Ultrasonic Investigations on Copper Canister Welds in Preparation for the Storage of Spent Nuclear Fuel in a Deep Repository

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Abstract. The Swedish KBS-3 design for the disposal of spent fuel is based on its encapsulation cast iron cylinders that have an outer 30 – 50 mm thick shield of copper and deposition in crystalline rock embedded in bentonite at a depth of about 500 m.

The KBS-3 system is based on a multi barrier system where the canister is the primary barrier. The cast iron insert gives the canister the necessary strength and the outer shell that gives corrosion protection is made of oxygen free copper.

SKB's efforts are based on a stepwise program for the implementation of deep geological disposal of spent fuel including concurrent activities in the areas of deep repository- and encapsulation technology. Major milestones in the program are application for construction and building of an encapsulation plant at 2006 and a deep repository at 2008. According to the program initial operation for the system will start at 2017.

The critical part of the encapsulation of spent fuel is the sealing of the canister which is done by welding the copper lid to the cylindrical part of the canister. Two welding techniques have been developed in parallel, Electron Beam Welding (EBW) and Friction Stir Welding (FSW). Mid 2005 SKB decided that FSW is the preferred sealing technique.

Determining the reliability of non-destructive testing (NDT) for FSW and EBW welds were investigated by BAM during 2004–2005. Since the welding methods are based on different principles, the NDT methods that were developed by SKB were tailored to the particular welding methods. The aim of the investigations were to determine the reliability of the NDT in terms of probability of detection (POD) and size estimation accuracy for the various kinds of discontinuities that could occur.

Ultrasonic investigations were executed as one reference measurement during the validation of the inspection procedures developed by SKB. Results were presented as C- Scans in order to show the extension of different discontinuities in the welds. The applied sound-fields of the used phased- array- equipment were determined by means of modelling calculations. Echo heights for different reflector geometries were calculated for comparison with measured data or for the generation of POD curves within a second working group.

1. Measurements on ring segments with FSW discontinuities

The detection of weld discontinuities by the SKB (Swedish Nuclear Fuel and Waste Management Co) using ultrasonic testing techniques has been quantitatively determined by automated ultrasonic reference measurements performed at BAM.

The investigated copper specimens have the same geometric dimensions and weld types (electron beam/ friction stir welds) as the original lid. Wall thickness was 60 mm. Measurements were performed using through transmission in immersion and direct coupling techniques using pulse-echo. Figure 1 and 2 illustrate schematically both techniques for a copper ring segment with a friction stir weld. It contains typical weld discontinuities, which may even occur under carefully controlled process conditions.

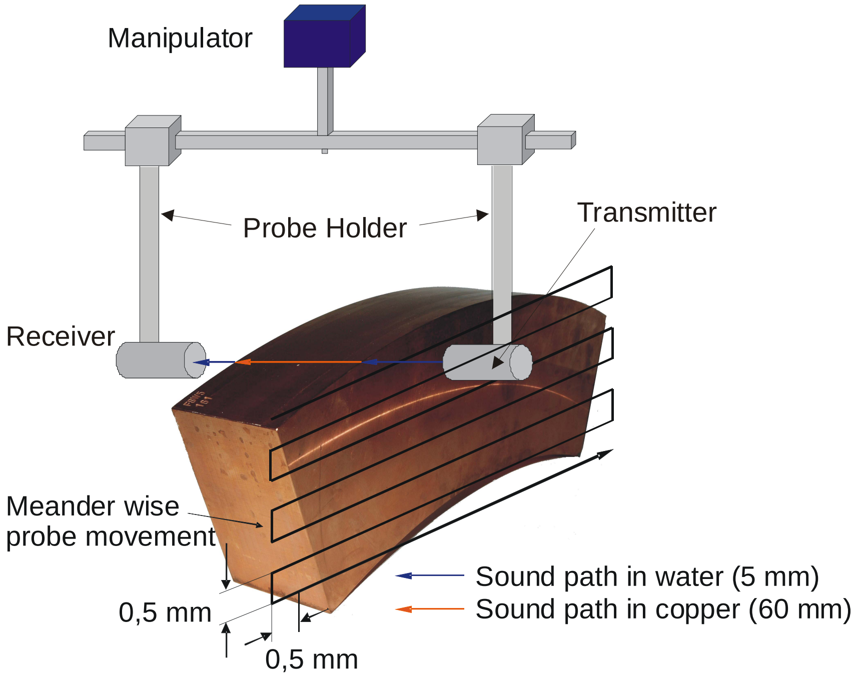


Figure 1. Measurement on ring segment with FSW discontinuities in transmission technique

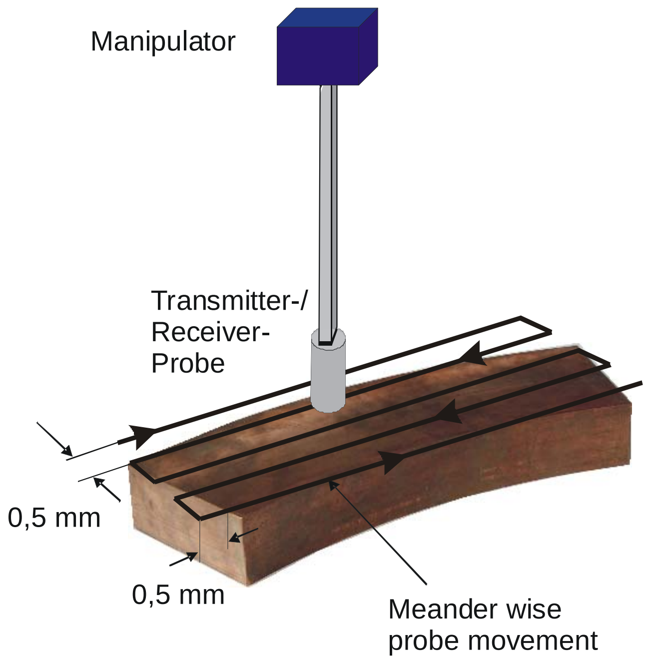


Figure 2. Measurement on ring segment with FSW discontinuities in pulse-echo-technique

Figure 3 and 4 show one measurement result as example for each of the two techniques. Both measurements were carried out using the same specimen. The measured data is represented by C-scans. The slit between the canisters lid and tube can be better recognised in transmission technique, whereas the detection of some smaller discontinuities is the advantage of the pulse- echo- technique.

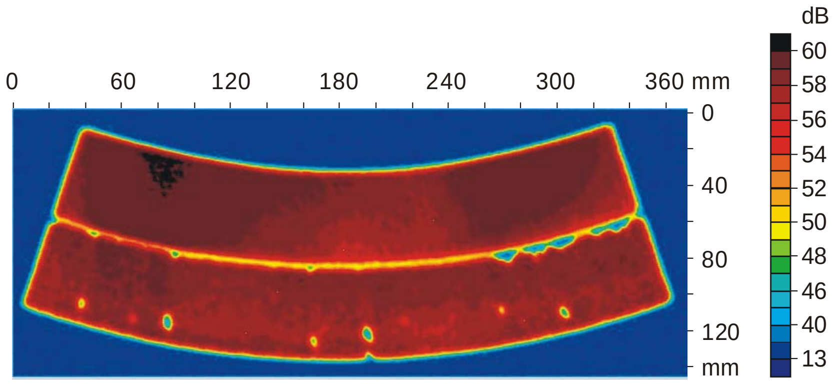


Figure 3. C-Scan measured in transmission technique

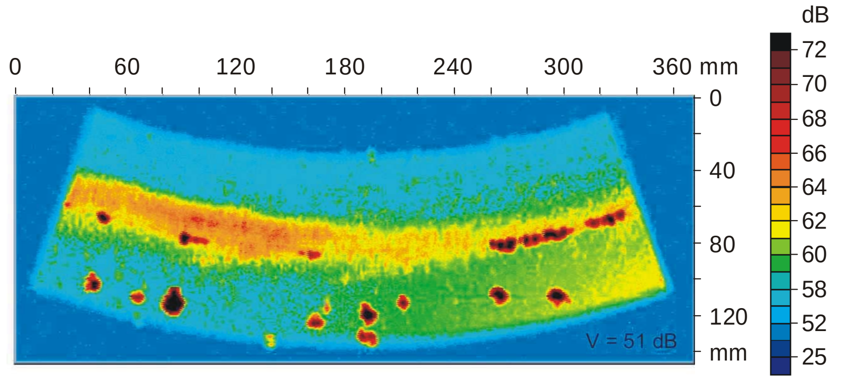
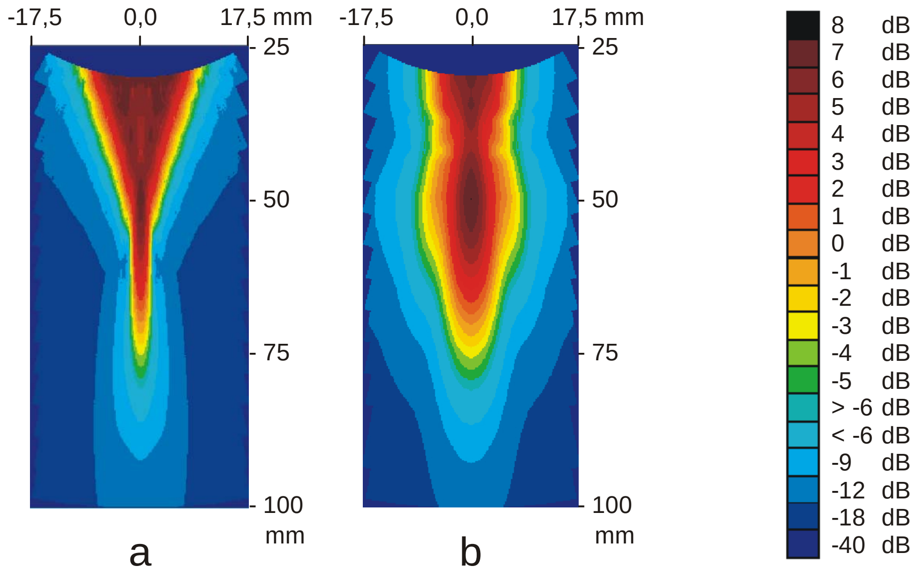


Figure 4. C-Scan measured in pulse-echo-technique

2. Sound field evaluation and model calculations

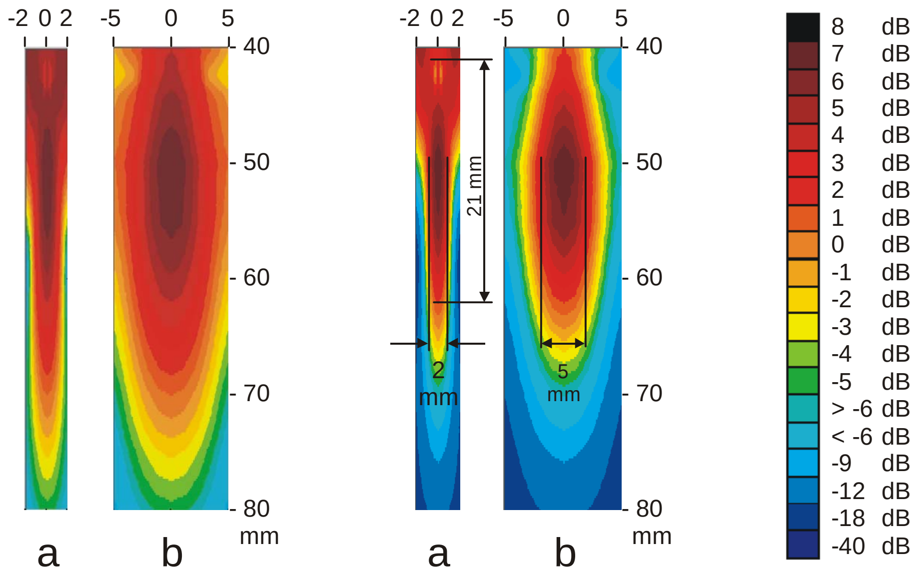
A second topic within the R&D- project was the evaluation of the sound fields which were generated by the phased array probe used by SKB.
Therefore the sound field for each of the applied incidence angles (0°, ±10°, ±20°) was simulated with a computer model developed by BAM ([1],[2],[3],[4],[5]). The calculated area was a quadratic area of 35x35 mm² around the sound field axis at distances from 25 and up to 100 mm from the transducer.
Figure 5 shows cross-sections of the sound field presentation for an incidence angle of 0°. On the left side of figure 5 one can see the cross-section within the plane of incidence, where the sound-field is focused. The right side in figure 5 shows the unfocused plane in the sound-field.



a: in plane of incidence b: perpendicular to plane of incidence

Figure 5. Sound field presentation

Figure 6 shows a smaller part of the sound-field around the focus area. In the presentation of the echo height distribution one can evaluate the focus size (2x5 mm²) of the sound field.



a: in plane of incidence b: perpendicular to plane of incidence

Figure 6. Left side: Sound field presentation; Right side: Echo height distribution

3. Theoretical echo height calculations

The simulated sound fields were used for echo height calculations based on different reflector geometries. This enabled comparison of echo heights for different artificial reflectors such as flat bottom holes, side drilled holes, rectangles and cylindrical reflectors with the results from SKB measured on the test specimens.
On the other hand simulations of real discontinuities occuring in the welds could also be considered. These calculations were necessary to improve physical understanding and to create POD (probability of detection) curves. The so called joint line hooking (JLH) discontinuity (see microsection in figure 7) was of a special interest concerning friction stir welds. Complex geometries can be divided into segments of simpler reflector geometries for modelling purposes in order to simulate a variety of defects. The joint- line- hooking discontinuity was described by a combination of curved and planar rectangle models (see figure 7).

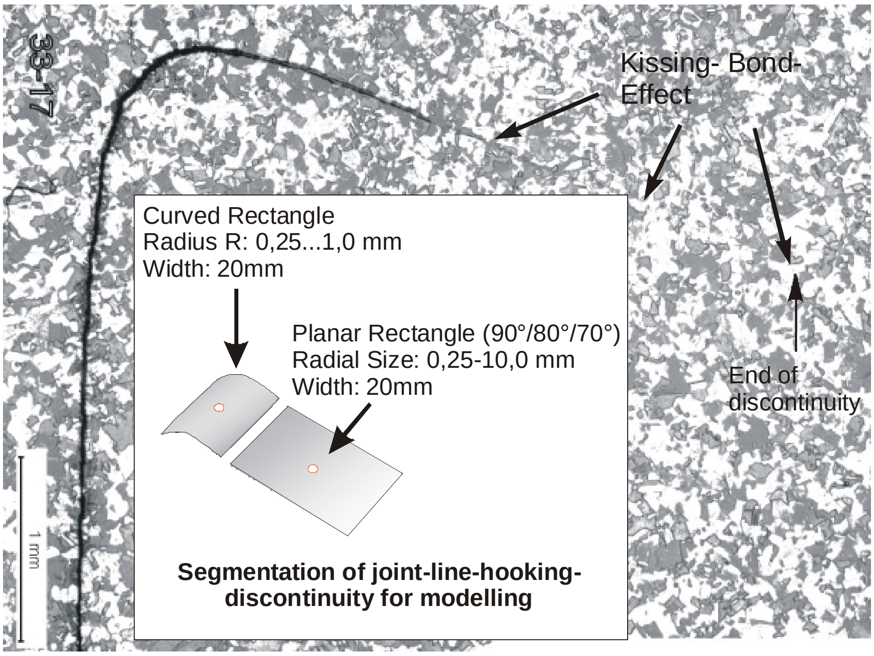


Figure 7. Microsection and theoretical description of the joint- line- hooking

Figures 8 and 9 illustrate calculated echo heights for different reflector types in relation to a 2 mm flat bottom hole used in practice by SKB to adjust sensitivity.
A comparison between measured and calculated echo heights is difficult because of unknown effects, e.g. kissing bond effect and physical or geometrical deviations from expected parameters.

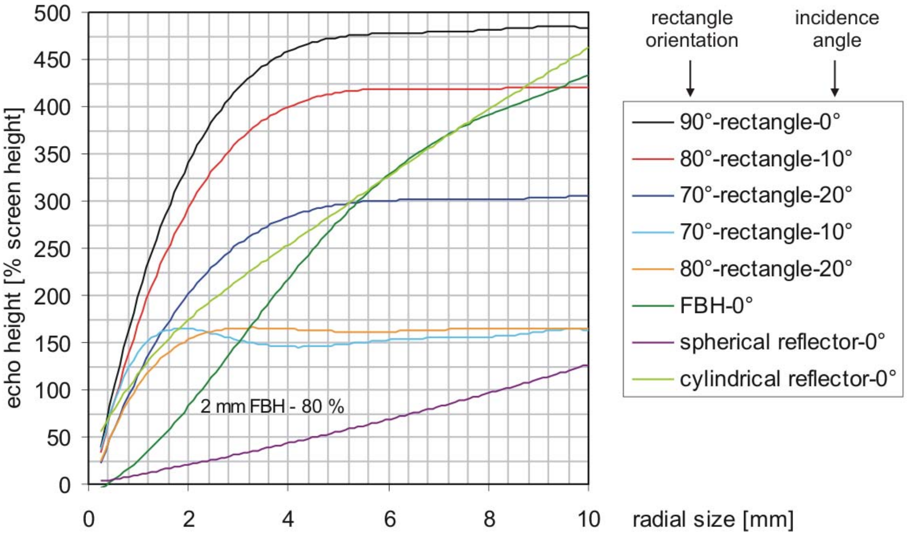


Figure 8. Results of echo height calculations for different reflector types

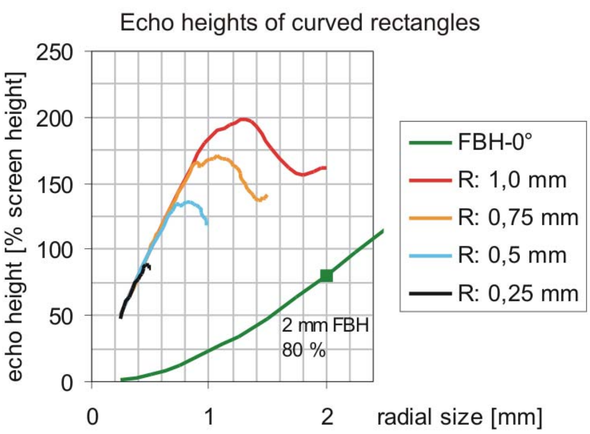


Figure 9. Results of echo height calculations for curved rectangles

References

[1] Erhard, Anton; Tscharntke, Dirk; Wüstenberg, Hermann: Ultraschallprüfung an Schweißnähten - Bewertung kritischer Befunde mit Modellrechnungen. In: Materialprüfung, 42(2000), H. 11-12, S. 433-436

[2] Boehm*, R.; Lohmann**, H.- P.; Becker**, E.; Schreiner**, T.: Vergleich von Messung und Modellierung am Beispiel der Ultraschallprüfung einer aufgeschrumpften Turbinen- Radscheibe. Vortrag DACH- Jahrestagung d. DGZfP, Berichtsband 63.1, Bamberg, 7. 9.9.1998, S.59-71, *BAM Berlin, **Siemens AG Mühlheim

[3] Boehm, Rainer; Erhard, Anton; Schulz, Eduard; Wüstenberg, Hermann: Winkelspiegel- und Rissspitzenecho in Abhängigkeit von der Reflektororientierung: Ein Vergleich von Messung und Modellrechnung in TD- Bilddarstellung. Vortrag DACH- Jahrestagung d. DGZfP, Berichtsband 52.2, Lindau, 13.-15.05.1996, S.568f

[4] Möhrle, Walter; Wüstenberg, Hermann: Erfahrungen mit theoretischen Modellen für Schallfeld- und Impulsverhalten beim Bau von Sonderprüfköpfen für die Ultraschallprüfung. Vortrag DACH-Jahrestagung d. DGZfP, Berichtsband 28, Luzern, 06.-08.05.1991, S.204-215

[5] Boehm, Rainer; Erhard, Anton; Wüstenberg, Hermann: Darstellung des Entwicklungsstandes des schnellen, halbanalytischen Modells (FSAM) für die US- Prüfung anhand von Beispielen. Vortrag DACH- Jahrestagung d. DGZfP, Berichtsband 68, Band 1, Celle, 10.-12.05.1999, S. 317-323