DEKRA Material Testing & Inspection

DP700 Task 4.4 Inspection

Coen Boxma

DP 700

Introduction

- Austenitic steels are used in the nuclear industry and (petro)chemical industry because of the high corrosion resistance, high strength and creep resistance required at high temperatures.
- Occurrence stainless steel: castings, dissimilar metal welds and cladding
- Review paper 1985 (Hudgell and Gray): “It is well known that the inspection of austenitic welds is difficult or even impossible”
- Intergranular stress corrosion cracks (igscc) not detected in pipelines (forgings) of BWRs USA with standard ultrasonics
- Extensive research performed, most publications on CCSS and claddings

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Anisotropy (1)

Crystal structure:

- Ferritic material :BCC: body centered cube (left figure)
- Austenitic material: FCC : face centered cube (right figure)

Material properties – number of atoms in different directions not constant for austenitic material → Anisotropy

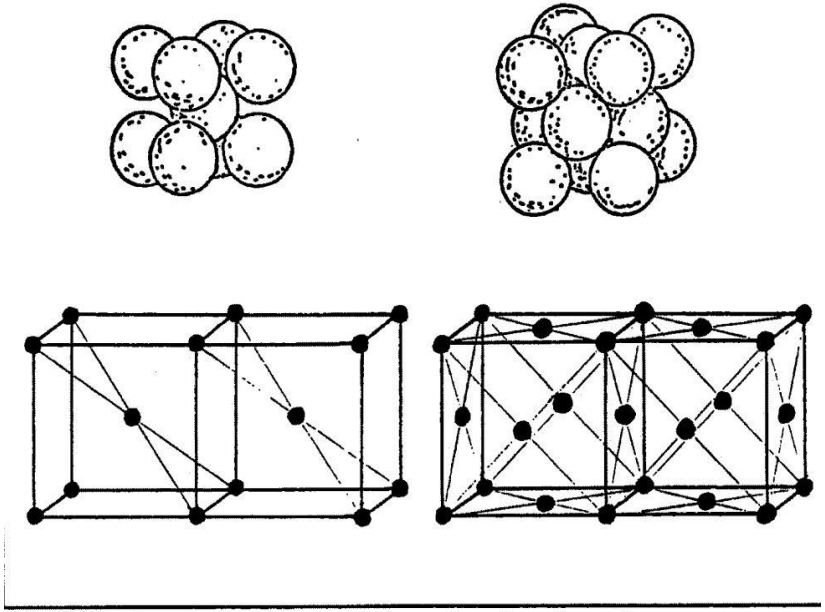

fig. 9.4: kristalroosters; links α-ijzer of ferriet, rechts γ-ijzer of austeniet

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Anisotropy (2)

Figure to the right:

Variation speed of sound compression wave, horizontal and vertical polarized shear waves as a function of the direction in respect to the crystallographic axis.

Standard shear waves (vertically polarized) : much variation

Least variation: horizontally polarized shear waves: can only be generated with EMAT probes (or lasers)!

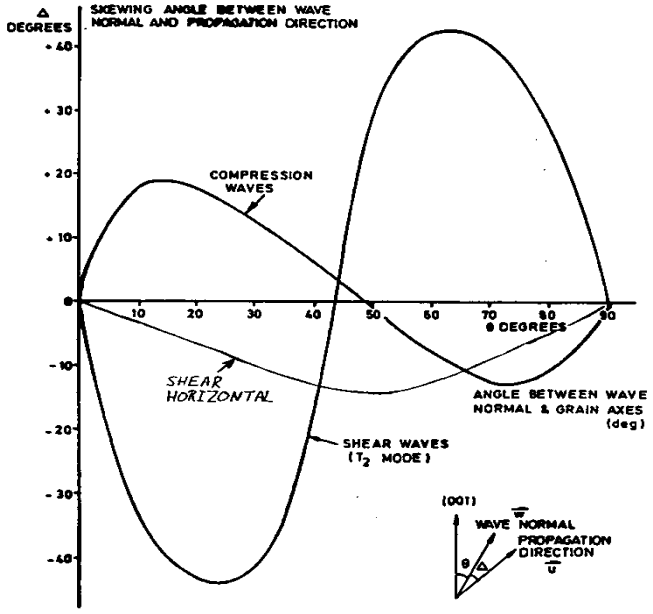

Fig. 3 Skewing angles for compression and shear waves in fibre-textured austenitic steel.

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Effect of austenitic microstructure on ultrasound propagation (1)

- Ideal materials: sound pressure reduces only due to beam spreading:

  i.e. 6 dB for 2x distance back wall echo or 12 dB loss in sound pressure for the flat bottom hole (FBH)

- Natural materials: sound pressure reduction also due to scattering and absorption (attenuation)

- Damping coëfficiënt: $\alpha = \alpha_s + \alpha_a$, α_s : scattering, α_a : absorption α : [dB/mm}

- Absorption, mainly of influence at plastics and rubbers: less of a problem than scattering: damping $\alpha_a \sim$ frequency

  Absorption usually solvable by using a lower frequency and higher gain/amplification

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Effect of austenitic microstructure on ultrasound propagation (2)

Scattering dependent on the relation wave length (λ) and grain size (D). Four ranges identified:

No scattering for $\lambda >> D$

Rayleigh scattering:
$\alpha_s \div D^3 \cdot f^4 \quad (D \leq \lambda/3)$

Stochastic scattering:
$\alpha_s \div D \cdot f^2 \quad (\lambda/3 \leq D \leq 3 \cdot \lambda)$

Diffuse scattering
$\alpha_s \div 1/D \quad (3 \cdot \lambda \leq D)$

Austenitic welds:: $D \approx \lambda$

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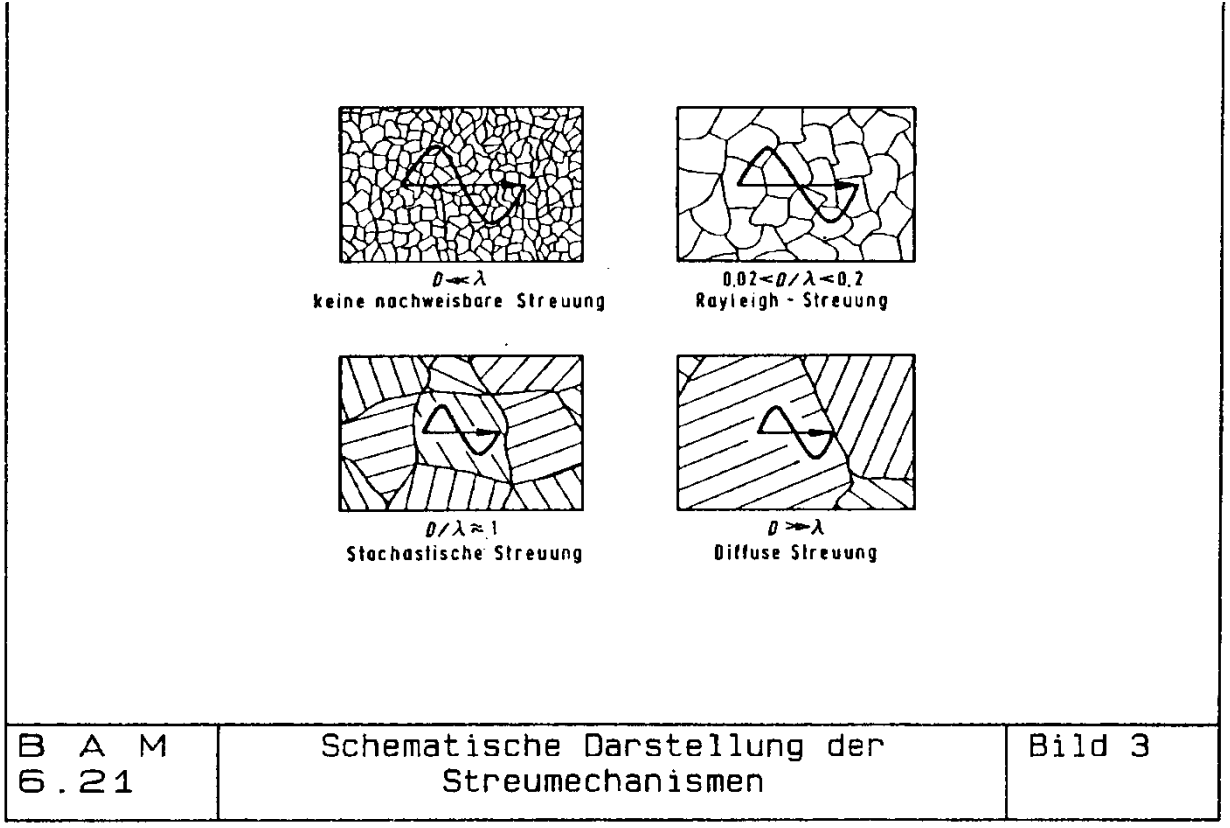
Effect of austenitic microstructure on ultrasound propagation (3)



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Effect of austenitic microstructure on ultrasound propagation (4)

Effect from scattering:

- Loss of energy due to reflection at grain boundaries
- Part of the reflected energy at the grain boundaries will be seen by the UT probe resulting in a lower signal to noise ratio – more grain noise

Scattering based on random distribution of grains (base material)

Grains not oriented randomly for welds or cladding

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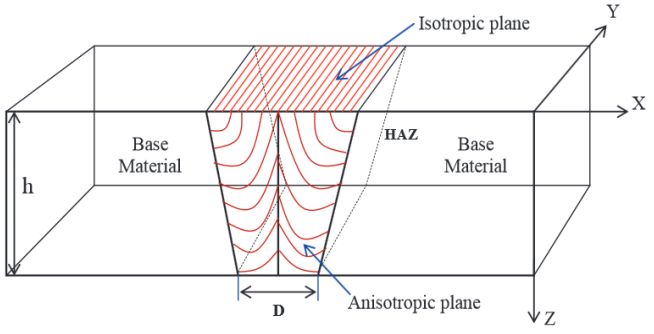
Effect of austenitic weld microstructure on ultrasound propagation (1)

- Austenitic welds are transversely isotropic, i.e. elastic properties are independent on direction in one plane. Isotropic in the yx-plane.
- Variation in elastic constants with direction in an anisotropic material affects components of the beam velocity differently with respect to an arbitrary initial direction of travel.
- Propagation of waves: the beam direction – the direction of energy travel – is not perpendicular to the wave front.
- An ultrasonic beam passing through such a material will be skewed off the straight through direction
- Sound beam skewing leads to incorrect interpretation of flaws, i.e. position and sizing errors



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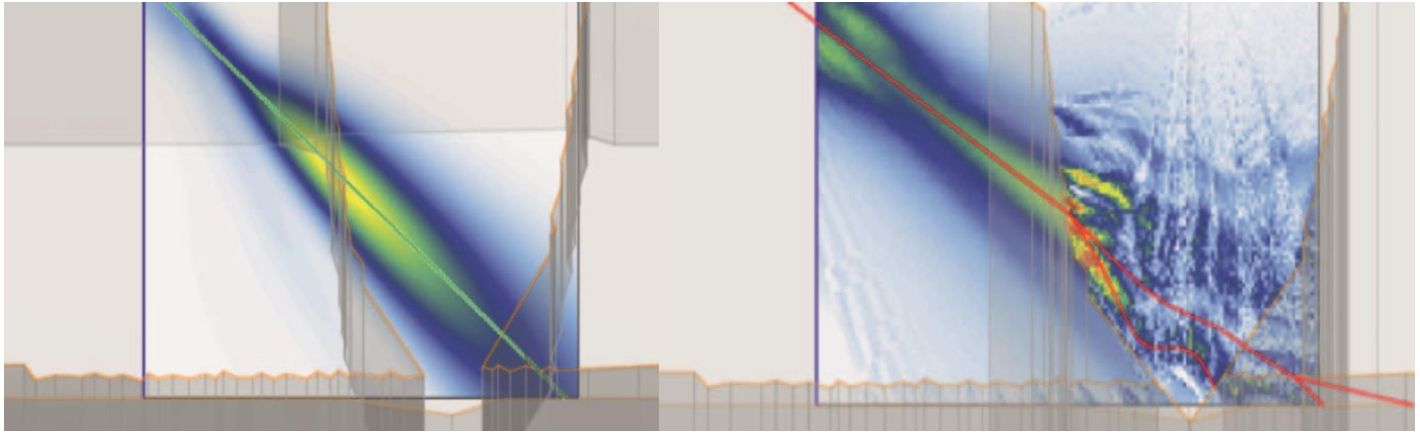
Effect of austenitic weld microstructure on ultrasound propagation (2)



Similar weld

dissimilar (bimetallic) weld with shear waves: skewing and attenuation of the beam

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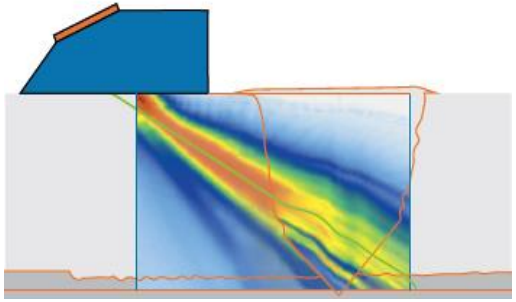
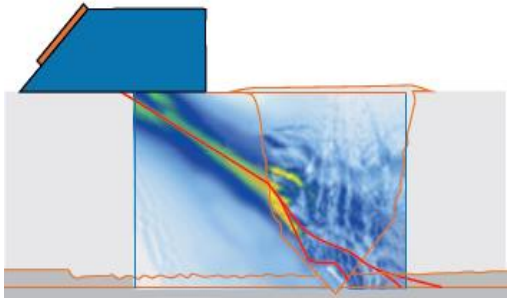
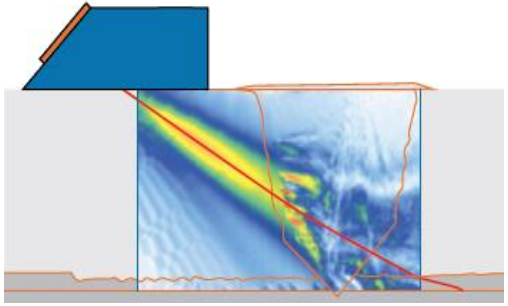
Effect of austenitic weld microstructure on ultrasound propagation (3)



Longitudinal wave 2.25 MHz



Shear wave 2.25 MHz



Shear wave 1 MHz

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Inspection techniques for austenitic materials and welds

Measures and special techniques to enhance signal to noise ratio for an austenitic UT inspection:

1. Longitudinal sound is used instead of shear waves (S_V) because of the larger wavelength for the same frequency
2. Use of separate transmitter –receiver longitudinal angle beam probes
3. Use of lower frequencies (larger wavelength), probes with a large bandwidth etc.
4. Use of mode conversion probes (Self tandem, LLT)
5. Special design probes (Adept, UPR Unter Plattierungs Risse, SLIC)
6. Lens focussed probes or phased array technique
7. SAFT or TFM algorithmen
8. EMAT probes for dissimilar welds – generation of S_H waves

2,6,7 → focussing techniques, 2,6: during measurement, 7: after measurement

Some of the above measures will be discussed

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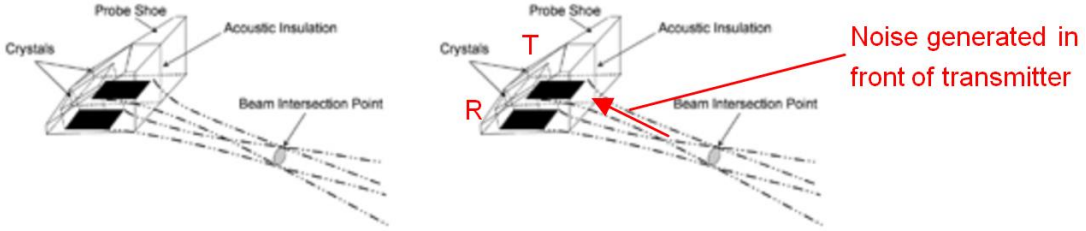
Inspection techniques TRL probes (1)

:

The SNR with TRL probes is higher compared to single crystal probes.

- The two crystals are mounted on a wedge with an angle so there can be focussed on a certain depth where the beams intersect. Focus reduces noise from the area that is not of interest.
- Using separate transmitter and receiver means that the noise below the surface (in the zone below the transmitter) is not or less reflected to the receiver.



- The effect of a dead zone in front of a probe is also strongly decreased using separate transmitter and reducer.

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Inspection techniques TRL probes (2)

:

Disadvantage of TRL angle beam probes:

- Many probes needed to cover the whole thickness (number can be reduced with phased array technique)
- TRL angle beam probes can only be used for half skip distance due to mode conversion

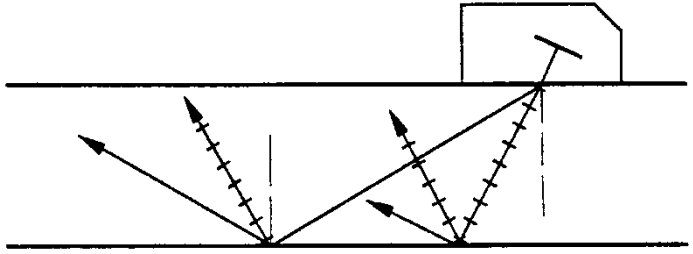

Abb. 10 Reflexion mit Wellenumwandlung beim Longitudinalwellen-Winkelprüfkopf

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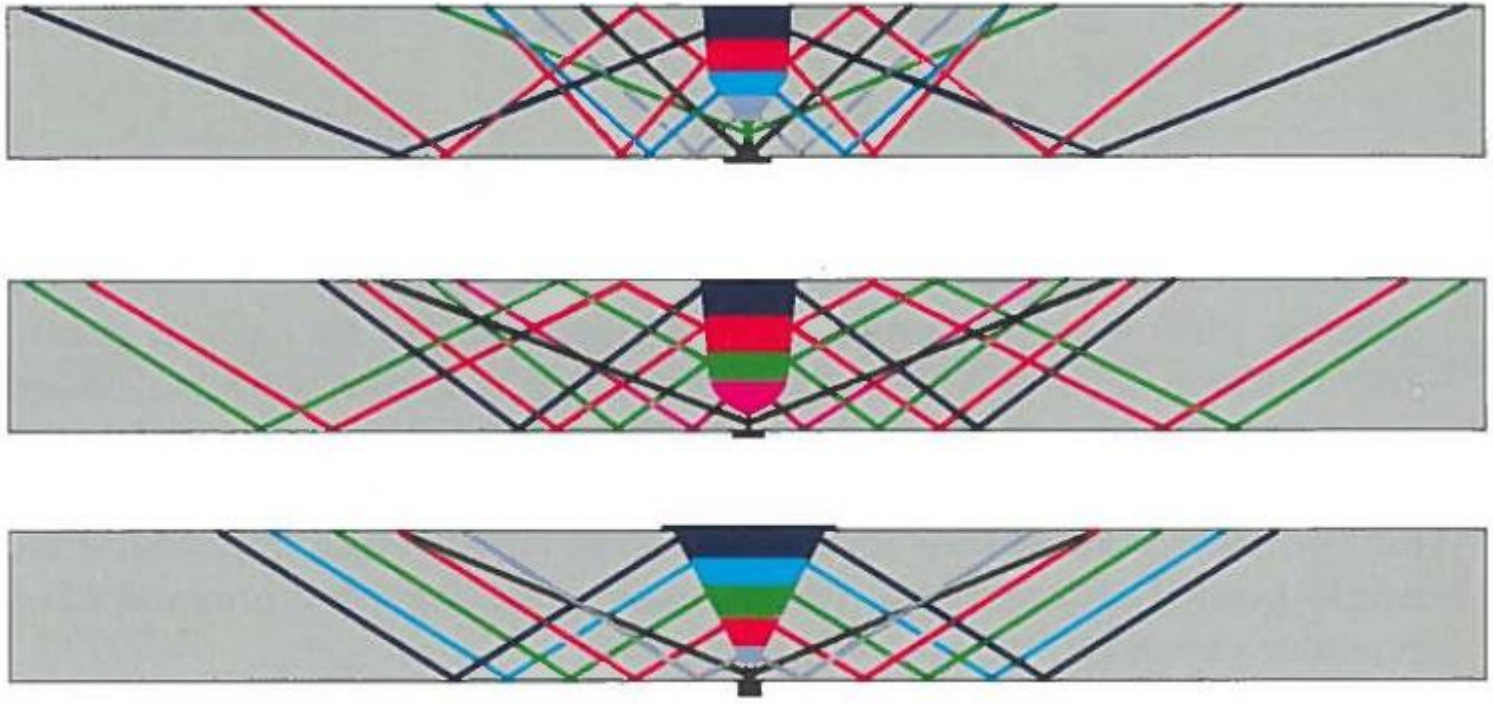
Inspection techniques TRL probes (3)

zonal concept – many TRL probes needed! → PA technique



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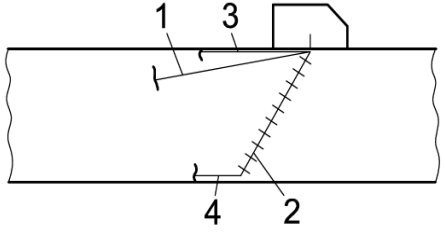
Inspection techniques: Mode conversion (1)

- Creeping wave is a special case of refracted longitudinal wave which is used to detect surface and near-surface flaws.
- Flaws located near or on the surface of the back wall can be detected with secondary creeping wave, which is generated by shear waves from the primary creeping wave.
- Since creeping waves are constantly generating shear waves, causing energy loss as they propagate, they cannot be used over large distances.
- Advantage CWs: use of longitudinal sound and less disturbance from the weld geometry (root/cap) than other techniques
- Not useful with cladded components due to shear waves at back surface: mode conversion at back wall



1 longitudinal wave,
2 shear wave,
3 primary creeping wave,
4 secondary creeping wave;

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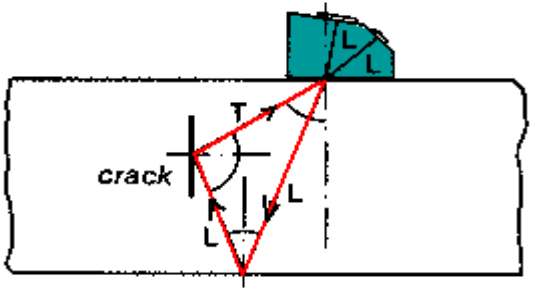
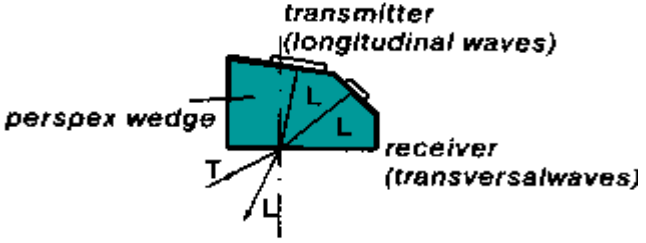
Inspection techniques: Mode conversion (2)

- LLT technique is a special case of mode conversion, method applied for detection of large planer flaws in thick (austenitic) components.
- A separate transmitter (longitudinal) and receiver (shear) crystal is used.
- Both crystals are placed behind each other in the same housing.
- Method developed at Fraunhofer Institut in Saarbrücken
- Very useful for narrow gap (dissimilar) welds in thick austenitic materials, useful range: 0 – 70% of WT
- Mode conversion occurs at defect





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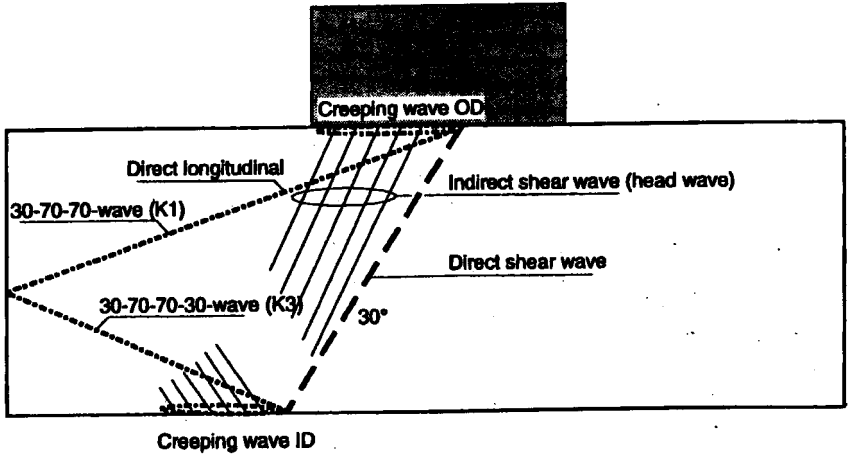
Inspection techniques: Mode conversion (3)

- Other mode conversion techniques: round-trip tandem to the left: focal depth determined by the probe angle
- Here, mode conversion occurs at the back-wall



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Special techniques Imaging techniques

Pre phased array era: SAFT: synthetic aperture focusing technique executed with conventional probes: calculation of a focussed image from raw A-scan data

Now:

- FMC: Full matrix capture. A data collection technology. Every element is pulsed in sequence and the elementary A-scan data is collected for each combination of pulsing and receiving element
- TFM: Total focusing matrix PA processing method using collected FMC data to generate a frame of pixels where each pixel is computed using a dedicated focalized focal law

Connection between the 2:

The TFM post processes the Full Matrix Capture (FMC) data in the time domain to synthetically focus ultrasonic energy at every pixel in the image field.

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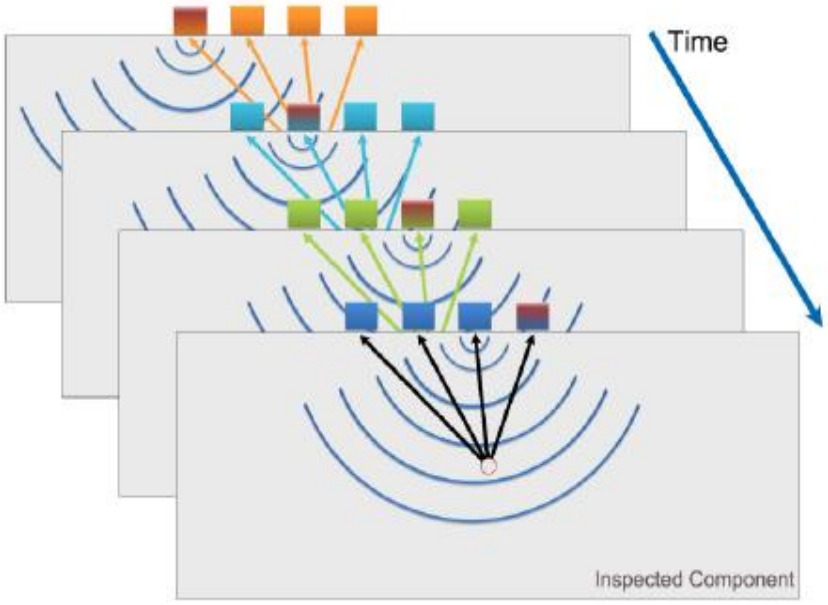
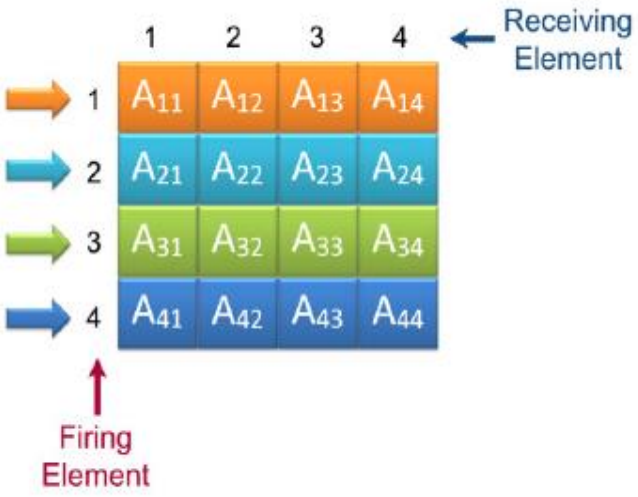
Special techniques Imaging techniques - Full Matrix Capture





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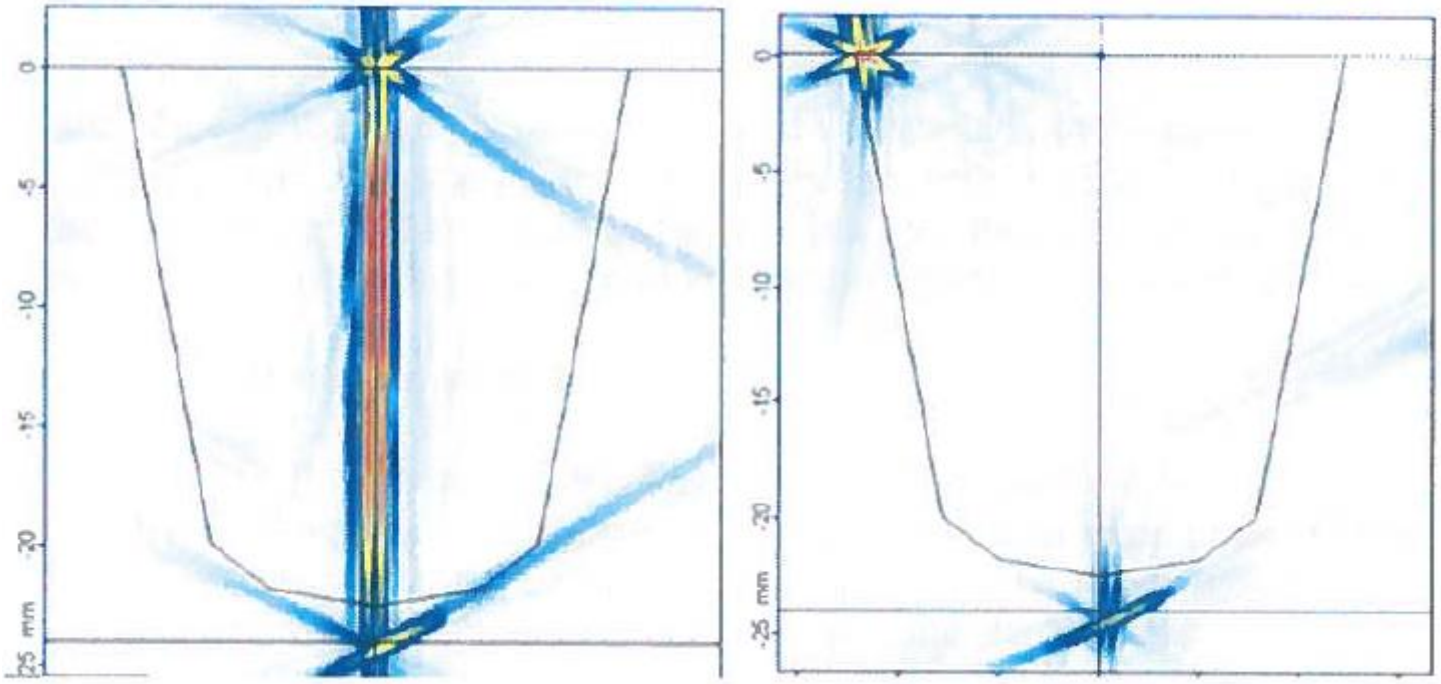
Inspection techniques: Imaging techniques – example of result

FMC/TFM sensitivity calibration. Slot (left) and cap and root notches (right)



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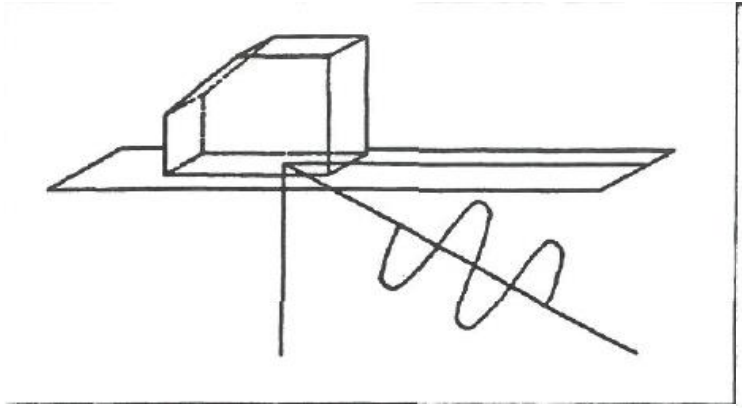
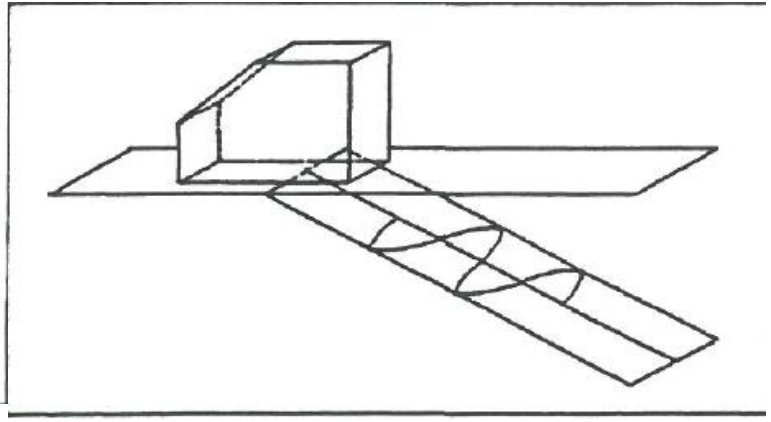
EMATs for inspection of dissimilar welds (1)





- S_V waves, normal shear wave probe

S_H wave: generated in test object itself → EMAT generation

(also no couplant needed)

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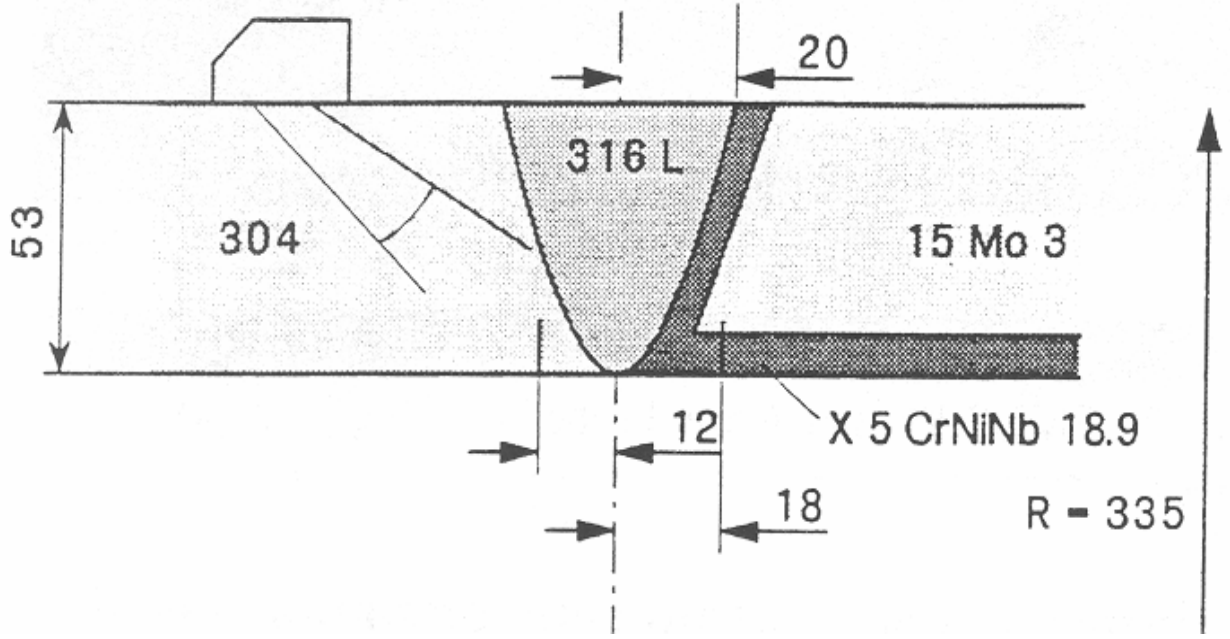
EMATs for inspection of dissimilar welds (2) example



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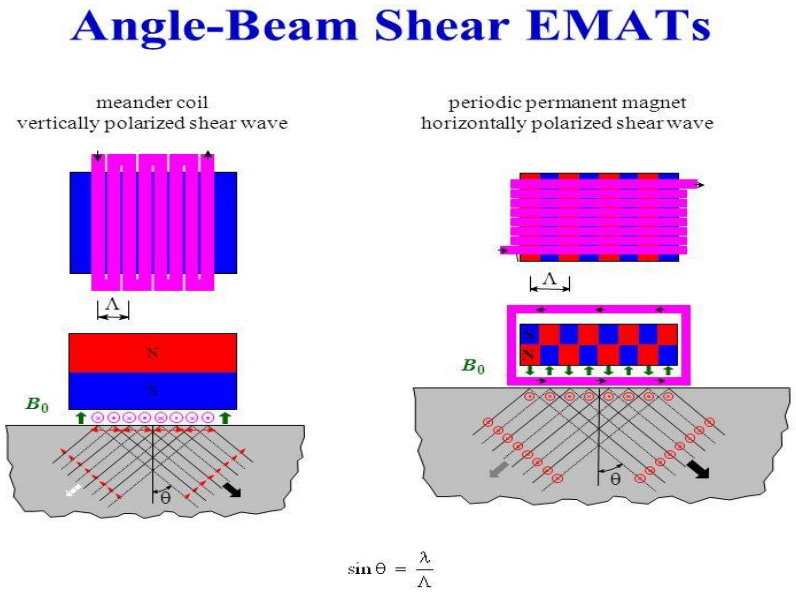
EMATs for inspection of dissimilar welds (3)



Example of the design of an EMAT probe for S_v and S_H wave generation in the test object

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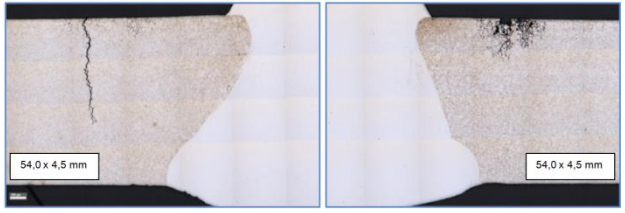
Examples of inspection techniques DEKRA (1)

- HR3C is an austenitic material that has been applied in recent years for boiler tubing in supercritical coal-fired power plants.
- Intergranular cracking has been observed in the HAZ of HR3C welds that initiates at the steamside.
- Qualification programs for inspection based on UT-PA: weld defects in newly build welds and IC in HAZ for in-service inspection up to 9 mm WT
- Qualification programs for inspection based on creeping wave (IC in HAZ for in-service inspection only) for WT range of 4-5 mm)
- Execution PA/creep wave method in 4 power plants in the Netherlands , 4 in Germany and one in Czech Republic



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Examples of inspection techniques DEKRA (2)

- NEXTGENPOWER inspection of rotor weld 300 mm and 1,000 mm diameter A263 – COST F (no buttering layer)
- A very small weld preparation angle prohibits the use of angle beam probes for the detection of lack of side-wall fusion
- Detection of planar side-wall fusion defects, volumetric defects in the weld and surface breaking defects.
  - 45, 60, 70º TRL probes (weld volume),
  - TRC probes (creep wave probe for outer and inner surface breaking defects)
  - mode conversion LLT probes (for the side wall fusion defects)
- Validation and calibration is performed on several test objects with the same dissimilar weld type and the following dimensions: a Ø300 mm cylinder with a wall thickness of 100 mm and a Ø1000 mm cylinder with 120 mm wall thickness.

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Examples of inspection techniques DEKRA (3)

KIRR in-situ rotor retaining ring inspection

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Thank you!

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