Ultrasonic Flaw Detection across a Water Gap

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Abstract. Crack detection in the region of the weld root for control rod nozzles installed in the reactor pressure vessel cap, is difficult due to limited accessibility. For ultrasonic testing, probe coupling is possible only at the inner surface of the engine rod guide tube. There is a water gap of 2 to 3 mm between guide tube and control rod nozzle.

Investigations were preformed to determine ultrasonic inspection parameters best suited to crack detection across a water gap. Measurements across a water gap were carried out on planar, convex and concave surfaces specimens. Test reflectors (spark eroded notches) were introduced at different depths for the respective specimen. The notches had different positions and orientations in relation to the weld.

After detection of test reflectors, sizing tolerances were reviewed. Measurement data were post processed by means of reconstruction technique using SAFT. Measurement and analysis results are presented.

Introduction

Starting point for investigations relates to the question of feasibility concerning crack detection at the weld root region of control rod nozzles installed at the reactor pressure vessel cap. The schematic design of a control rod nozzle is shown in Fig. 1.

The nozzle can be accessed by probes guided by a manipulator from the inside of the engine bar guidance tube. Accessibility is made difficult by the fact that the probe has to be coupled on the inside of the engine bar guidance tube Futhermore a 2 to 3 mm wide water gap exists between the engine bar guidance tube and the control rod nozzle.

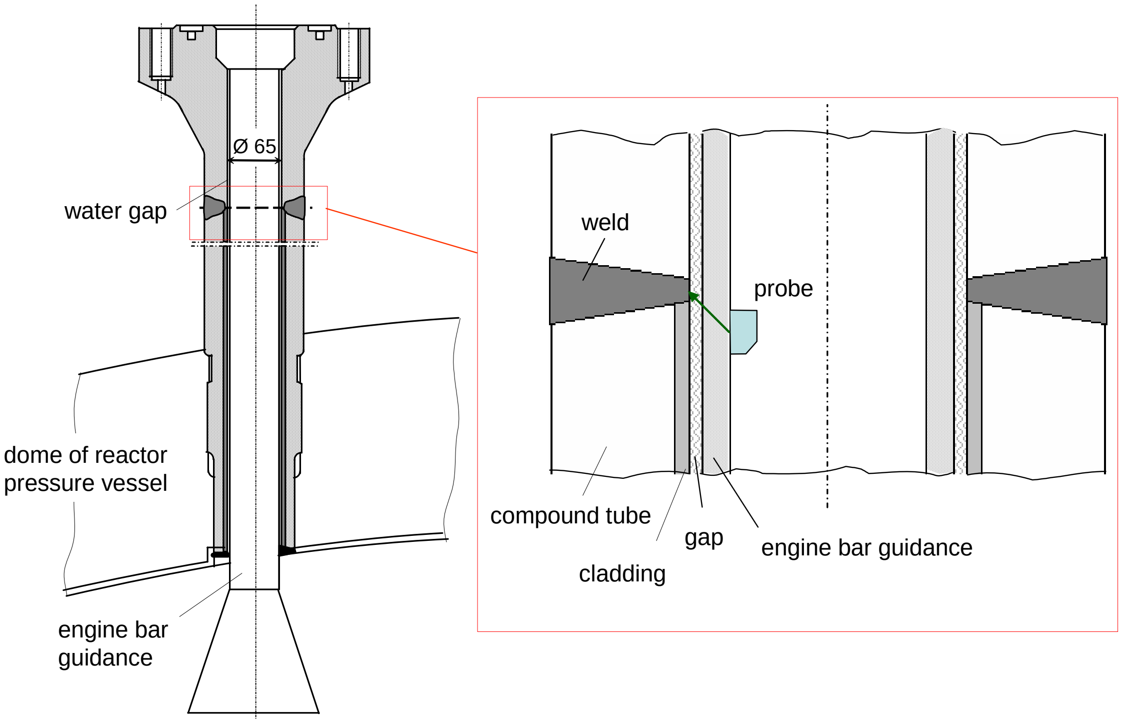


Fig. 1 Schematic cross section of a control rod nozzle

In order to detect cracks at the weld root of the control rod nozzles when probe coupling takes place at the inner surface of the engine bar guidance tube, ultrasonic waves will have to propogate through the tube wall and the water gap. Tube wall and water gap represent two thin layers, which produce a lot of reverberant ultrasonic echoes especially in the case of oblique angle scanning. [1]

One issue of the investigations was to optimize inspection parameter for crack detection across a water gap.
Further evaluations of measurement results have been performed to review whether sizing of flaws is possible in spite of the water gap.

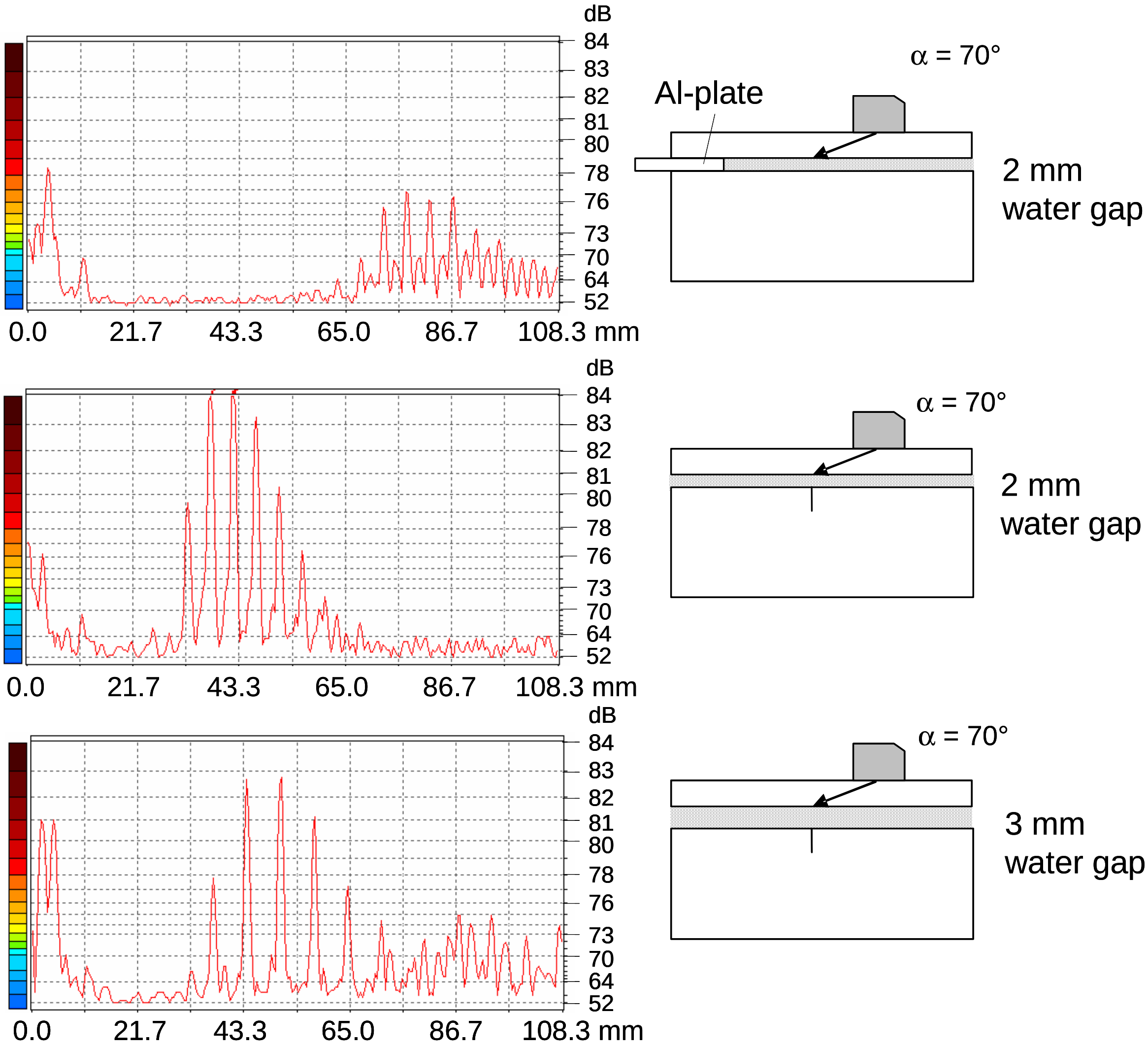


Fig. 2 A-scans of preliminary investigations

2. Measurement results

Some measurement results of preliminary investigations are shown in Fig. 2.
A probe with a beam angle of 70° for shear waves and a test frequency of 4 MHz is coupled on a metal sheet with a thickness of 5 mm. The sheet is positioned in water at a distance of 2 mm to a test block. In the A-scan some echo indications are observed.
These indications may arise from reflections on the metal plate at the end of the water gap or by reflections at a notch positioned in the metal surface under the water gap.
This notch positioned in the metal surface beneath the water gap generates a hedgehog formed echo sequence produced by sound beam deflections in the water gap and by reflections at the notch. The high number of multiple echo indications is created by diffractions at the water interface and by the small width of the water gap.
An increase in the water gap from 2 to 3 mm produces a greater distance between adjacent peaks in the echo indication sequence.

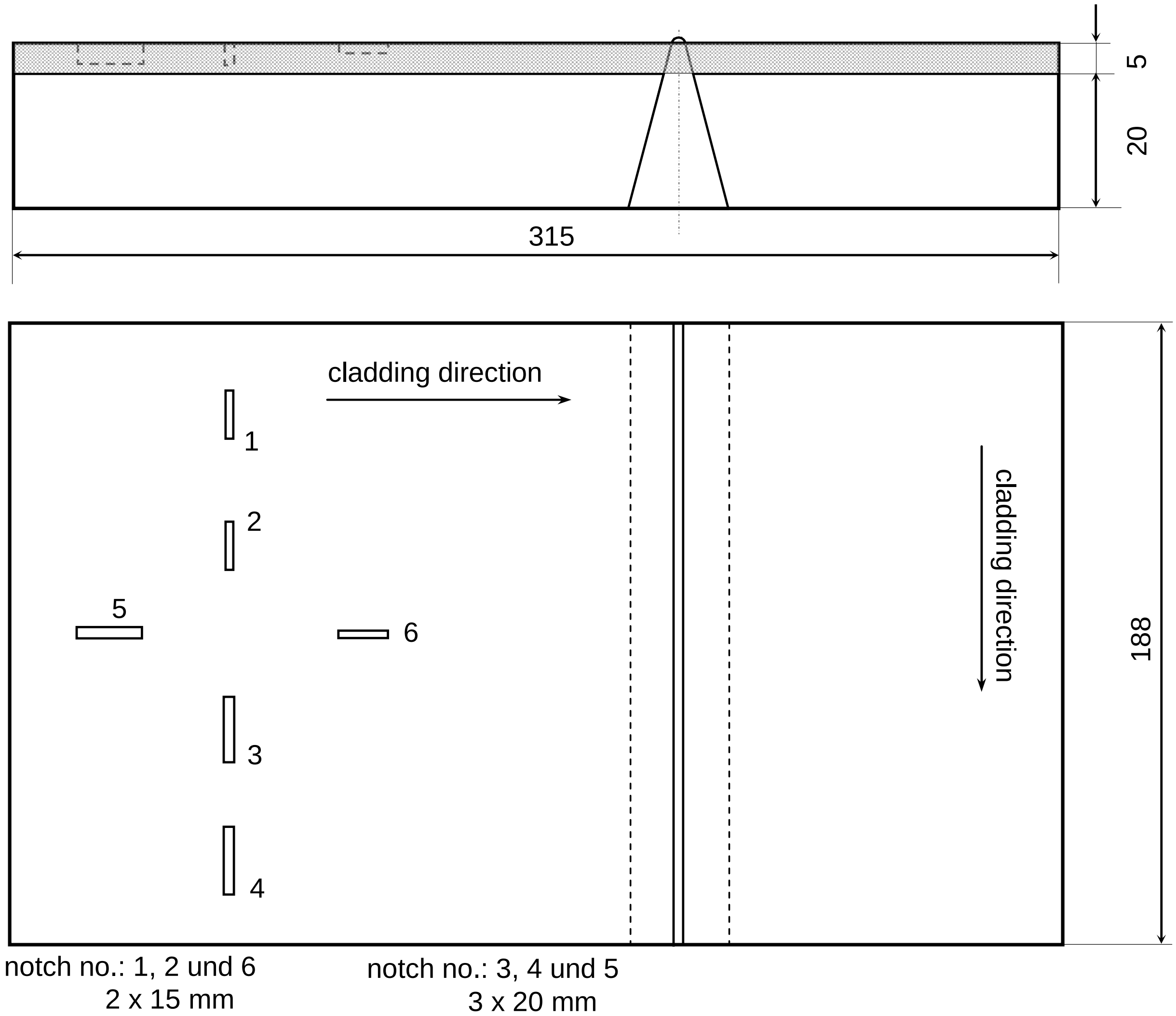


Fig. 3 Test block with notches in the cladding

Preliminary investigations have been executed on a flat cladded test block with a thickness of 25 mm. A schematic illustration of the test specimen is illustrated in Fig. 3. The test specimen has a cladding thickness of 5 mm.

The test block in the cladding shows spark eroded notches with depths of 2 and 3 mm. The notches have transverse and longitudinal orientations in relation to the cladding direction. The notches could have been detected by using a 70° angle beam probe (test frequency 2,25 MHz) when the probe directly coupled on the test block and when the probe coupled on a thin metal sheet positioned in a distance of 2 mm above the test block where the spacing is filled with water.

Fig. 4 represents measurement results for detection of notches with transverse orientation in relation to the cladding direction.

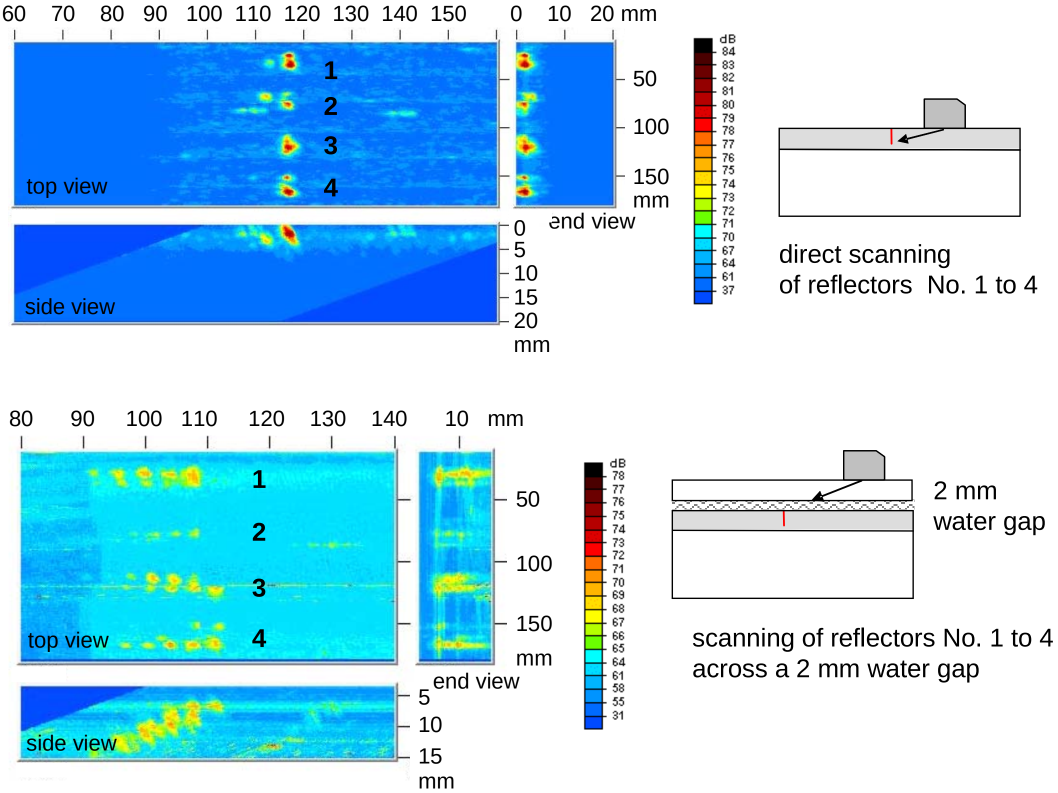


Fig. 4 Detection of reflectors No.1 to 4

Further investigations were executed on a weld in a tube segment from Inconel 625. (The wall thickness is 17 mm and the radius of curvature is 315 mm.) Positions of test reflectors and arrangement of water gap and covering metal sheet are schematically shown in Fig. 5.

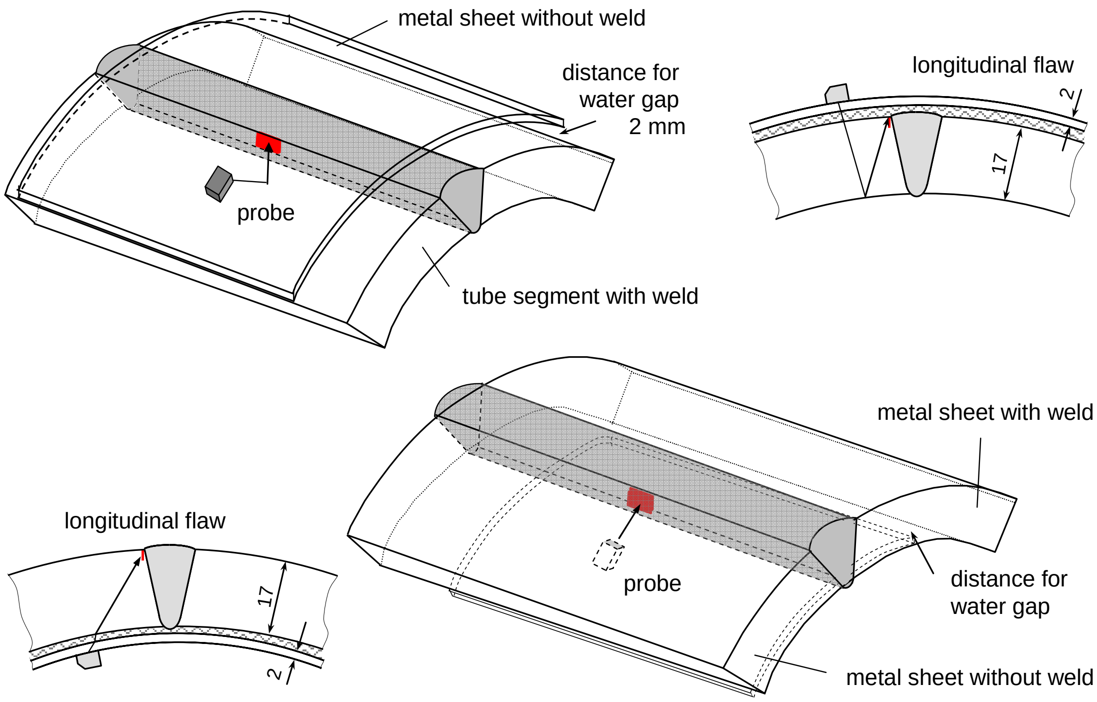
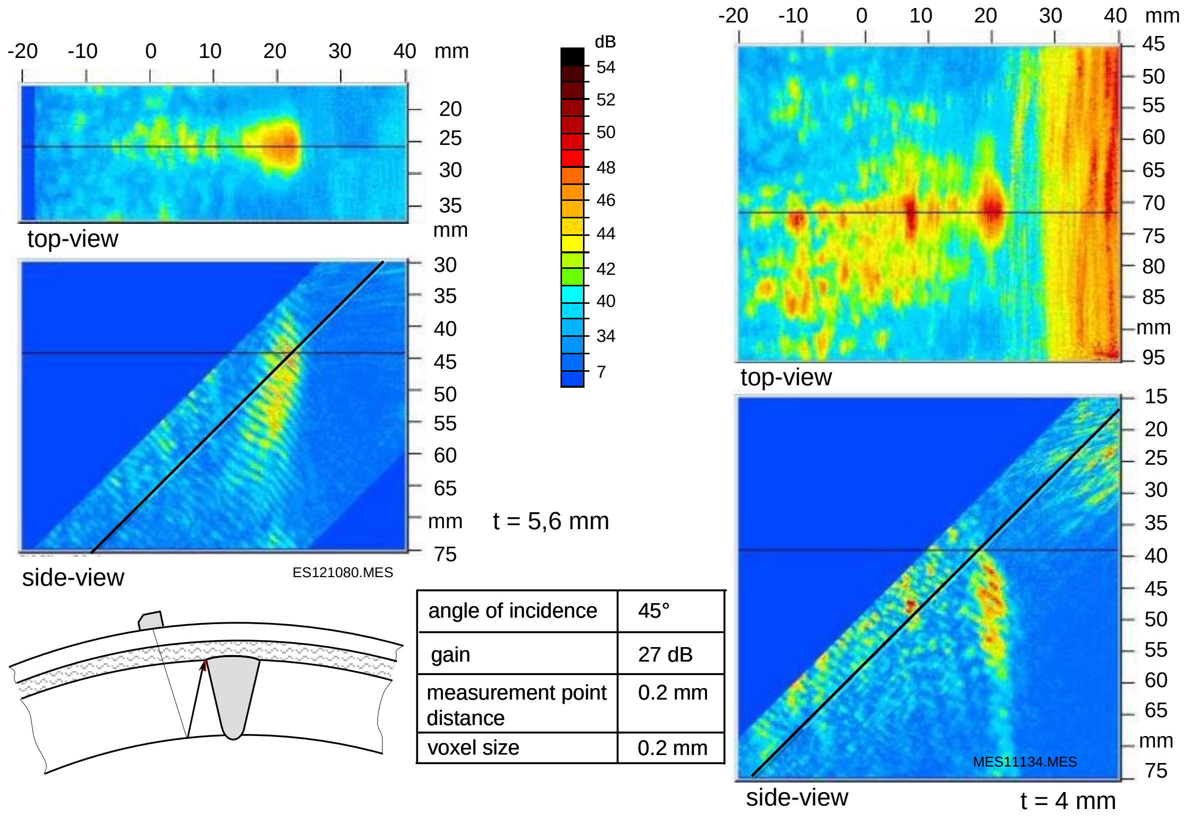


Fig. 5 Arrangement for flaw detection across a water gap at a convex surface and at a concave surface

Measurements were executed on the convex and concave shaped surfaces.

In both cases angle beam probes were directly coupled on the curved surfaces and on a metal sheet showing an adapted curved surface in relation to the ring segment. In the case where the probes are coupled on the adapted metal sheeting a water gap will exist between sheet and ring segment (Fig.5).



angle of incidence	45°
gain	27 dB
measurement point distance	0.2 mm
voxel size	0.2 mm

Fig. 6 Longitudinal flaw detection across a water gap at a convex surface

In the case of convex curvature a longitudinal flaw near to the weld and also close to the surface may be detected across a water gap with a 45° angle beam probe as shown in Fig.6. Even if the flaw is positioned near to the weld root and the sound beam has to cross the full half skip distance a longitudinal flaw detection across a water gap may be realised at a concave surface with a 70° angle beam probe (see Fig. 7). A transverse flaw may be detected in the weld even when there is a water gap between metal sheet and weld root and the probe is coupled on the metal sheet.

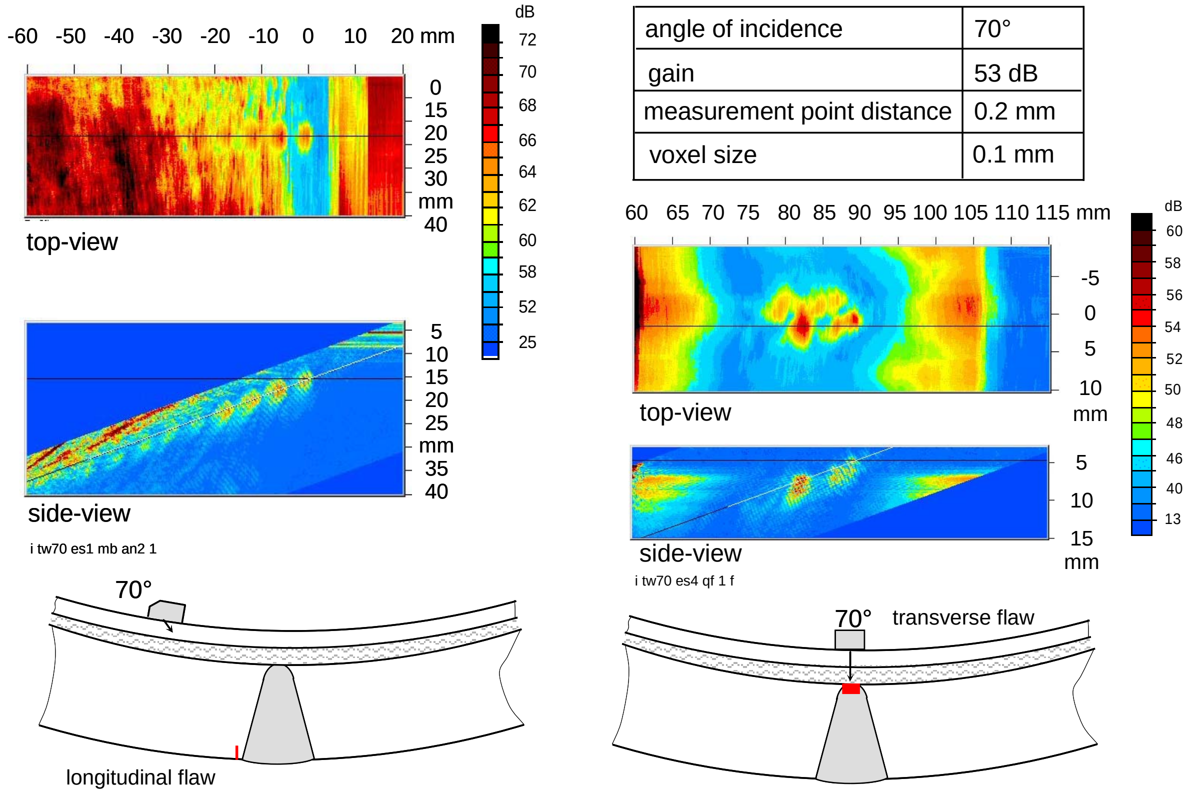


Fig. 7 Longitudinal and transverse flaw detection across a water gap at a concave surface

3. Analysis of measurement results

For sizing of test reflectors analysis procedures have been tested using the Synthetic Aperture Focussing Technique (SAFT). For application of this technique a measurement performance has to be performed taking into consideration special scanning conditions. Only small distances between adjacent measurement points and adjacent scanning tracks are permitted which means that the distance can only be a small fraction of the wavelength used. The measured and stored A-scans have to be RF A-scans to get phase informations of detected reflector indications. Since the angle dependent correlation within the sound beam is unknown registered echo amplitudes in each A-scan will be recorded in a time of flight dependent manner into the pixels within the sound beam aperture. As result a circle like broadening of echo amplitudes will be received. At all positions circles of same time of flights produce phase correct superpositions of echo amplitudes. At reflector positions high echo amplitudes are produced. The defect indication may be distinguished the better from the background the higher the number of hits may be counted. Here the number of measurement points per unit length is decisive.
In Fig. 8 the echo indications from a 4 mm deep notch are shown in RF-representation for transverse waves. For sizing measurement results from the convex and concave surface were used. Measurements were analyzed by submitting measurement data to a SAFT reconstruction. The distance between adjacent measurement points was 0.1 mm and the wavelength was 1.4 mm at a test frequency of 2.25 MHz.

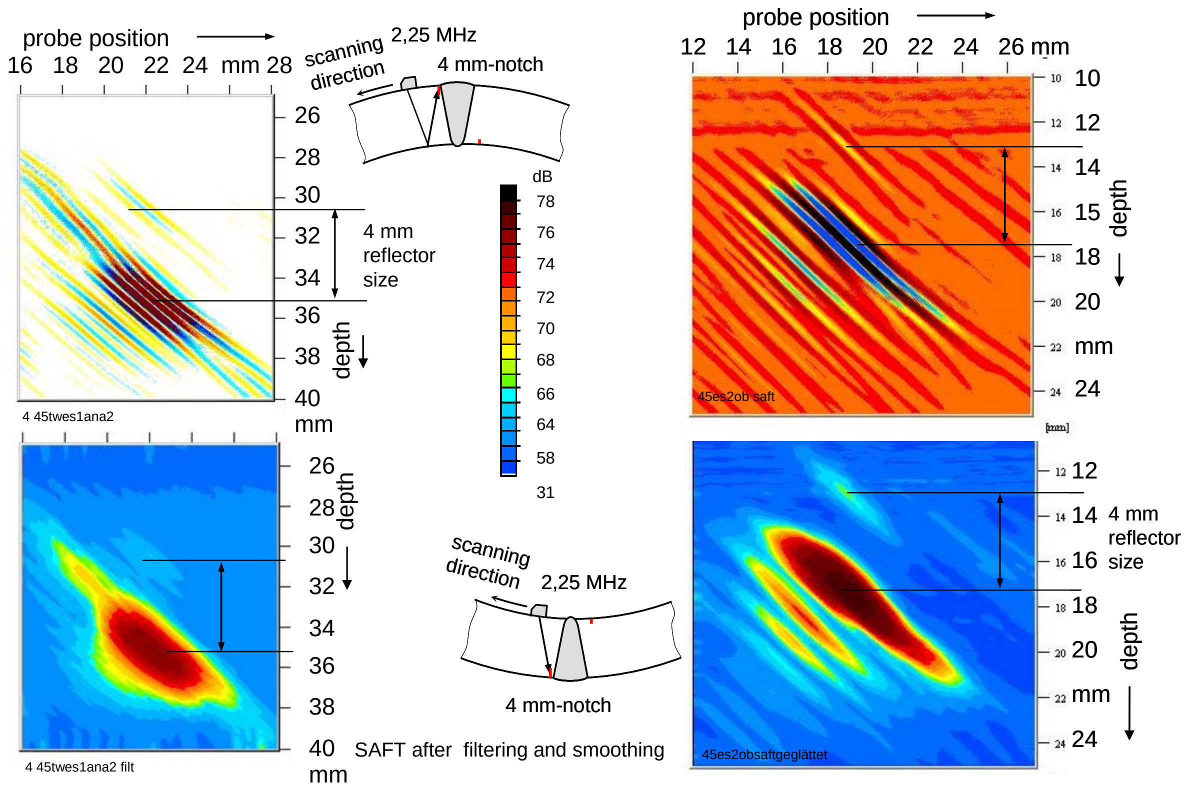


Fig. 8 Sizing using a SAFT reconstruction based on a measurement without a water gap

The crack tip indication and the indication of the corner effect can be used to analyze the depth of the detected notch.

4. Summary

Measurement results were presented for flaw detection across a water gap for convex and concave surface curvatures. A 45° angle beam probe transmitting and receiving shear waves with a frequency of 2.25 MHz was used to detect artificial flaws for both surfaces. In the absence of a water gap a 45° angle beam probe can also be used for sizing by means of SAFT reconstruction. In the case of a flaw close to a concave surface a 70° angle beam probe delivers good inspection results even across a water gap.
It was shown that longitudinal and transverse flaws at the inner and outer curved surface of a control rod nozzle may be detected across a water gap.
With regard to the applicability of SAFT reconstruction for determination of flaw size an optimization of inspection parameters is necessary in order to adapt specific testing conditions.

References

[1] D.T. Nagle, J. Saniie; Analysis of oblique angle scanning in the imaging of multilayered targets; Acoustical Imaging Vol.16 (1988) 73-84