Development and Implementation of UT Procedures for Nuclear and Other Applications Using TRL Phased Array Probes

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Abstract. In the past, Vinçotte developed, qualified and applied various UT procedures for the automated in-service inspection of austenitic and dissimilar metal welds, using conventional ultrasonic probes. In a process of continuous improvement, Vinçotte is upgrading these existing procedures by applying low frequency TRL phased array probes. This presentation situates this recent innovation within the phased array history of Vinçotte. Particular attention will be paid to these newest phased array developments, in terms of probe development, angled beam generation and scanning patterns.

Introduction

It is commonly known that the ultrasonic examination of austenitic and dissimilar metal welds requires specific ultrasonic probes design. Due to the coarse grain structure of the base and weld material, the frequency of the transducers to use is typically found between 0.3 and 2MHz. Among others, typical characteristics are wave type, high damping and high sensitivity piezocomposite elements.

This knowledge resulted in the use of multi-probe ultrasonic examination combining the benefits of different angles and wave types. Examination of welds with this technique required a large number of probes. These probes are applied and moved simultaneously in so-called frames. Such a frame is carried by a mechanised scanning system (figure 1).

Vinçotte qualified several procedures based on this technique covering thicknesses from 10 to 120 mm and pipe diameters from 3” and up. These procedures were mostly applied in European nuclear industry for the examination of main coolant piping and pressuriser welds.

With the development of phased array probes and the arising phased array technology it was for Vinçotte a logical step to implement this technology into ultrasonic examination procedures.

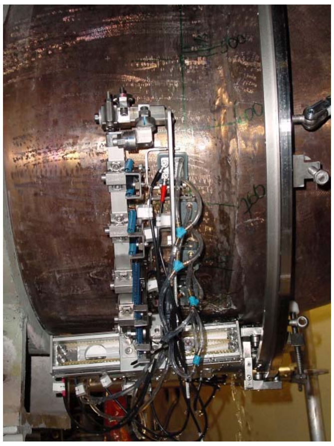


Figure 1: multi-probe configuration

Probe development

In a first step, an analysis was performed on the existing procedures to identify all ultrasonic probes and theirs characteristics in relation to the thickness, material type and curvature applied on. A second step was to summarise this information in such way to identify the needs for the phased array probes and wedges in terms of frequency and size. In most procedures it was seen that the leading examination techniques were TRL 0°, 45° and 60° probes.

Knowing the needs for the ultrasonic techniques, different probe pre-designs were made. Beam simulations based on these pre-designs were done using the PASS software (figure 2). The outcome (figure 3) of these simulations allowed for verifying the theoretical beam, the angle steering capability and the angle skew possibilities. Whenever necessary, feedback was given to the design and new simulations performed.

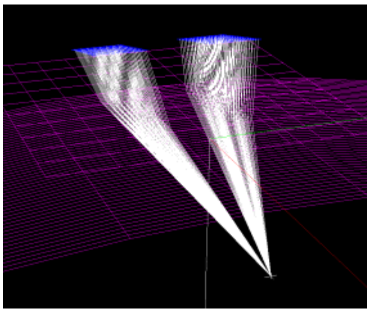


Figure 2: PASS 3D configuration

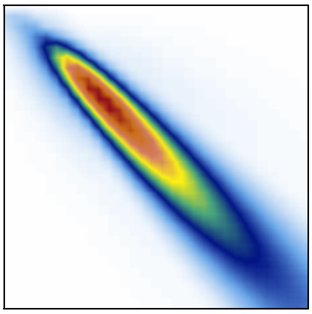


Figure 3: Beam simulation

Another point of interest is the flexibility of the phased array probe. TRL probes are known to have a wedge with, among others, characteristics like material velocity, wedge incidence and roof angles. A fix wedge probe concept (figure 4), where a pair of phased array modules is imbedded into a housing, has beam steering and skewing capabilities limited by the pre-designed wedge angles. The choice was made to acquire a number of modular matrix phased array probes with typically 3x10 or 4x8 piezoelectric elements with frequencies 0.5, 0.75, 1, 1.5 and 2 MHz in different sizes. These modules are mounted on a specific wedge having characteristics depending on the component geometry, required angles and focal depths. The assembly is then acting as a TRL PA probe (figure 5).

Figure 4

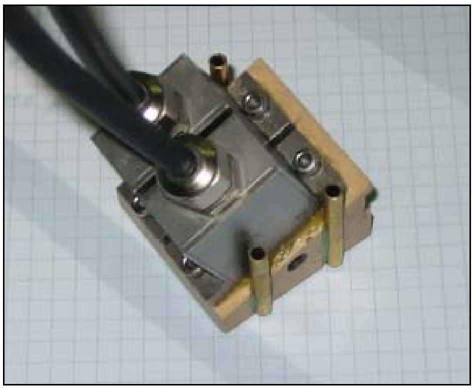


Figure 5

Beam generation

Depending on the examination configuration (weld type, material, thickness, etc…) an examination strategy is defined in the scan plan. The scan plan describes the necessary angle beams and skews to use during the examination. The angle beams are generated by applying a specific delay on each element of the phased array probe. A set of such delays is called a law. These laws are calculated by means of the Advanced Phased Array Calculator, software that can generate law files directly to be used by the Omniscan acquisition system. A graphical representation of such a law is shown in figure 6 for the transmitter module, the resulting angle and focal point is shown in figure 7.

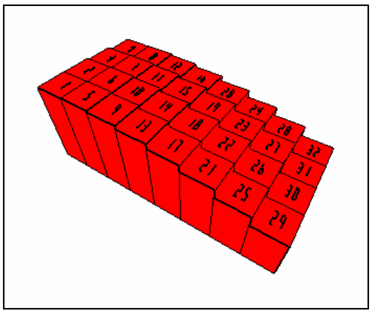


Figure 6: law graph

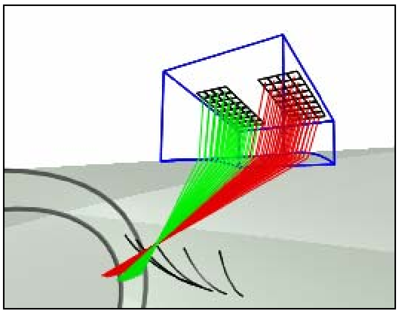
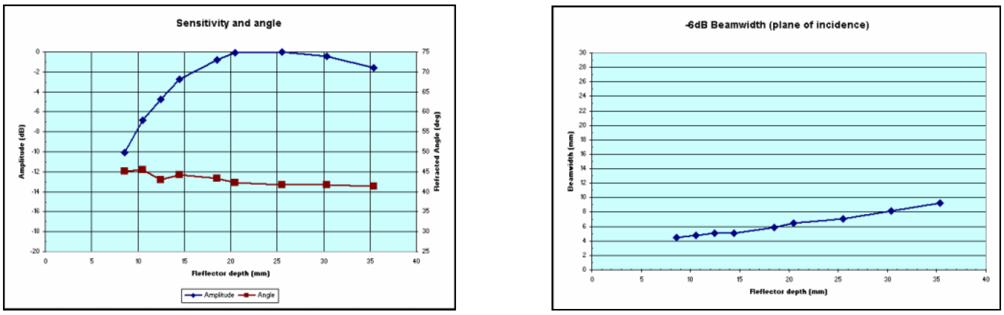


Figure 7: angle and focal point

Beam verification

The characteristics of the various beams that are generated for a specific examination configuration by the phased array system are measured on carbon steel reference blocks fitted with side-drilled holes (SDH). The resulting data shows for each beam, processed like an individual virtual probe, the following:

- The operational parameters (angle, exit point and internal delay),
- The beam characteristics like focal point depth, beam diameter at focal point, -6dB depth range (example shown in figures 8a and 8b).



Figures 8a and 8b: beam characteristics graphs

Beam deformation

As the surfaces of the components to be examined are often far from ideal, a simulation of the beam deformation caused by a gap between wedge and examination surface was studied. To get an idea how the beam would change, these simulations were done using a surface irregularity idealized as a portion of a circle. The gap between wedge and surface, filled with couplant, will alter the beam characteristics. Various simulations were done, like having a flat wedge on concave or convex component surface irregularities.

Figure 9 shows the resulting calculated beams for a TRL PA 45° 1MHz with 54x54mm flat footprint on concave gap ranging from 0 to 2.5 mm.

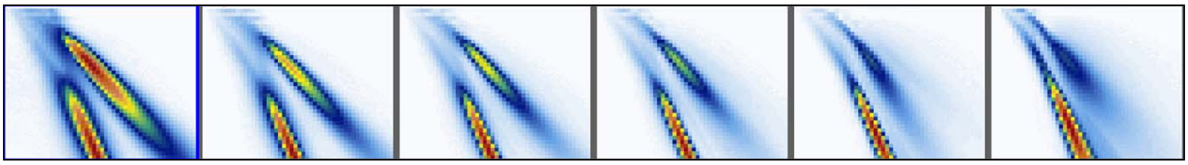


Figure 9: Beam deformation with increasing gap between wedge and surface

The results of the simulations showed also that with the use of TRL PA probes, one could adjust the law aimed at generating the beam, taking into account the known profile to compensate for eventual surface irregularities that alters the beam shape.

Scanning pattern

The conventional multi-probe ultrasonic examination is used with a scanning pattern in which the probes are moving towards the weld and back again while incrementing the circumferential position to fully insonify the examination volume. This scan type is in most cases time consuming. By using phased array probes, generating multiple angles, the scanning pattern can be in such a way that the examination time is reduced in a significant way. Scanning is performed by moving the PA probe along the weld while the beam is directed towards the weld and the increment is perpendicular to the weld centre line. As multiple angles are used together, the measurements of flaw indications can be done for the three directions: along the weld, across the weld and in through depth. Figure 10 shows an example of a one-line acquisition with a TRL PA probe on each side of a 25 mm thick, 9-Nickel base material welded plate. The SDH are clearly detected and can be positioned in the three directions.

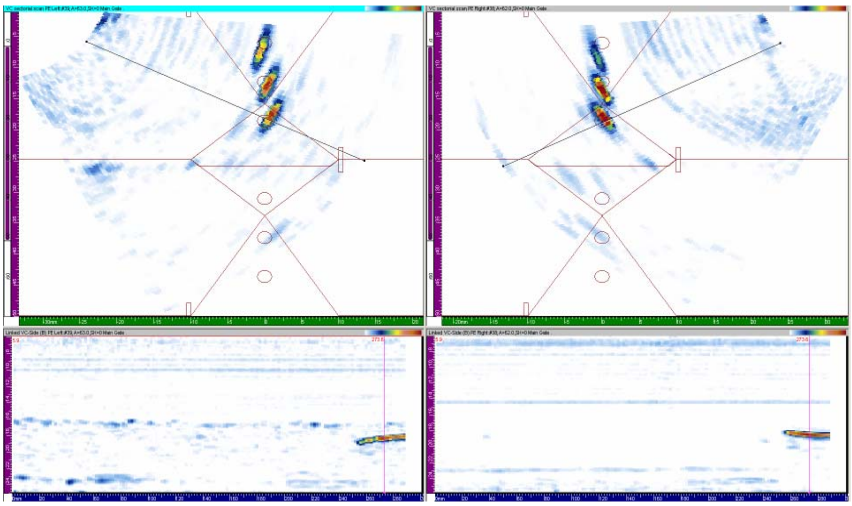


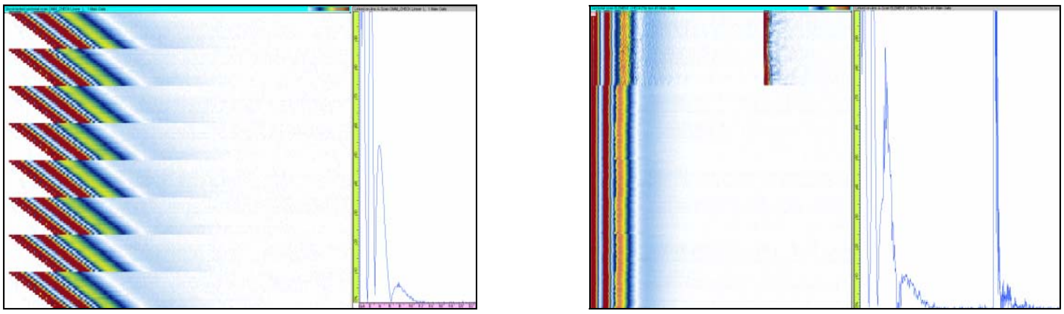
Figure 10: image of one-line scan with TRL PA probes

Quality assessment

The change of probes and equipment technology in existing procedures required some modifications and review of the quality assurance plan. Omniscan phased array equipments are verified for proper working pulser-receiver functions. As these have 128 pulsers, a quick GO/NO-GO way had to be found. This is done by a graphical user interface from the acquisition system whereby the operator can see whether the pulsers are working properly and the delays are applied correctly. In a similar way the elements of all phased array probes to be used are verified (figure 11a and 11b).

The phased array acquisition system is verified for accuracy and linearity of time base and amplification.

The phased array probe assembly is verified on a reference block in order to determine the operational parameters (angle, exit point and internal delay) and the time of flight and amplitude initial reference values of the used laws. A number of specific laws (beams) are then verified on site, on the reference reflectors, before and after the examinations.



Figures 11a and 11b: equipment and element check

Procedure and test results

A generic procedure for examination of main coolant piping and pressuriser welds was written and tested on reference blocks and representative welded specimens containing machined and real flaws. Among the test specimens was a 6" diameter, 18mm thick wrought to wrought stainless steel weld, a 14" diameter, 50mm thick dissimilar metal weld and a 32" diameter, 60mm thick cast stainless steel weld. A specific scan plan is drawn for every configuration type. This scan plan describes the probe(s) to apply, the angles necessary to insonify the required volume, the focal depth for these angles, probe orientation and scanning pattern details.

The examination is split in a detection phase and a sizing phase. During the detection phase the TRL PA probe (figure 12) is moved along the weld with a resolution of 2 mm while the increment perpendicular to the weld is 5 mm. Wherever applicable an additional share wave angle probe is added.

The detection phase during the tests showed to be very effective. The results of detection capability and signal to noise ratio (SNR) were compared with results from previous procedures. An equal or better detection was achieved in a considerable lesser time, f.e. a single side access detection scan on a 32", 60mm thick specimen takes about 30 minutes where the previous system needed about 4 hours. An overall increase of SNR was observed which is mostly due to the use of piezocomposite elements.

The sizing phase, only performed in case of detection of a suspected indication, is similar to the conventional raster scan mentioned earlier. However the length and the height of flaws are already approximatively determinable, a sizing scan has been proved to be necessary as it contains the fully echo dynamic of the flaw response for all the applied angles. The use of a large diversity of angles increases the ability to discriminate and characterize flaw indications.

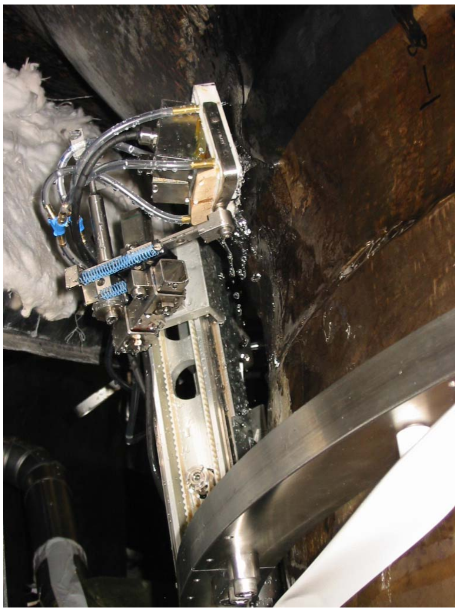


Figure 12: TRL PA probe on MCP weld

Applications

This procedure has been already successfully applied in Belgian nuclear power plants on main coolant piping welds (cast elbow to safe end welds, safe end to steam generator dissimilar metal welds) and pressuriser welds (dissimilar metal weld on discharge line).

A procedure was written for the examination of homogeneous wrought stainless steel welds on piping systems with diameters of 6”, 8” and 10” having thicknesses of 18 and 30 mm. Both, procedure and personnel, were recently (April 2006) successfully qualified at the Kernkraftwerk Beznau, Switzerland.

Conclusion

As in the past, the development of TRL transducers led to the development of procedures for the examination of stainless steel welds, the current development of TRL PA probes led to the development of procedures based on the phased array technology. Although the higher cost for phased array probes, their flexibility and versatility in a various number of applications compensates for it. The information presented in this paper showed that the use of TRL PA probes in conjunction of specific procedures and work instructions, applied by qualified personnel, increases considerably the performances of the ultrasonic examination of austenitic stainless steel welds.