ASSESSEMENT OF SECONDARY WELDS OF STEAM GENERATOR BY MEAN OF THE UT PHASED ARRAY TECHNOLOGY

H. Sweerts (Electrabel, Kerncentrale Doel, Belgium)
H.Vandriessche (AIB-Vinçotte International, Brussels, Belgium)
M. Delaide (AIB-Vinçotte International, Brussels, Belgium)
J. Cermak (AIB-Vinçotte International, Brussels, Belgium)

ASSESSEMENT OF SECONDARY WELDS OF STEAM GENERATOR BY MEAN OF THE UT PHASED ARRAY TECHNOLOGY

H. Sweerts (Electrabel, Kerncentrale Doel, Belgium)
H Vandriessche (AIB-Vinçotte International, Brussels, Belgium)
M. Delaide (AIB-Vinçotte International, Brussels, Belgium)
J. Cermak (AIB-Vinçotte International, Brussels, Belgium)

Abstract

A dedicated system has been implemented for semi-automated UT examinations, conducted from the external surface, to be used for preservice and inservice inspection of Steam Generator secondary welds. This paper shall address the design of the phased array (PA) based UT system, the examination procedure, and the experience gained from the qualification.

The TOMAS semi automated scanning mechanism allows for the examination of welds in straight as well as in conical configurations, carrying on up to four probes. Appropriate UT PA transducers were selected allowing full thickness examination in one scanning operation of carbon steel welds, with thickness up to 130mm. For each weld configuration, the probes are assembled into dedicated probe frame to minimise both mechanical manipulations and effective scanning time.

The qualification process for the UT examination procedure and the phased array equipment was conducted according to the European methodology developed within ENIQ, and will be assessed by an ad hoc Qualification Body. A technical justification document, involving both experimental evidence and physical reasoning, was prepared to demonstrate the capability of the UT system. Relevant examples from the trials shall be presented to illustrate the excellent examination capability of the applied methods.

Introduction

Ultrasonic testing of thick carbon steel components like steam generator secondary welds.

In thick carbon steel components, such as the steam generator (SG) secondary welds (thickness between 70 and 130 mm), conventional pulse-echo ultrasonic testing techniques (UT) perform a reliable detection of flaws.

But the accurate sizing of flaws is often limited by the low resolution offered by the standard probes. Further, with conventional ultrasonic testing several probes have to be applied to achieve the code requirement in coverage of volume to be inspected and in sensitivity of examination. This results in time consuming examination and does not always satisfy in through wall sizing accuracy. As a consequence, conventional UT examination of components like steam generator welds (see figure 1) results in rather high radiation doses for the involved personnel (especially for the tube-sheet to vessel weld).

For the examination of SG secondary welds, the improvement of the sizing performances and the reduction of exposure to radiation time require definitively a procedure based on advanced UT technology.

The UT phased array technology offers therefor very interesting capabilities

Principles of the UT phased-array technique

The Phased Array concept is based on the use of ultrasound probes made up of a great number of individual elements that can each function separately as transmitters and receivers (Reference .3). Rapid electronics and advanced software are incorporated into the acquisition system, so that one can generate several virtual probes starting from one physical mutlielements probe. The parameters of those electronic created probes, like refracted angle in compression or shear wave modes, aperture and focussing properties can be easily set to satisfy the requirements of specific and complex ultrasound investigations.

Code evaluation and Defect Tolerance Analysis (DTA)

In Belgium, the ASME XI code, edition 1992 (Reference 1) is to be applied to the examination of welds of interest shown in figure 1.

The ASME XI code, edition 1992, refers to section V, article 4 which describes parameters such as refracted angles, inspected volume and gain setting to be used for detection.

The volume to be inspected is extended to the whole thickness in one direction and to the welded material enlarged by ½ inch on both sides of the weld, in the other direction. The typical width of the volume to be inspected is 60 mm for thickness of 100 mm, as shown in figure 2.

The weld has to be insonified at least from two sides, by mean of 0°, 45°, 60° and 70° refracted angle probes.

The reference gain setting is given by the responses of side drilled holes of Ø3.2 mm for near surface examination and Ø4.7 mm for the volume. The registration level is imposed at 20% (+14 dB) of the reference gain setting.

The same code allows for application of “alternative examination techniques”; these techniques should demonstrate to be equivalent or superior to the methods specified in the code.

Beside the ASME XI code, the Belgian utilities undertook a specific defect tolerance analysis (DTA). This study has established the minimum through wall size to be detected regarding the stress submitted to the steam generator secondary welds in extreme conditions. The result is that an inner surface-breaking crack having a minimum height of 5 mm should be detected and accurately sized, on a 5 years examination interval basis. It is to be noted that the minimum through wall size of a similar flaw, according to the acceptance criteria of the ASME XI code, is around 2.5 mm.

In order to achieve reliable detection and sizing of these critical flaws, a work program was performed by the Belgian utilities Electrabel for the qualification of an advanced SG dedicated Non Destructive Examination (NDE) procedure (Program managed by LABORELEC and realised by Aib-Vinçotte international).

The qualification process was conducted according to the European methodology developed within ENIQ, and will be assessed by an ad hoc Qualification Body. A technical justification document, involving both experimental evidence and physical reasoning, was prepared to demonstrate the capability of the UT system (detection and sizing according to code requirements and to the results of the Belgian DTA) and the ability of the procedure to be applied in real condition (In Service Inspection).

GV dedicated alternative examination technique

Design of the technique

The design of the developed alternative technique is aiming:

- to detect and size the critical defects in the required volume (2.5mm high, at a depth of 100 mm for the worse case)
- the reduction, in comparison with conventional technique, of the examination duration and related radiation dose.

The UT phased array (PA) technology offers an efficient way to reach these objectives. In particular, the ability to generate, from one linear array probe, multiple angles in compression and shearing waves, with adjusted aperture, allows for working simultaneously with accurate time of flight diffraction (TOFD) and pulse echo (PE) techniques.

The Phased Array TOFD technique (PATOFD) is used to generate wide ultrasonic beams with angles ranging from 40° to 80°L (compression mode), in steps of 5° or 10°. The PATOFD covers the whole thickness and the required width of the volume to examine using a single probe index separation.

The Phased Array Pulse-Echo technique (PAPE) generates 3 to 4 angles ranging from 30° to 50°, aiming the detection of the corner effect of far surface braking flaws (inner surface of the steam generator). This gives the opportunity to distinguish the difference between far-surface flaws and near surface embedded ones.

The both techniques are generated by a single pair of linear array transducers, disposed on each side of the inspected weld and translated in the direction parallel to the weld (see figure 5).

Reference Gain setting consideration

The code requires the calibration on side drilled holes (SDH) of ∅3.2 and 4.7 mm, situated at different depths. The responses are conventionally plotted in distance-amplitude curve (DAC). The nominal registration level is set 14 dB below this level (DAC +14 dB).

The proposed alternative technique has to be at least as sensitive as the code requirements. A direct way to assess the capabilities of the different proposed UT configurations is to verify that predetermined small reference SDH reflectors, giving, with conventional probes, a response corresponding at the nominal DAC level plus 14dB", are well detected and sized.

In order to determine the diameter of these small reference SDH, families of regression curves were deduced from experimental measurements on several SDH diameters, at various depths, with different frequencies, and transducers sizes (fig3 a).

The figure 3 b gives the example of the curve computed for a depth of 100 mm were the parameter {SDH diameter / wavelength} is plotted versus the echo amplitude in dB. The formulation permits to find, for a given frequency, the diameter of the small SDH giving an amplitude response 14 dB lower than for the Ø3.2 mm and the Ø4.7 mm SDH.

The results obtained are in good accordance with the Reference 2, where it is also demonstrated that similar relations do exist for flat bottom hole reflectors (FBH).

The final result of the experiments and calculation is that a SDH of about Ø 0.2 mm can be used as DAC + 14dB reference for all the UT configurations involved in the proposed alternative technique.

As it is difficult to produce such small SDH, spark-eroded (EDM) notches, with tip radius of 0.1 mm have been used. Further, the experimental results demonstrate that this kind of notches are detected with comfortable signal to noise ratio.

Volume to be inspected

As mentioned in previous paragraphs and drawn in figure 2, the volume to examine is about 30 mm on each side of the weld centre line (WCL). To demonstrate that this width is covered by the proposed UT configurations and settings, several scan lines were performed on test specimens containing reference EDM notches located on the WCL (see Table 1). The Scanning operations were performed from {WCL –30 mm} to {WCL +30 mm} with step of 10 mm.

Assessment of the UT-Phased Array capabilities on steam generator secondary welds

Test specimens

The UT configurations and settings proposed in the alternative technique were assessed on four representative test specimens called Config 1, 2, 3 and 5 and described in the Table 1.

The four blocks, made of carbon steel (material SA 508 M Cl 3), reproduce the geometric configuration of the welds to be examined. Each block contains three EDM notches with through wall extents of 2.5, 5, and 8 mm and a width of about 0.2 mm. Further, the block called Config 1 contains the five SDH required by the ASME code.

Equipment

The PA probes used for the trials consist of 2.25 and 5 MHz, 32 elements, linear array transducers made by Imasonic.

The UT data acquisition and the characterisation measurements were performed with a R/D Tech FOCUS 32/128 phased array system, and the R/D Tech TOMOVIEW software.

The TOMAS, semi automated scanning mechanism dedicated to TOFD (see figure 4), and a motorised mechanical {X, Y} scanner, both equipped with position encoders, were used for the scanning operations.

The TOMAS, developed by AIB-VINCOTTE INTERNATIONAL, allows for the examination of welds in straight as well as in conical configurations, carrying on up to four probes; if needed, a motorised unit can also be added.

Data recording

Centred and ex-centred scan lines were registered with the 2.25 and 5 MHz PA probes, using various combination of array elements, in order to select, for each geometrical configuration, the optimal UT settings satisfying to the above mentioned requirements.

The sketch in figure 5 illustrates the configuration of the PATOFD and PAPE techniques (centred configuration) The figure 6 presents an ex-centred configuration.

Config 1 test block.

The volume coverage in the direction perpendicular to the WCL, with the required signal to noise ratio, is achieved by a good compromise between the beam aperture (number of exited elements and frequency), the virtual probe index (position of the exited elements) and the quantity of generated refracted angles.

The figure 7 illustrates the covered volume while performing ex-centred scans at distances ranging from 0 to 30 mm at both sides of the WCL with various probe settings.

Two configurations provide the desired coverage and have been finally selected for field application. The difference between the two is the nominal frequency (2.25 and 5 MHz). The frequency is to be chosen on site, in function of the UT propagation in the material.

A sample of the results obtained on the Config. 1 specimen is given in the figure 8 (B, C, A and S-views).

The through wall sizing capability is demonstrated to be about 1 mm with the PATOFD settings.

Further, the interpretation of the PAPE signals enables to distinguish embedded flaws from far surface breaking ones because the corner effect is clearly detected with the nominal gain settings (fig. 8b).

Other test blocks

The two selected UT configurations were applied on the other test blocks mentioned in Table 1.

Some parameters were matched to the thickness and the shape in the cone region of the SG. The detection and sizing capabilities are found similar to the case of the Config 1 specimen. The figure 9 gives an overview of the results obtained on the Config 2 specimen, on the inner and outer surface.

The examination duration

The length of each weld to be examined is approximately 15 m.

The conventional techniques impose to use several fixed angle probes on both sides of the welds; as a consequence, the total duration of a manual testing would be at least 8 hours and much more if indications should have to be reported.

The proposed PA technology allows for a single line scan of 15 m long. The operation on site takes about one hour (theoretically no more than 10 minutes if the manipulation and acquisition file management time is deduced), which is about 8 times less than for the manual examination.

Conclusions

Several blocks representing the steam generator secondary welds have been investigated, using the phased array technology and according to the code requirements. The detection and the through wall sizing, in the to be inspected volume were demonstrated.

The PA technology allows the detection, in one single translation parallel to the weld, of reflectors situated in the entire volume and with the sensitivity required by the code.

The smallest imposed reference reflector (2.5 mm height) is detected with a good signal to noise ratio (≥ 12 dB).

The accuracy of the through wall sizing was demonstrated to be 1 mm.

The nominal duration of the scanning operation, and thus exposure time to radiation, is reduced by at least a factor eight in comparison to conventional UT pulse-echo manual techniques.

References

1. ASME Boiler & Pressure Vessel Code, Section XI, edition 1992 without addenda.

2. E. Mrianeschi and T. Tili, “A note on the smallest defect that can be detected using ultrasonics”, NDT international, April 1983.

3. M. Delaide, G. Maes and D. Verspeelt, "Design and application of Low-Frequency, Twin Side-by-Side, Phased Array Transducers for Improved Ultrasonic Testing Capabilities on Cast Stainless Steel Components", 2nd Int. Conf. on NDE in Relation to Structural Integrity for the Nuclear and Pressured Components, New Orleans, May 24-26, 2000.

Figures:

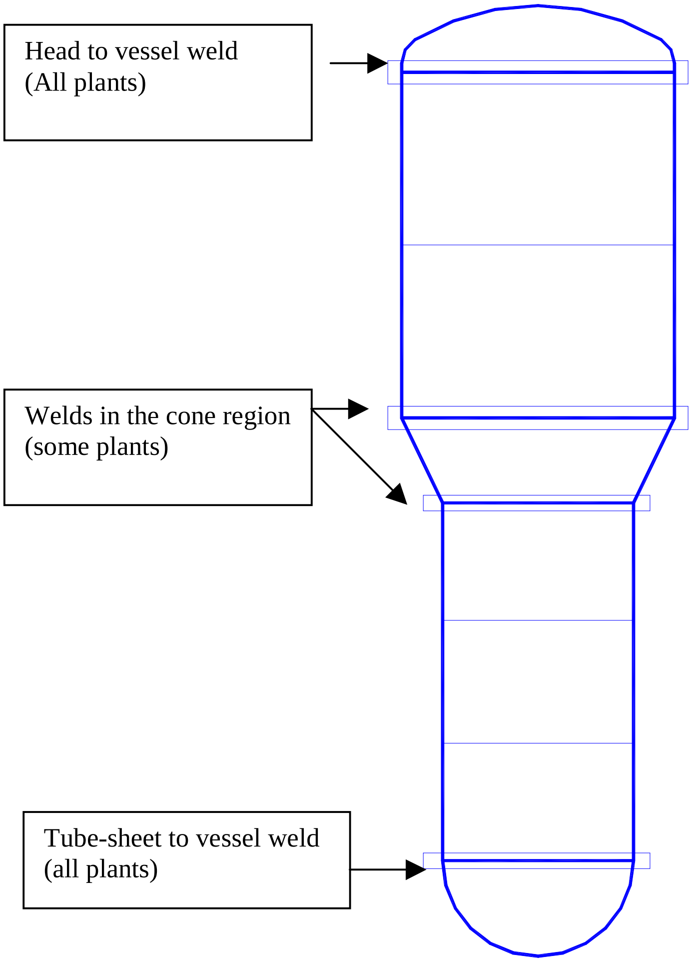


Figure 1: Steam generator: welds of interest

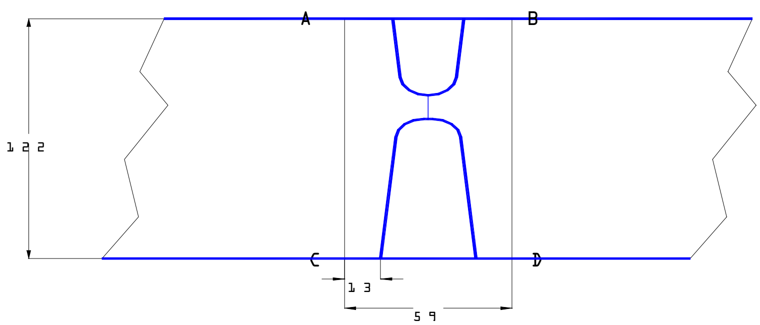


Figure 2: Typical volume to be inspected

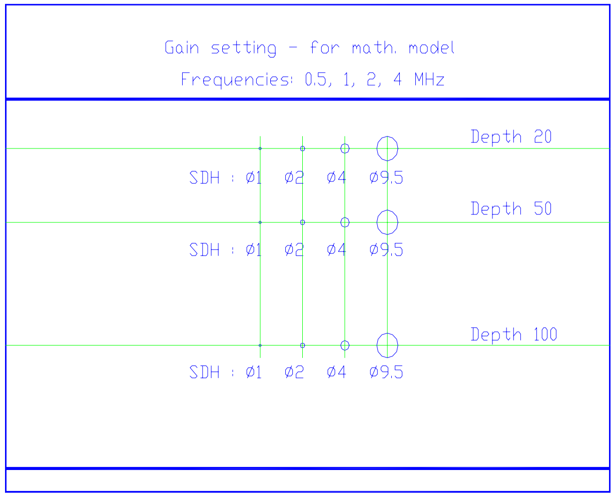


Fig.3 a: SDH diameters, depths and frequencies used for the mathematical analysis

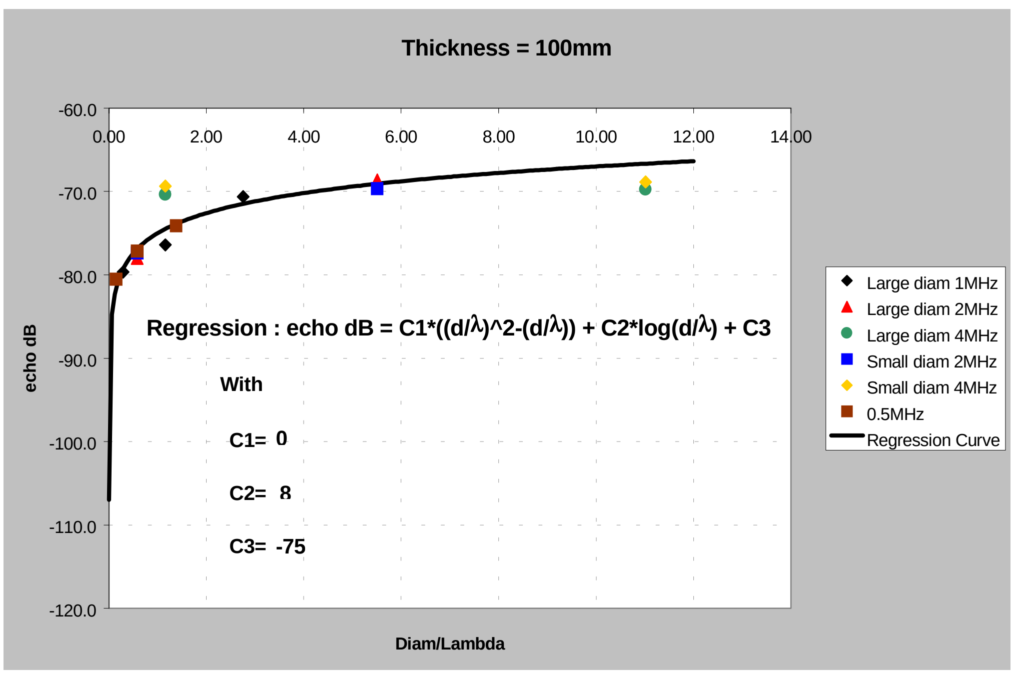


Fig.3 b Example of regression curve (Thickness 100 mm case)

Figure 3: Determination of equivalent SDH reflectors

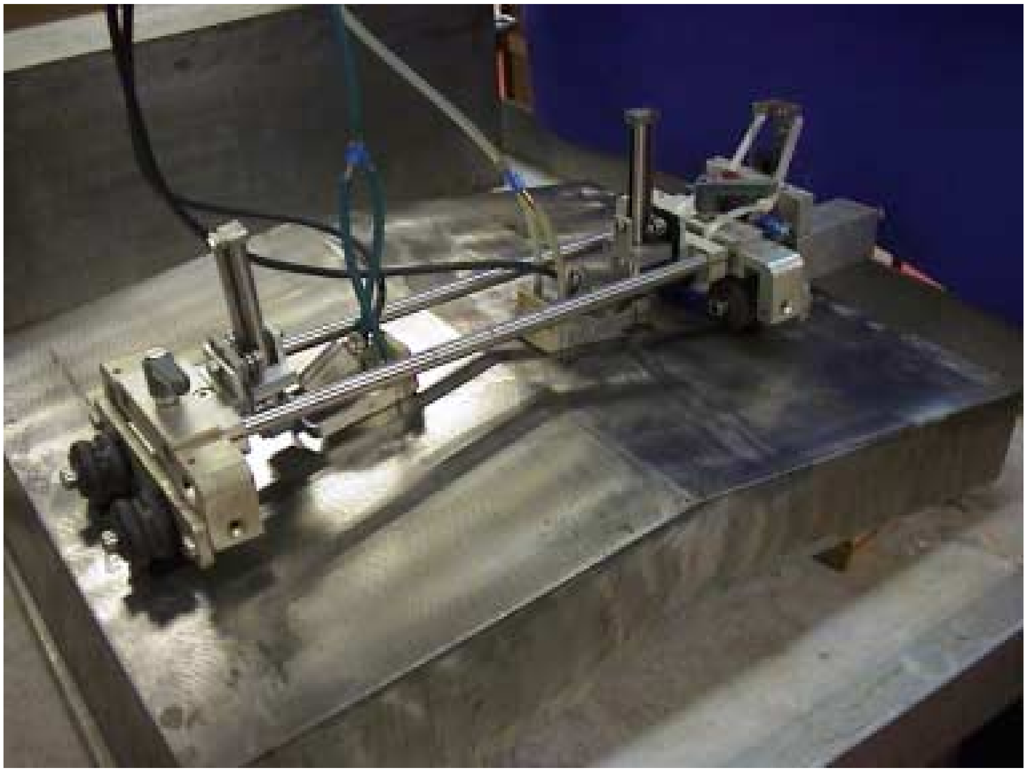


Figure 4: TOMAS on the Config. 2 specimen.

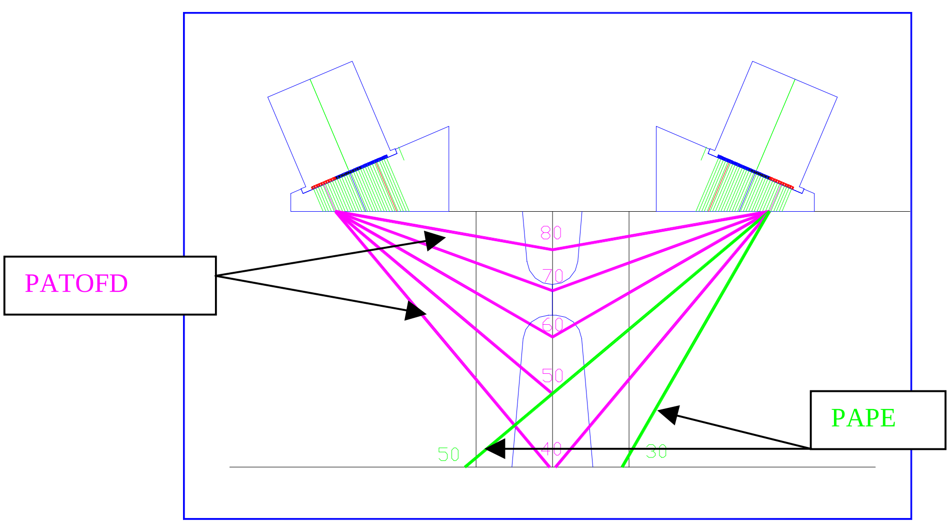


Figure 5: centred PATOFD and PAPE techniques.

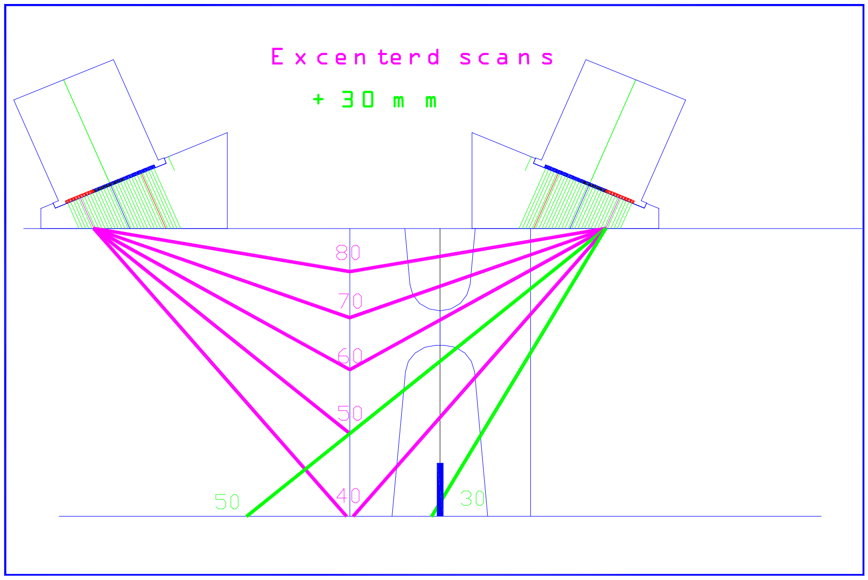


Figure 6: Scan configuration ex-centred of 30mm

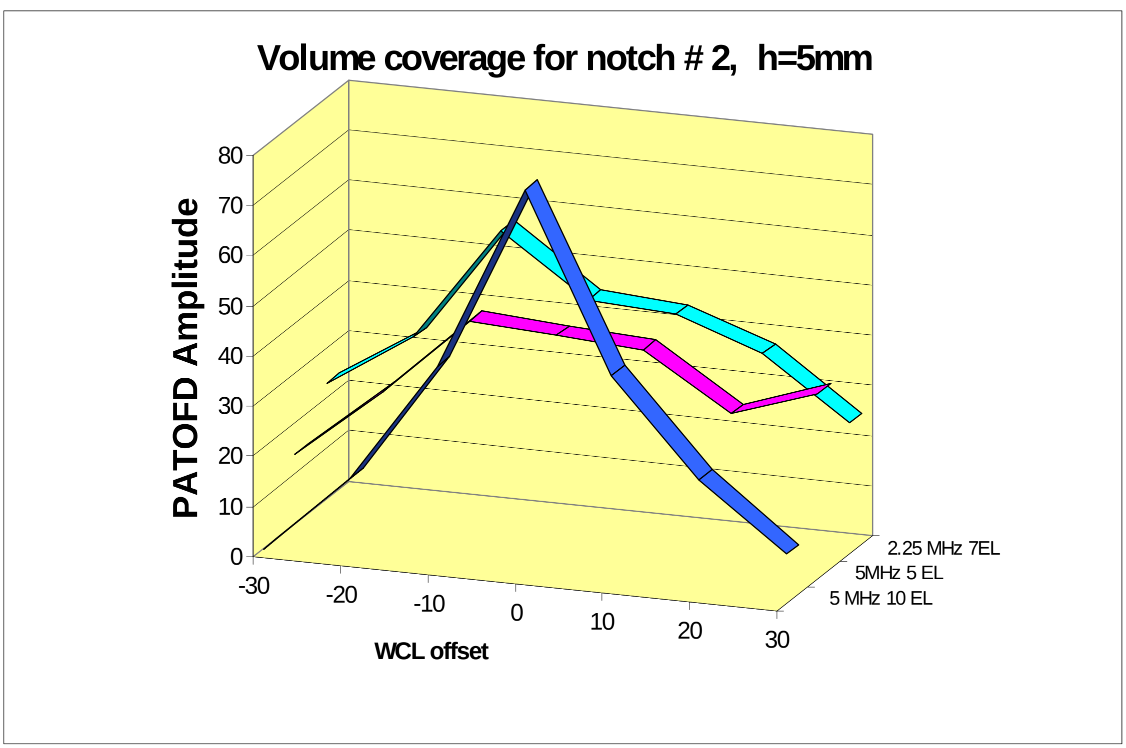


Figure 7: PATOFD volume coverage with various settings.

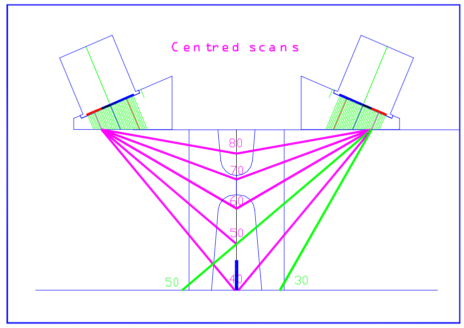
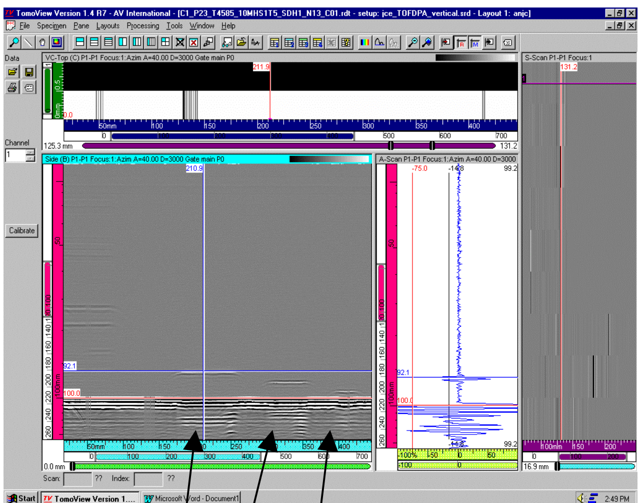
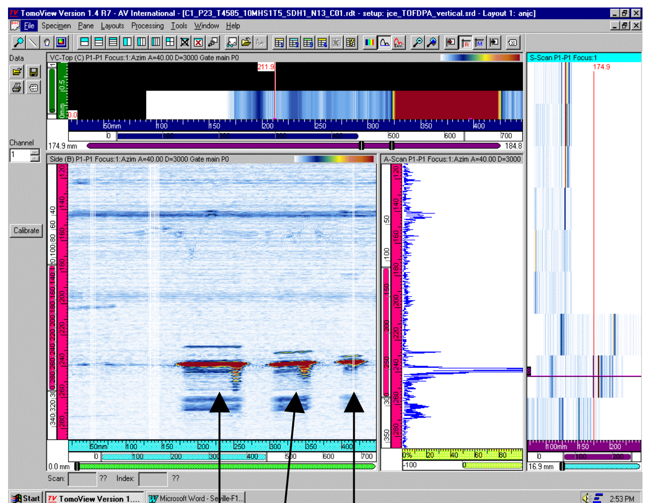


Fig 8a: PATOFD technique

Fig 8b: PAPE (pulse-echo)



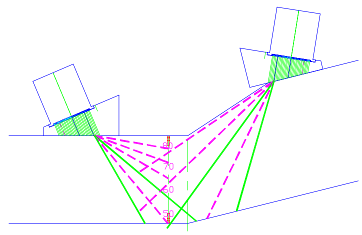


technique

Notches 8, 5 and 2.5 mm high

Notches 8, 5 and 2.5 mm high

Figure 8: Config 1: Scans centred on the WCL.



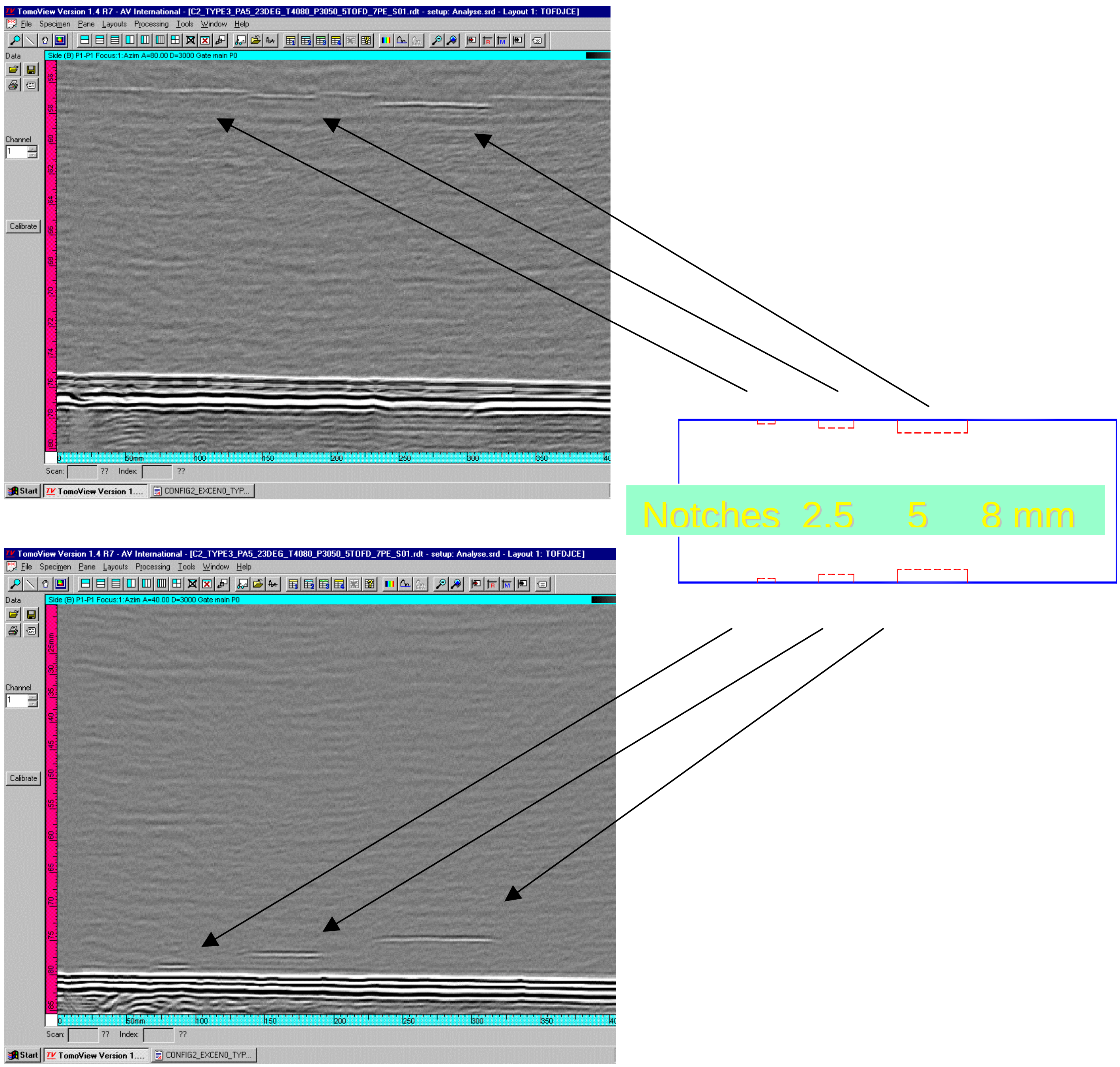

TomoView Version 1.4 R7 - AV International - [C2_TYPE3_PA5_23DEG_T4080_P3050_5TOFD_7PE_S01.rdt - setup: Analyse.srd - Layout 1: TOFDJCE]
Notches 2.5 5 8 mm
TomoView Version 1.4 R7 - AV International - [C2_TYPE3_PA5_23DEG_T4080_P3050_5TOFD_7PE_S01.rdt - setup: Analyse.srd - Layout 1: TOFDJCE]

Figure 9: Config 2: Scans centred on the WCL.

Specimen	**Represented weld**	**Flaws** (h = height in mm)	**Trough wall positions**
Config 1	Head to vessel	EDM notches h = 2.5, 5 and 8 mm SDH Ø 4.7 mm SDH Ø 3.2 mm	Far surface ¼, ½, ¾ of thickness at 12.7 and 25.4 mm
Config 2	Welds in cone region	EDM notches h = 2.5, 5 and 8 mm	Near and far surface
Config 3	Tubesheet to vessel	EDM notches h = 2.5, 5 and 8 mm	Far surface
Config 5	All	EDM notches h =5 mm	Embedded at 67.5 and 87.5 mm

Table 1 Representative test specimens