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WELD INTEGRITY ASSESSMENT OF A STEAM GENERATOR SECONDARY OUTLET NOZZLE

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ABSTRACT

Several defects were detected in the weld between the steam outlet nozzle and the elbow of a Belgian PWR steam generator. Conventional UT techniques estimated one of them beyond the acceptance threshold defined by the ASME code Section XI. Subsequent investigations conducted with high frequency contact focusing transducers permitted to improve the flaw sizing accuracy, demonstrating eventually the weld integrity.

THE PAPER REPORTS ON A CASE STUDY concerning the nozzle-to-elbow weld of the steam generator outlet of a Belgian Pressurized Water Reactor. During the tenth year in-service inspection, small planar defects were detected, using ASME ultrasonic testing procedures from the outer surface.

The various investigations performed during the outage resulted in the reporting of several indications, among which one was above the acceptance threshold.

WELD DESCRIPTION

The weld is located at the top of the steam generator and joins the steam outlet nozzle to the elbow (Fig.1). The weld chamfer is V-shaped and the nominal thickness is 30 mm. Because of the weld grinding, the external surface exhibits a rather irregular geometry. The inner surface was drawn after ultrasonic thickness measurements. A typical section of the weld region can be seen on Fig. 3.

The nozzle material is Soudotenax 55, the elbow is made from A48C1 steel, and the weld metal is Ductilend 55.

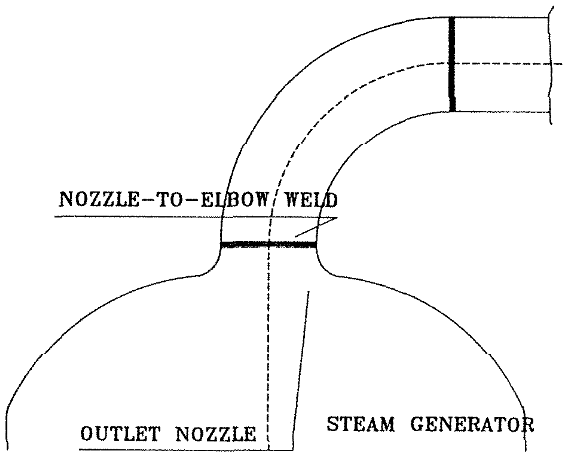


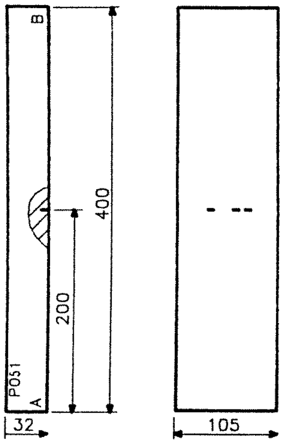
Fig.1 OUTLET NOZZLE WELD

CONVENTIONAL IN-SERVICE INSPECTION

The regular ISI procedure is based on the requirements of the ASME code, Section XI. Ultrasonic indications producing peak amplitudes above 50 % of the Distance-Amplitude Correction curve (DAC) are sized by the conventional 6 dB drop method.

The application of that procedure found several indications in the weld zone. Consecutive investigations involved magnetic particle examination and replicas from the inner surface, as well as further ultrasonic evaluation. The measurements led eventually to the reporting of 17 indications, with heights ranging from 2 to 4 mm. Most were connected to the inner surface, and some could be eliminated by grinding, during the ISI.

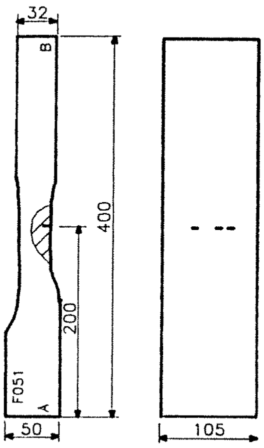
One of the remaining defects exceeded the applicable ASME XI acceptance criteria. A fracture toughness calculation was then performed, with satisfactory outcome, on the



SLOT DIMENSIONS (mm)

DEPTH	LENGTH
0.5	2
1	4
2	8
4	16
8	32

Fig. 2 FLAT BLOCKS



SLOT DIMENSIONS (mm)

DEPTH	LENGTH
0.5	2
1	4
2	8
4	16
8	32

Fig. 3 SHAPED BLOCKS

basis of the ultrasonic size estimates.

Nevertheless, it was recognized that the UT size estimate and the accuracy of the sizing method had the same order of magnitude, and that a better sizing capability was needed to assess the weld integrity. Therefore, investigations were undertaken to evaluate different sizing methods.

TEST SPECIMENS

The available calibration block, referred to as TH1/4 in the following, is a flat Soudotenax specimen, with a thickness of 39 mm ; it contains conventional ASME reflectors (3.2 mm diameter side-drilled holes and 0.5 mm deep notches). As the dimensions do not allow the introduction of any further reflector, it was used only for propagation measurements.

Two series of fine grain carbon steel specimens were fabricated to investigate the sizing capability. The first series (Fig. 2) consists in flat rectangular blocks with several elliptical slots machined by electro-erosion. The aspect ratio of all reflectors is 4.

The second series (Fig. 3) is identical, except that the section is machined so as to simulate the real profile of the defective weld.

TEST BLOCK VALIDATION

Time and frequency analysis was used to characterize wave propagation in the various blocks and in the steam generator material. The following parameters are measured from a backwall reflection echo : sensitivity (peak signal strength), maximum frequency, central frequency and bandwidth (at -3 and -12 dB).

As an example, Fig. 4 shows frequency data collected in various configurations with a 5 MHz probe. It can be seen that the design frequency is maintained in all conditions. The same conclusion was reached with frequencies up to 10 MHz.

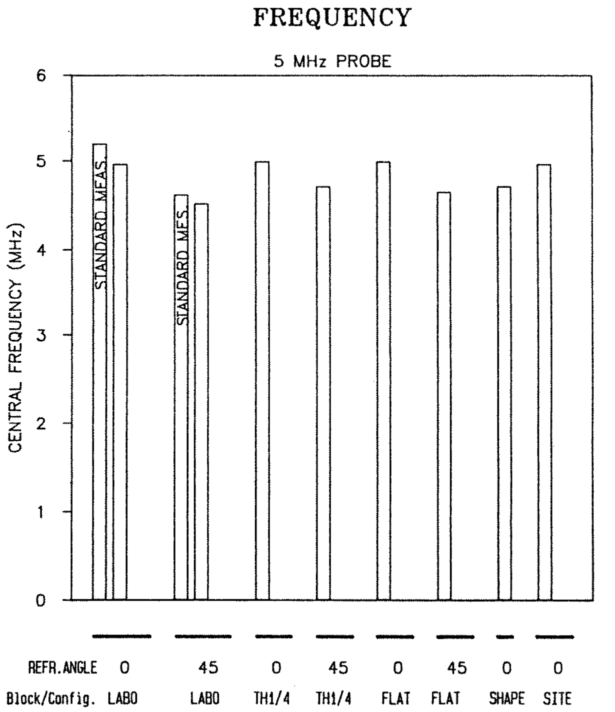


Fig. 4 – Backwall Echo Frequency Data

Fig. 5 illustrates the sensitivity values obtained with a 4 MHz transducer. The straight beam data clearly show that the signal strength is drastically influenced by the geometry of the examination surface. The diagram justifies and validates the fabrication of the shaped blocks.

More globally, the analysis demonstrated that the test specimens are representative of the field material, and that the shaped blocks simulate realistic conditions.

ULTRASONIC TRANSDUCERS

Several 4 MHz shear wave probes were used, mainly to permit a comparison with the ISI results ; refracted angles of 45, 60, 70° were considered. Additionnally, two compression wave search units were used for straight beam examination.

Furthermore, the small dimension of the flaws to be characterized required a sharper resolution than that available from the standard probes above. A beam diameter of 2 mm or less was defined as an acceptable figure.

The beam focusing technique was selected to meet the objective. Considering the remaining uncertainty as to the acoustic behaviour of high frequency waves in the steam generator material, where a high density of micro-defects was suspected, two prototype transducers were developed. One is based on a 15 mm diameter 10 MHz crystal ; the other one, based on a 25 mm diameter 5 MHz crystal, is more sensitive to the scanning surface finish.
Both transducers generate shear wave pulses at 45° refracted in steel. The focal length and beam diameter are 30 and 1.5 mm respectively. Beam focusing is achieved by a liquid lens confined in the solid shoe of the probes (Fig.6).

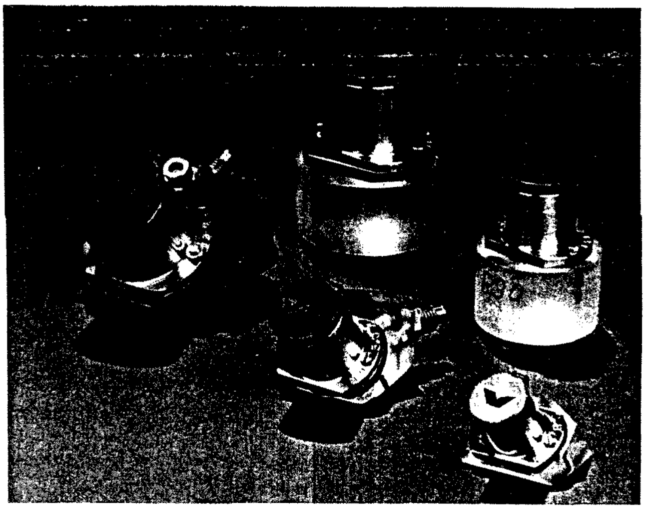


Fig.6 – Contact Ultrasonic Transducers with Focusing Shoes

REFLECTOR SIZING TECHNIQUES

The capability of three sizing methods was eventually investigated on the slots of the test specimens ; they are referred to in the following as 6 dB drop, flaw tip echo and amplitude. The resulting data are reviewed herebelow for each method.

6 dB DROP - Fig. 7 refers to the flat specimens. Not surprinsingly, no correlation is to be found between the correct sizing line and the experimental data, which can be explained only by referring to the respective beam dimensions. The

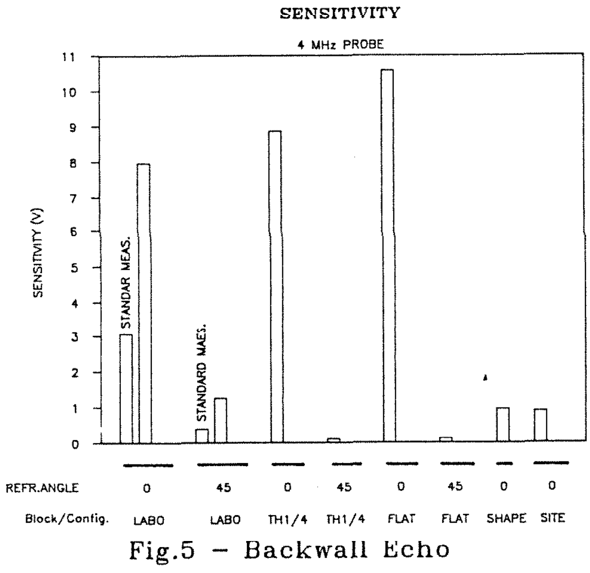


Fig.5 – Backwall Echo Sensitivity Data

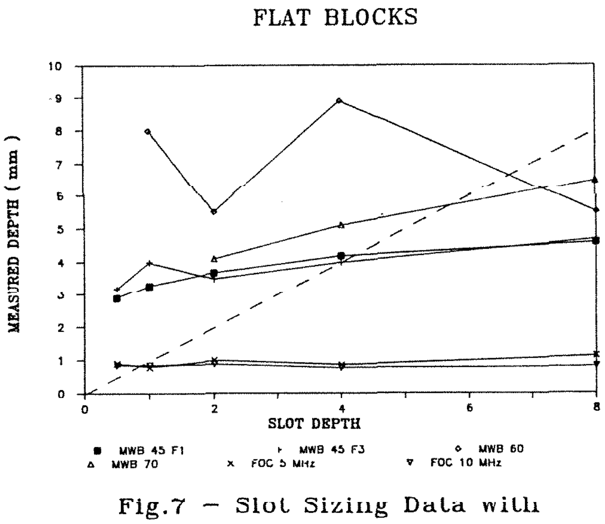


Fig.7 – Slot Sizing Data with 6 dB Drop Method

data collected on the shaped blocks are, needless to say, even worse. It follows obviously that the method is not able to size reliably the reflectors considered.

FLAW TIP ECHO - The defect height estimate is the difference between the measured depths of the upper tip signal and the corner reflection. Fig. 8 shows the excellent capability assessed on the flat specimens, particularly for the focusing transducers. Moreover, the degradation induced by the geometry of the shaped blocks remains acceptable (Fig. 9).

It is clear however that the applicability of this technique depends on the detection of the tip signal, which in turn depends on the sensitity and on the resolution of the search unit : the advantages of the beam focusing technique is evident when considering the smaller slots.

AMPLITUDE - Fig. 10 illustrates, for each search unit, the increase of the corner reflection amplitude with the reflector height. The left side of the diagrams can be used as reference for sizing. If an excellent accuracy may not be expected, that empirical procedure offers the advantage of providing size estimates even for the smallest slot. It must be noted however that the method relies heavily on the assumption that the slots can be considered as representative of the real defects.

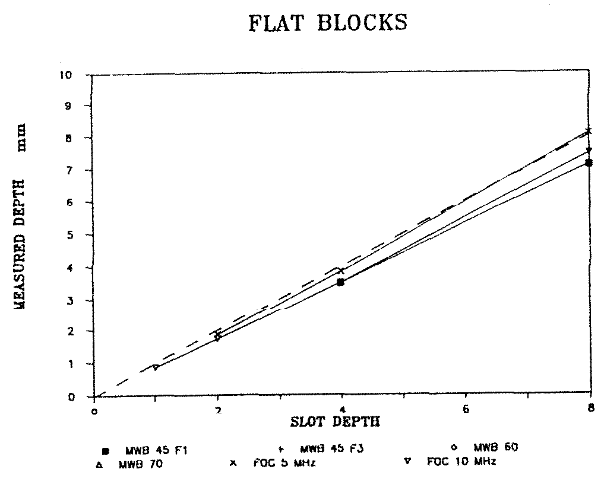


Fig.8 – Slot Sizing Data with Tip Echo Method

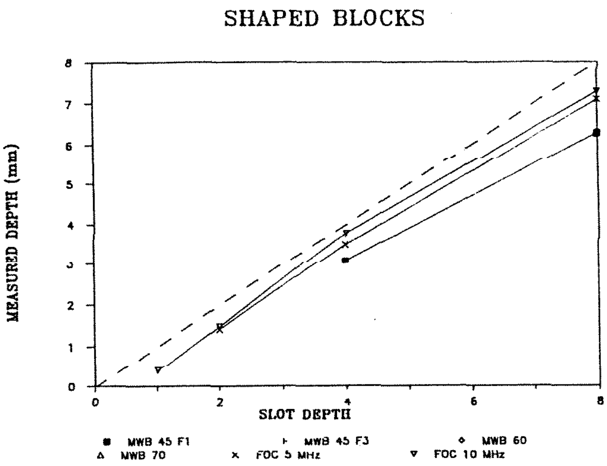


Fig.9 – Slot Sizing Data with Tip Echo Method

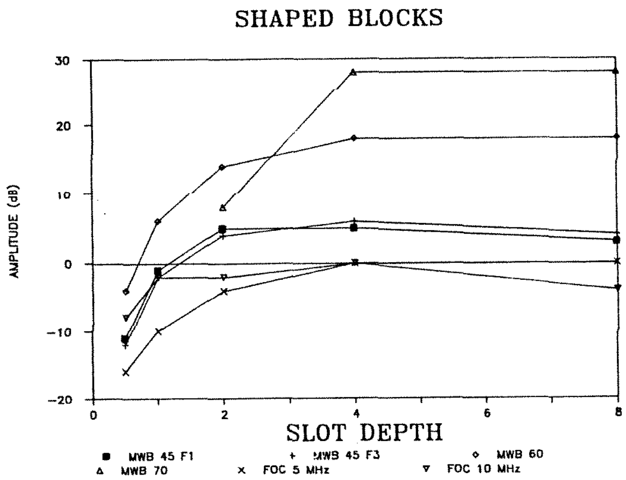


Fig.10 – Amplitude Reference Curves

FIELD EXAMINATION

The procedure draft for the examination of the steam generator nozzle weld was based on the flaw tip technique, backed up by the amplitude reference curves where no tip signal could be identified.

Indeed, none of the transducers could detect flaw tip echoes during the field testing of the main defect. In addition, the amplitude sizing method, implemented with several search units, led to height estimates ranging from 0.5 to 1.0 mm. Both observations led to conclude that the flaw dimension does not exceed 2 mm, which is well below the acceptance level, and eliminated any concern regarding the weld integrity.

SUMMARY

Contact probes fitted with focusing lenses generating very small beams were developed to improve the sizing capability of conventional UT on specific surface-connected defects.

Those probes and standard search units were used on representative steel specimens containing known reference reflectors, to evaluate flaw sizing techniques.

The laboratory tests resulted in the selection of two complementary sizing techniques, which were implemented on the nozzle-to-elbow weld of a steam generator secondary outlet.

The field examination provided a improved estimate of the defect dimensions, and showed that the previous conventional ultrasonic testing had oversized the indications.

Acknowledgement

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