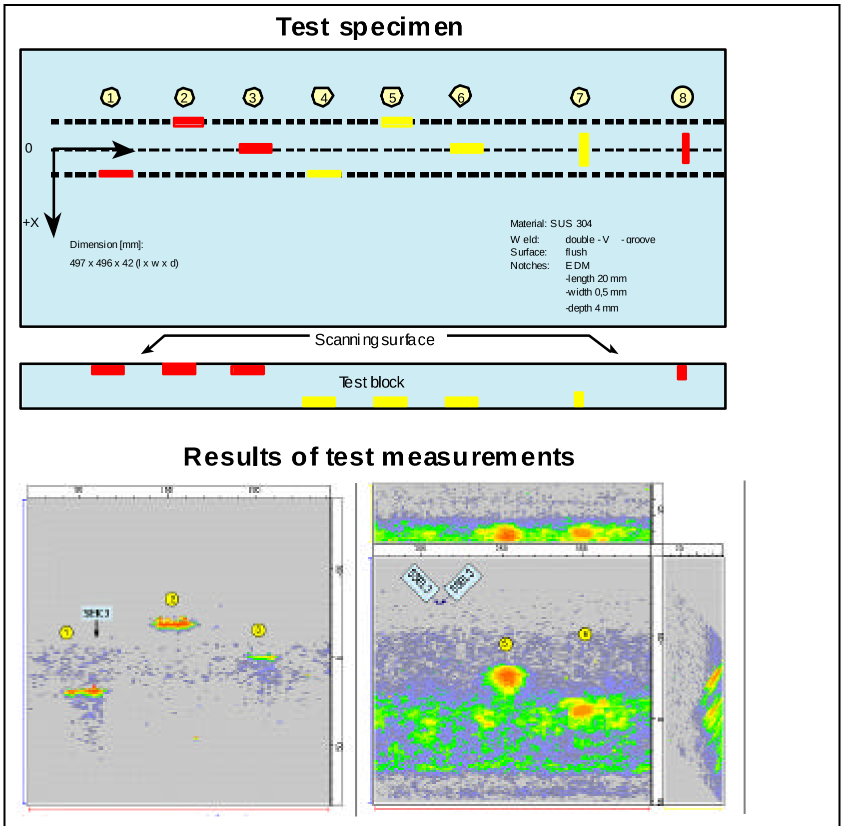

Figure 8 : Contact testing technique weld inspection

FIELD EXPERIENCES

The first unit, Takahama NPP unit 1, was inspected successfully in it's 17th annual inspection. It is three-loop PWR and has core internals manufactured by US vendor. The inspection was conducted from September 18 to October 10, 1997. The first stage of inspection was provisional to confirm the gap between core barrel and thermal shield, the shape of bolt head and the circumferential position of welds because of lack of detailed as-built material and geometric information, which was conducted with tools manufactured by MHI. The bolts and welds UT inspection was conducted with ABB systems by MHI. The inspection system shows good performance with no major trouble. The inspected area was a quarter part of barrel former bolts, one of longitudinal welds and about a quarter of a circumferential weld, which resulted in no indication of crack.

CONCLUSIONS

The first inspection of core barrel bolts and welds was successfully conducted by the joint efforts of Kansai, MHI and ABB Reaktor. There was no indication of crack in a quarter part of the core barrel bolts and welds. This result demonstrated the ability to inspect the core barrel bolts and welds using manipulator system and UT technique.