# Ultrasonic Testing of Railway Axles from a Borehole in Axial Direction

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**Abstract**: An ultrasonic phased array technique was developed for the detection of surface breaking cracks on railway axles containing a small bore hole in axial direction. Modelling calculations were used to get appropriate probe parameters for coupling on the concave curved inner surface. Influence of different probe parameters on sound field propagation and on sound field sensitivity in relation to crack detection will be shown. The phased array probe was built as prototype. A mechanical probe guide was developed to introduce the phased array probe into the borehole and to manipulate the probe to detect cracks in circumferential direction to the outer axle surface. The measurement data are used for reconstruction of the image and the results are presented as echo tomograms showing flaw positions on the outer circumference of the axle.

## Introduction

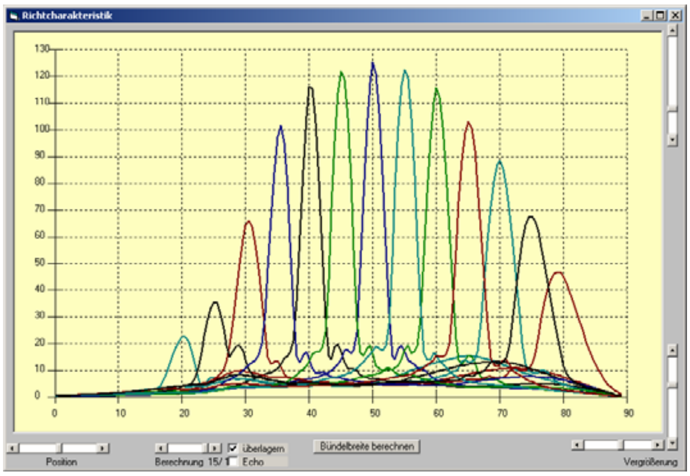
A phased array probe was developed for the detection of flaws on the outer axle surface of trains. The challenge was to develop a technique, which can be employed during maintenance or in-service checks without dismantling the axle. This can only be achieved through the borehole. The probe was adapted to couple on the concave curved inner surface. The borehole has a diameter of 70 mm. This phased array probe should be able to detect cracks in circumferential direction, which may arise due to changes cross section diameters.

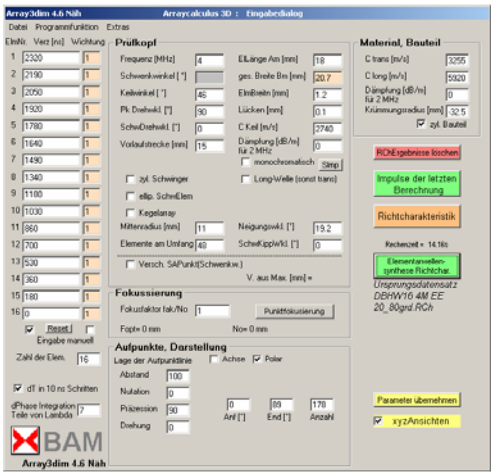
## Model calculations

The directivity was calculated in order to determine optimal design parameters for the phased array probe. To fulfil requirements the probe had to be built with 16 single elements and needed a large variety of beam angles (20°-80°) for adjustment. Calculated parameters und directivities are shown in Fig.1.

## Probe construction

With the calculated parameters the phased array probe was constructed using composite material. The Plexiglas (PMMA) wedge was aligned to the geometry of the borehole (Fig.2).



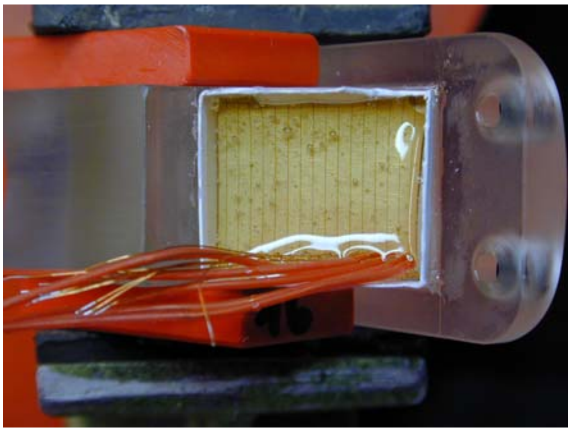




Phased array with 16 elements, 4 MHz trans.
Focus in a point of s = 100 mm and an angle of incidence from 20° to 80°

calculated directivity for coupling on the inner surface in the axle with bore hole (Ø 65 mm / Ø 70 mm).

Parameters for the calculation of directivity

Fig 1 Model calculation for dimensioning of phased array probe



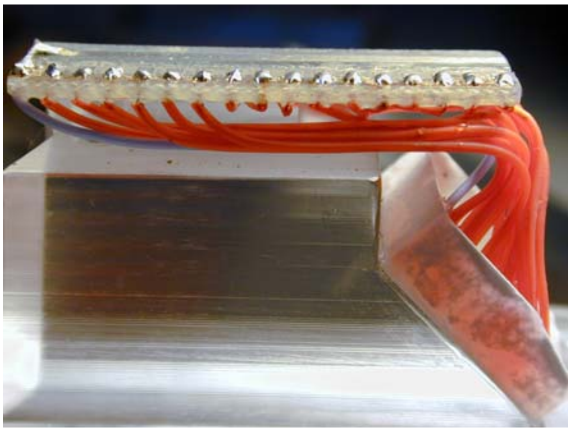


Fig 2 View on the phased array probe before housing

## The probe holder

In addition to the array, it was necessary to create a manipulation system, which allows us to insert the probe into the hole and to move it along a definite axis position. This must be possible for the two directions of incidence. To solve the problem a mechanical probe holder was realised, so that the probe can be moved forward and backward and also rotated in both circumferential directions. This movement is steered by a hand wheel at the end of the guiding rod (Fig.3). The signals of the 16 elements were transferred via a collector ring unit made by Columbus Contact Ltd. (Koblenz). Measured data is recorded in a separate box.

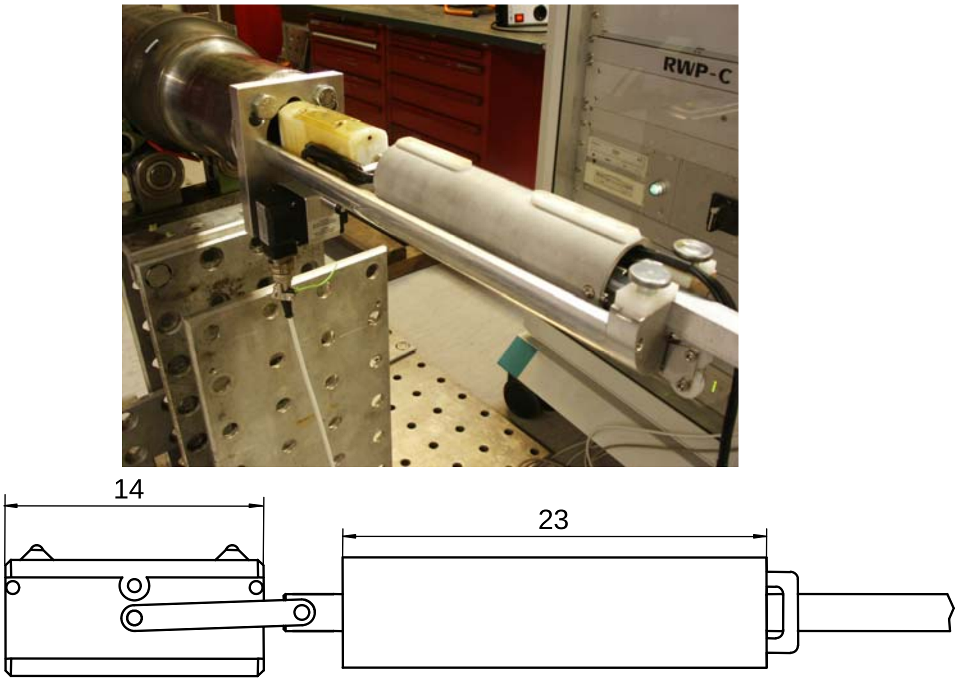



Fig 3 Two boxes for the probe and the collector ring unit

## Test assembly

For the measurements a phased array device from GE Inspection Technologies is used. Up to four phased array probes with 16 elements and operating at up to 8 MHz, can be connected at the device.
A typical axle with borehole such as used for the investigations is shown in Fig.4. On the outer surface sickle-shaped notches were prepared as shown at the marked positions. The notches have a depth of 2 mm.

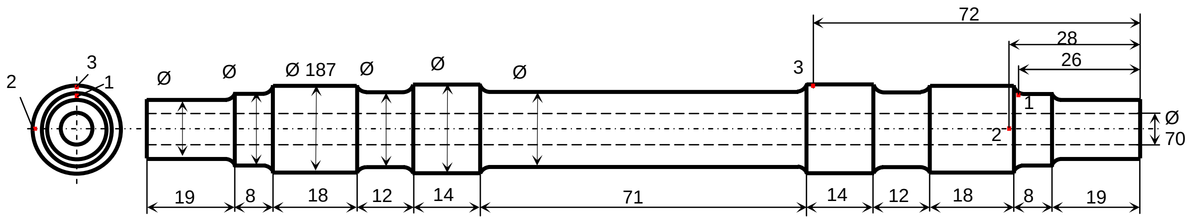



Fig 4 Red points mark notches in the axle with bore hole

## Data acquisition and analysis

Fig.5 shows the measuring system. The coupling medium was low viscosity oil. During an all-round scan of 360°, A-scans are recorded every 0.3°. The probe was positioned with the guiding rod. A position encoder sensor registered this position. The program “UTControl” was used for the data acquisition and “UTView” for the analysis. Tomograms are reconstructed from this data. Both software-programs have been developed at the BAM.


Fig 5 Measuring system for testing axles with bore holes using phased array technique

## Results

The reflectors numbered 1, 2 and 3 could be detected from both directions of incidence using incidence angles of 45° and 55°. The following pictures show the results of the measurements for both directions of incidence. The echo tomogram is shown on the left side and is reconstructed from single A-scans such as the A-Scan located on the right of the figure. The exact position is marked in the tomogram. Additional parameters employed are listed in the figure.
All notches are detected with a clear signal to noise ratio of more than 17 dB. Depending on the direction of incidence, form echoes from geometry changes of the cross section can be identified in the echo tomograms.

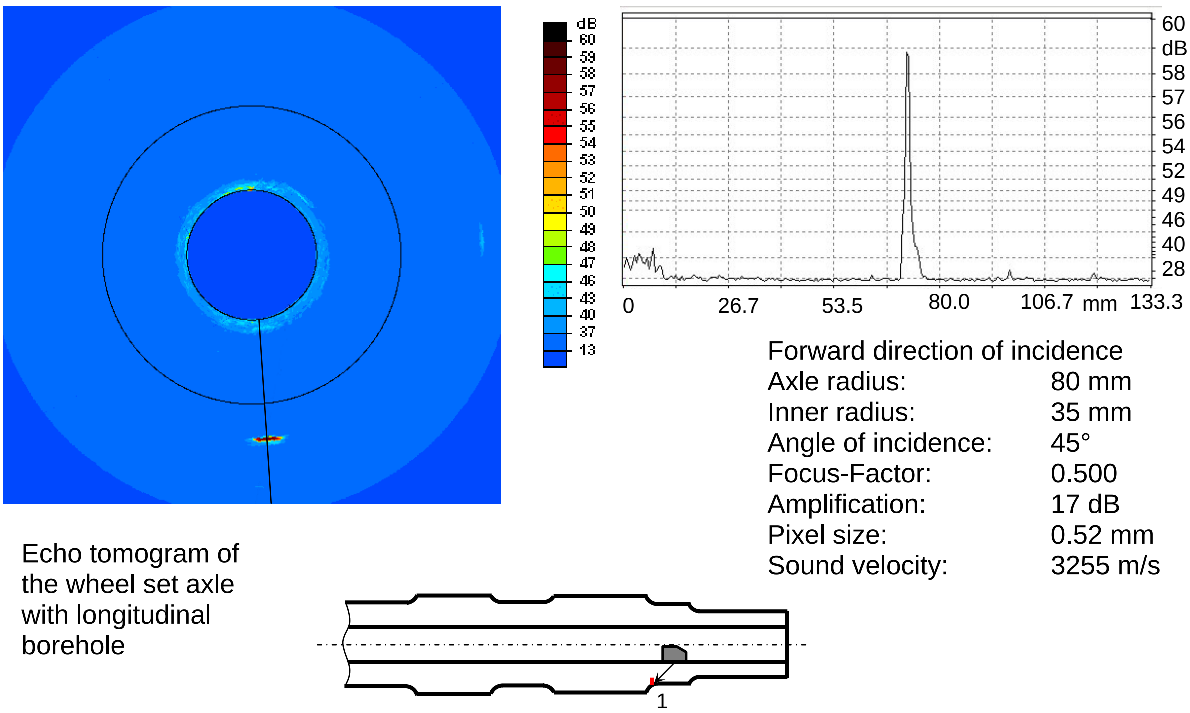
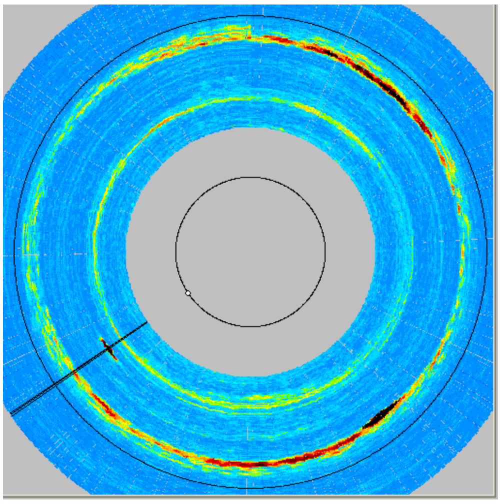
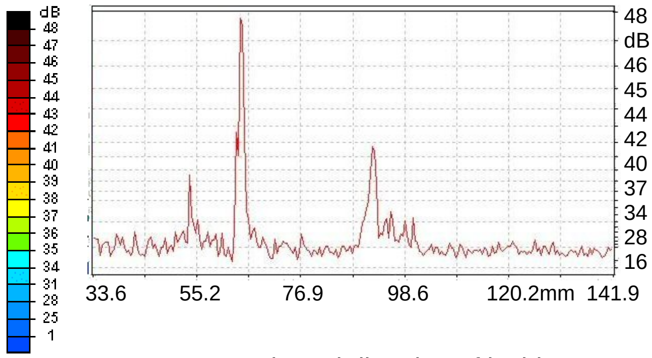



Fig 6 Testing of axles with a 4 MHz phased array probe. Detection of notch 1 with a depth of 2 mm, signal to noise ratio (SNR) = 35 dB






Backward direction of incidence

| | |
|---|---|
| Axle radius: | 80 mm |
| Inner radius: | 35 mm |
| Angle of incidence: | 45° |
| Focus-Factor: | 0.995 |
| Amplification: | 29 dB |
| Pixel size: | 0.42 mm |
| Sound velocity: | 3255 m/s |

Echo tomogram of the wheel set axle with longitudinal bore-hole

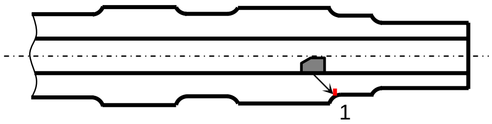
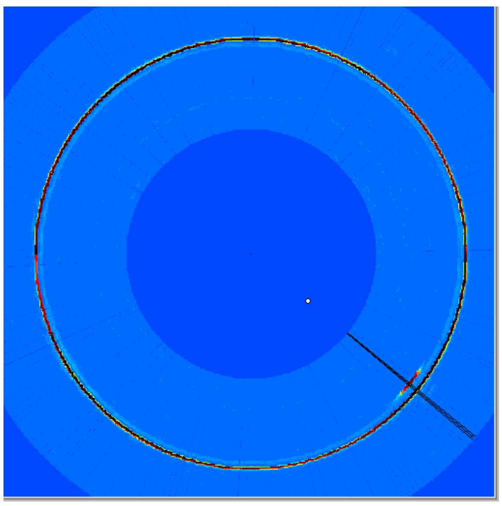
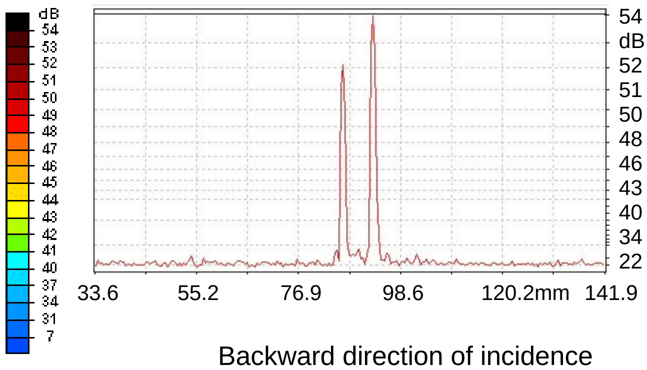



Fig 7 Testing of axles with a 4 MHz phased array probe. Detection of notch 1 with a depth of 2 mm, signal to noise ratio (SNR) = 20 dB






Backward direction of incidence

| | |
|---|---|
| Axle radius: | 98 mm |
| Inner radius: | 35 mm |
| Angle of incidence: | 45° |
| Focus-Factor: | 0.995 |
| Amplification: | 11 dB |
| Pixel size: | 0.42 mm |
| Sound velocity: | 3255 m/s |

Echo tomogram of the wheel set axle with longitudinal borehole

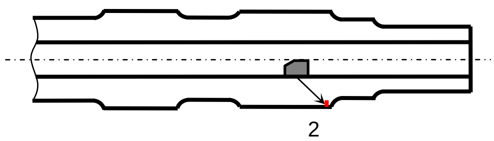
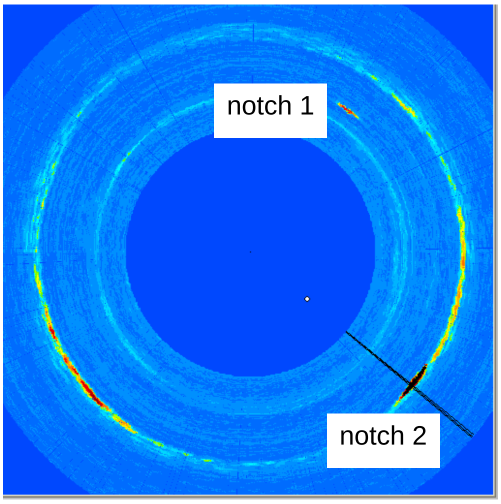
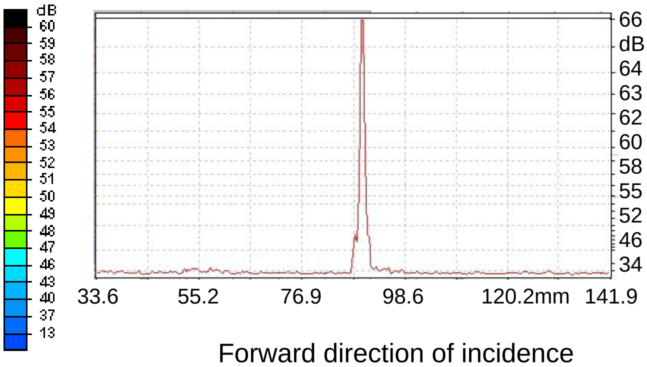



Fig 8 Testing of axles with a 4 MHz phased array probe. Detection of notch 2 with a depth of 2 mm, signal to noise ratio (SNR) = 22 dB



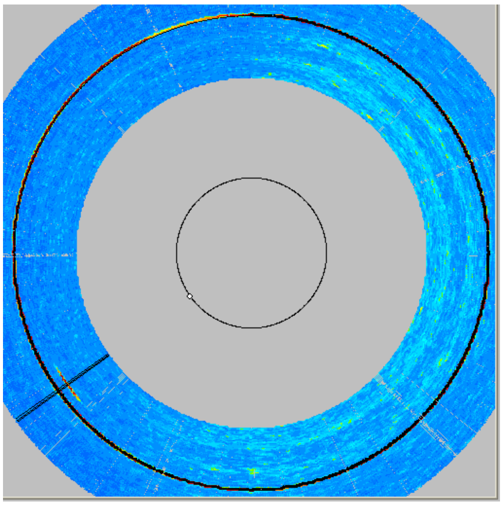



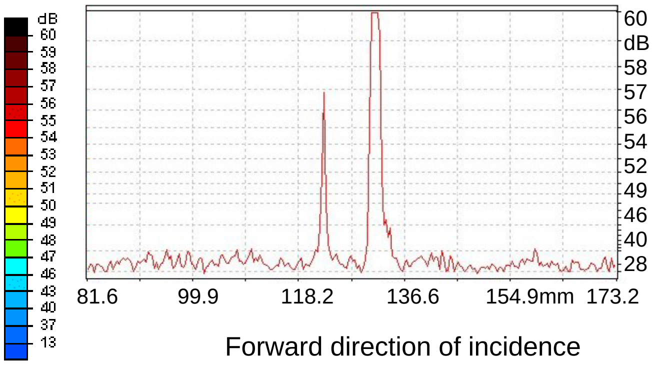

Forward direction of incidence

| | |
|---|---|
| Axle radius: | 98 mm |
| Inner radius: | 35 mm |
| Angle of incidence: | 45° |
| Focus-Factor: | 0.995 |
| Amplification: | 29 dB |
| Pixel size: | 0.42 mm |
| Sound velocity: | 3255 m/s |

Echo tomogram of the wheel set axle with longitudinal borehole


Fig 9 Testing of axles with a 4 MHz phased array probe. Detection of notch 2 with a depth of 2 mm, signal to noise ratio (SNR) = 35 dB






Forward direction of incidence

| | |
|---|---|
| Axle radius: | 98 mm |
| Inner radius: | 35 mm |
| Angle of incidence: | 55° |
| Focus-Factor: | 0.57 |
| Amplification: | 44 dB |
| Pixel size: | 0.36 mm |
| Sound velocity: | 3255 m/s |

Echo tomogram of the wheel set axle with longitudinal borehole

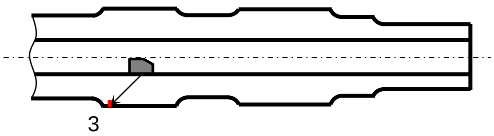



Fig 10 Testing of axles with a 4 MHz phased array probe. Detection of notch 3 with a depth of 2 mm, signal to noise ratio (SNR) = 17 dB

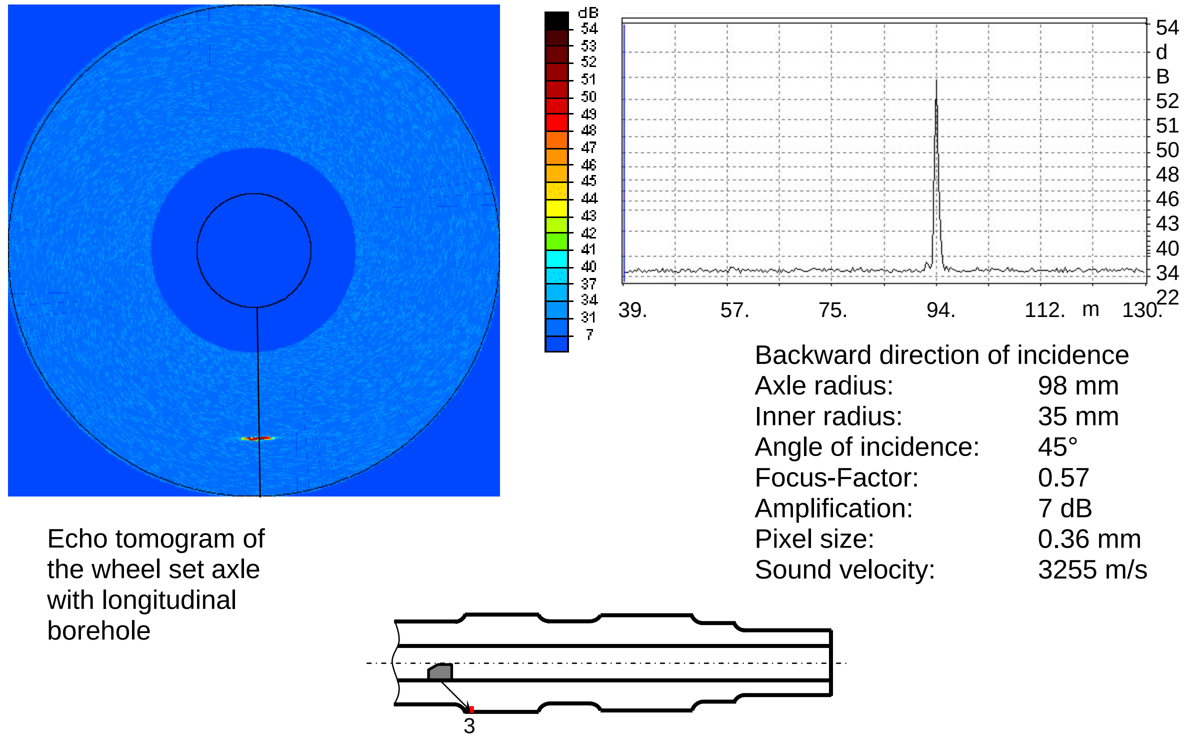



Fig 11 Testing of axles with a 4 MHz phased array probe. Detection of notch 3 with a depth of 2 mm, signal to noise ratio (SNR) = 23 dB

## Conclusion

A phased array probe with 16 elements and a middle frequency of 4 MHz was developed for in-service checks of train axles. Optimal design parameters were calculated using modelling.

Furthermore a probe holder was built, which makes it possible to record positions in longitudinal and circumferential direction and transfer the data to the phased array device. Reconstructed echo tomograms allow to distinguishing between echoes coming from changes in cross sections and echoes, which come from defects in the area of crossing profiles.