SALZGITTER MANNESMANN FORSCHUNG

A Member of the Salzgitter Group

Ultrasonic Inspection of adhesively bonded Joints

M. Kaack, **Th. Orth**

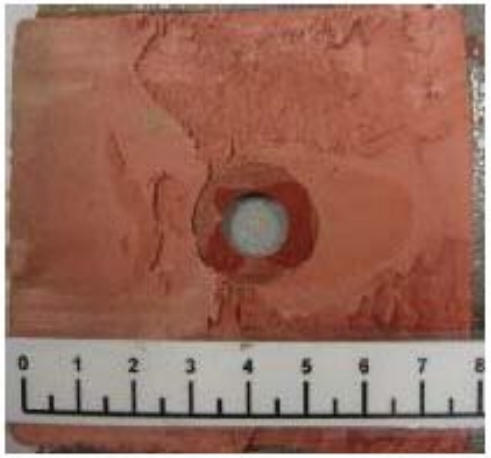
Fredensborg , 3rd/4th June 2009

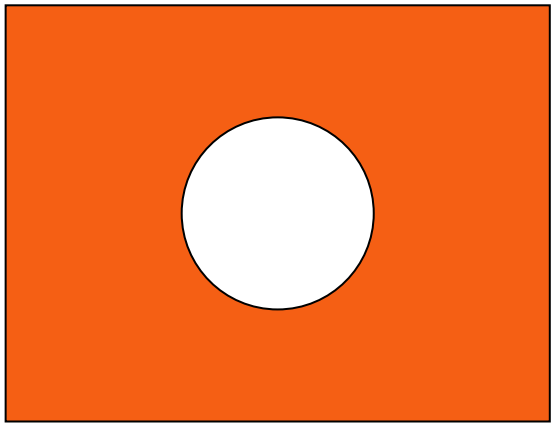
Defects of interest

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

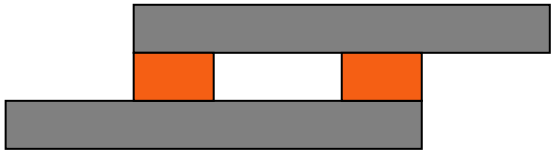
- Critical defects are air voids with diameter above 20 mm.
- Different types of defects were prepared and investigated:

A) artificial air void
diameter: 30 mm



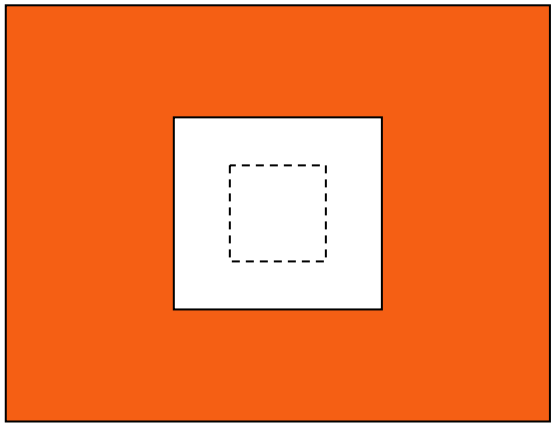


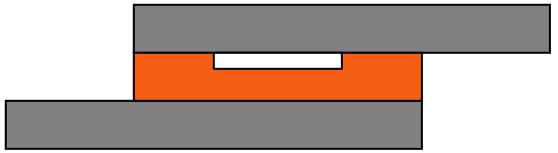
Top view



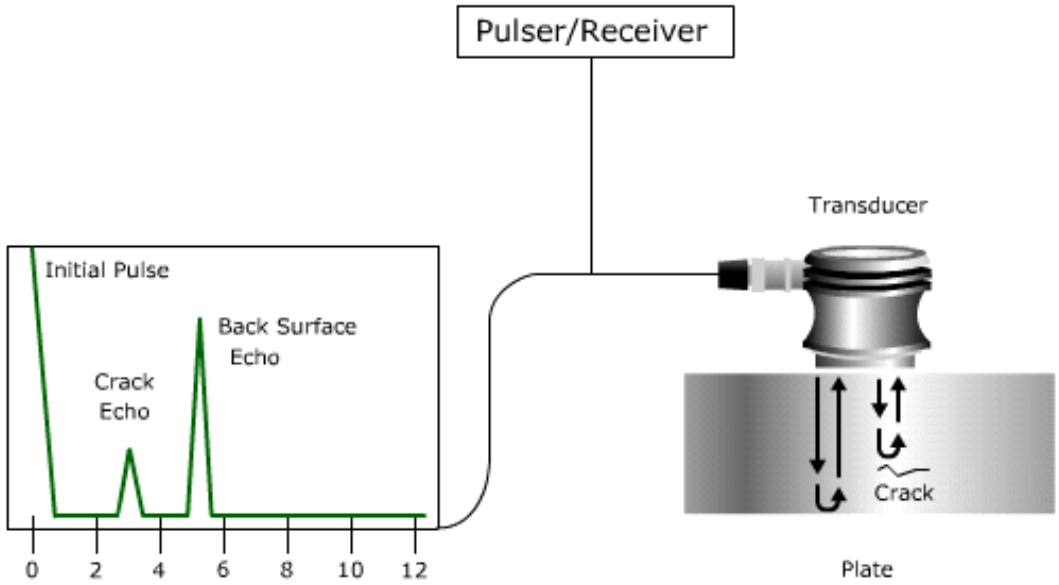
Side view

B) Teflon square
10 x 10 mm and
40 x 40 mm

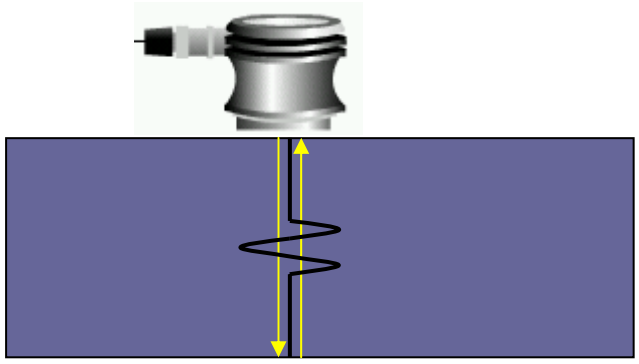


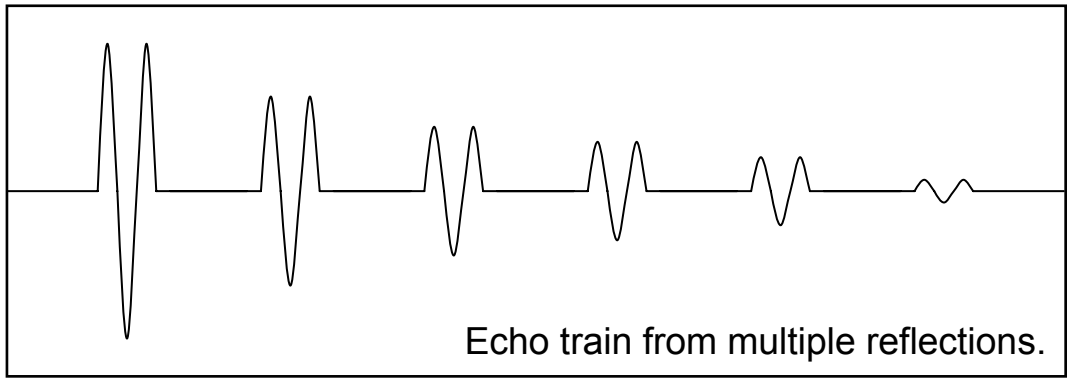


Perpendicular Inspection



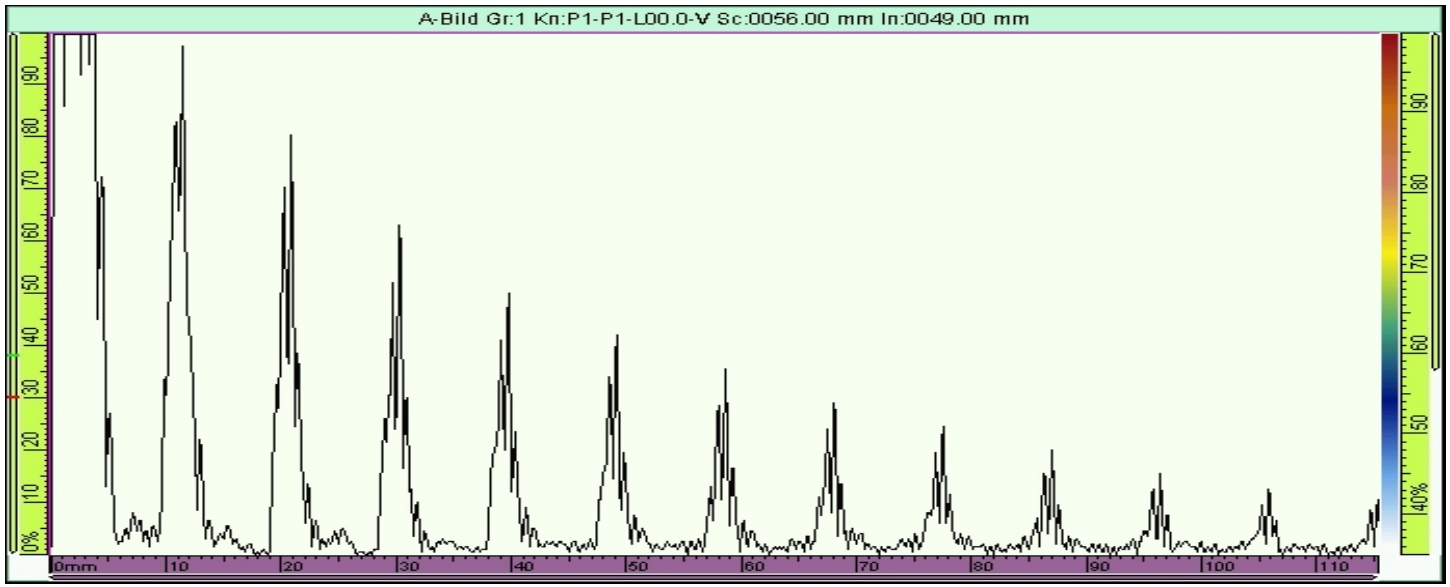
- Ultrasonic wave is generated by piezoelectric transducer supplied by some 100 volts.
- Coupling by oil or immersion technique.
- Reflections from interface layers.
- Ultrasonic wave runs several times through the sample.
- Wave is attenuated.

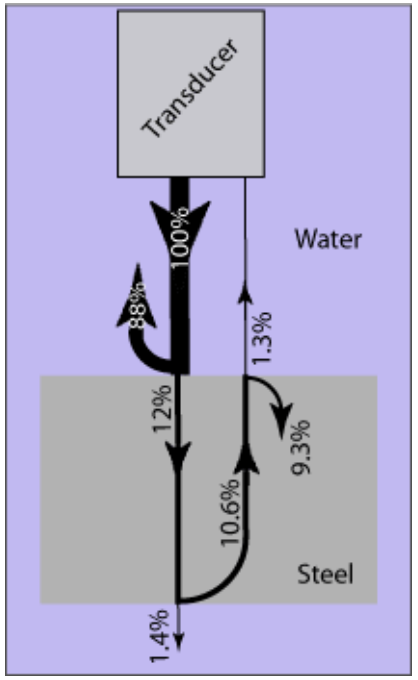




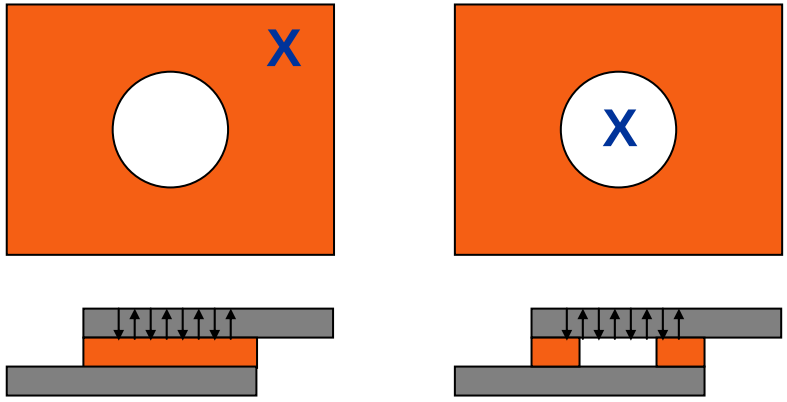
Attenuation in steel layer

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

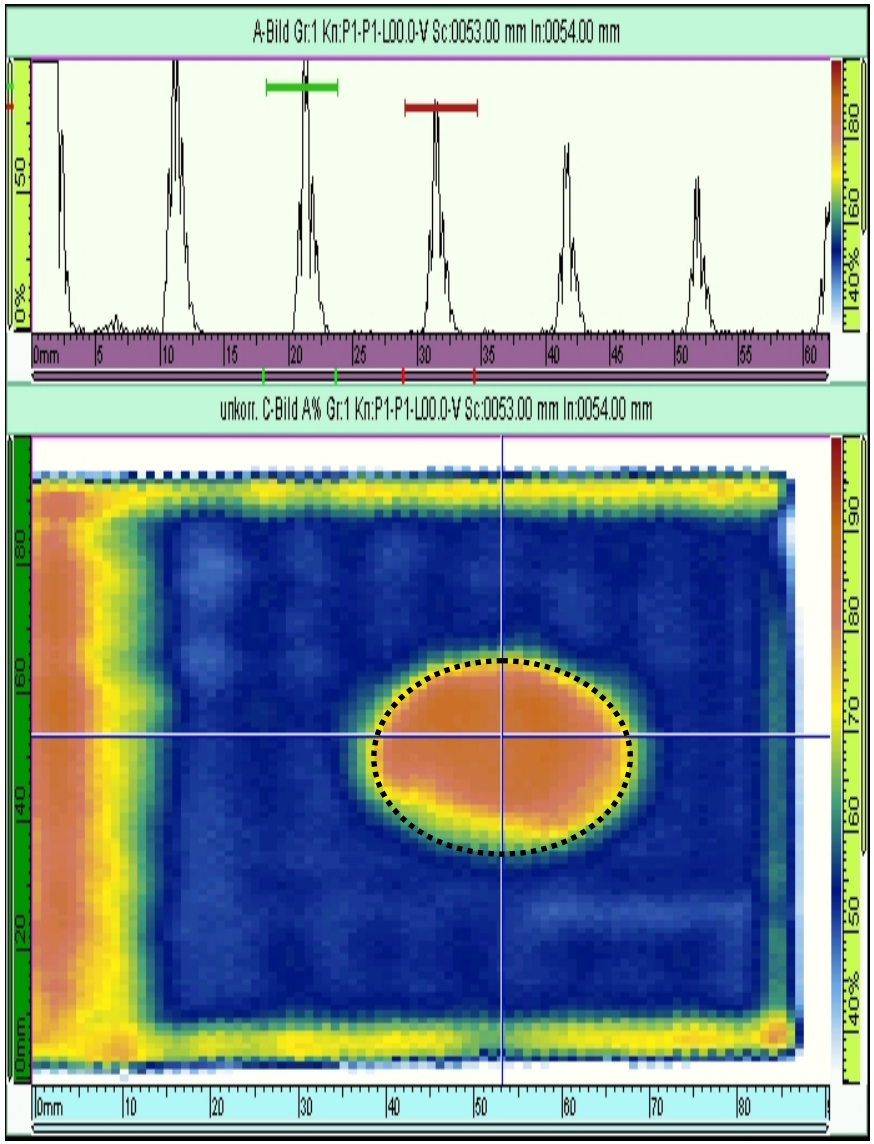




- Amplification now changed.
- Echo trains at locations of void and adhesive are compared.
- Significant differences in attenuation is found!

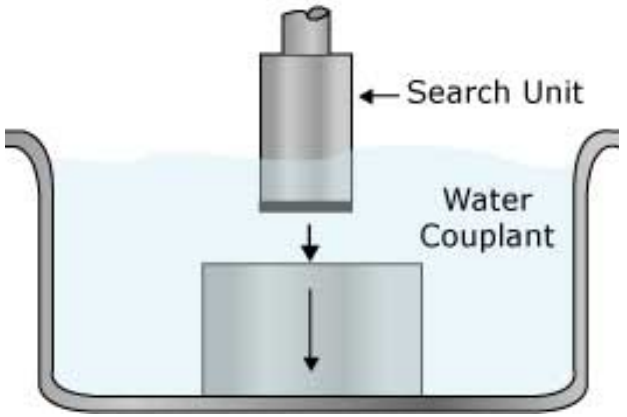


Attenuation in steel layer



- Amplitudes of third backwall echo was recorded by automated scanning the sample.
- Immersion technique in water bath was used.
- Circular void is clearly visible!
  (scaling on x- and y- axis different)

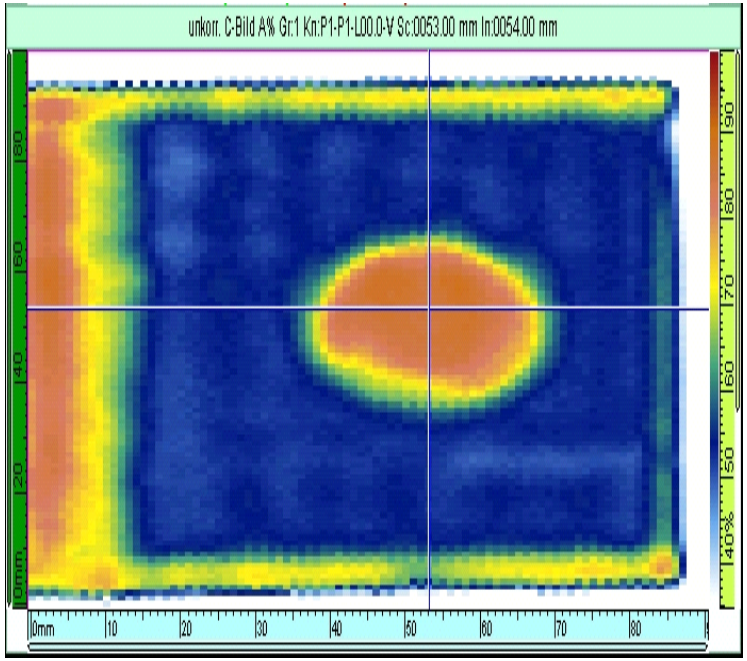
air void
diameter 30 mm
5 MHz

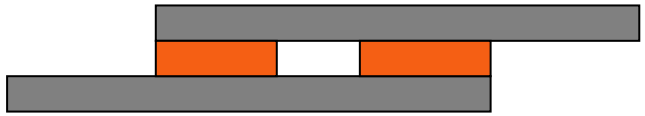


Different defect types

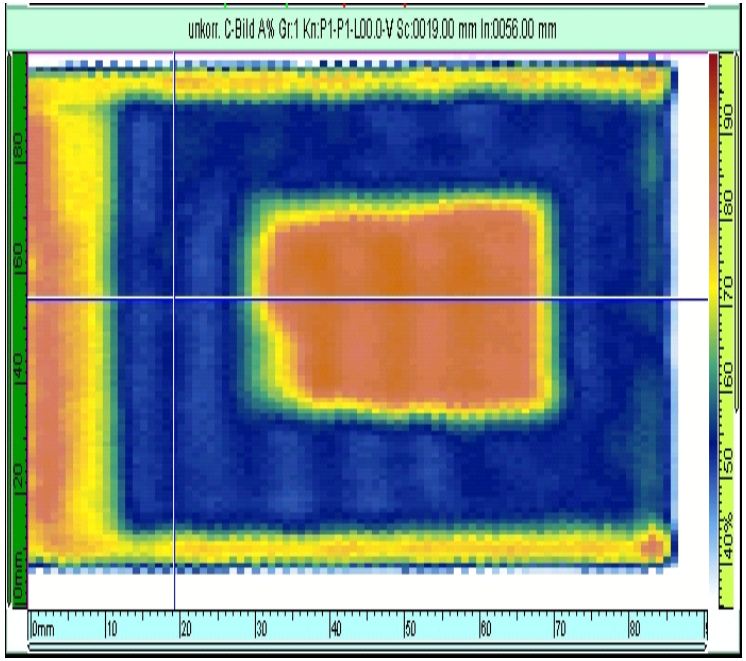
SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

Air void, diameter: 30 mm





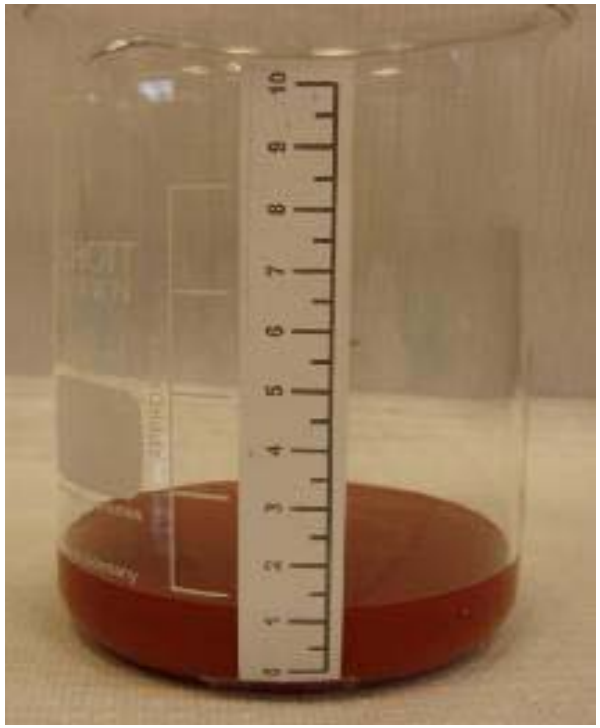
Teflon square, 40 x 40 mm



- Air voids and Teflon plates behave very similarly in UT inspection.
- Teflon stripes can be used to simulate relevant defects.

Foam

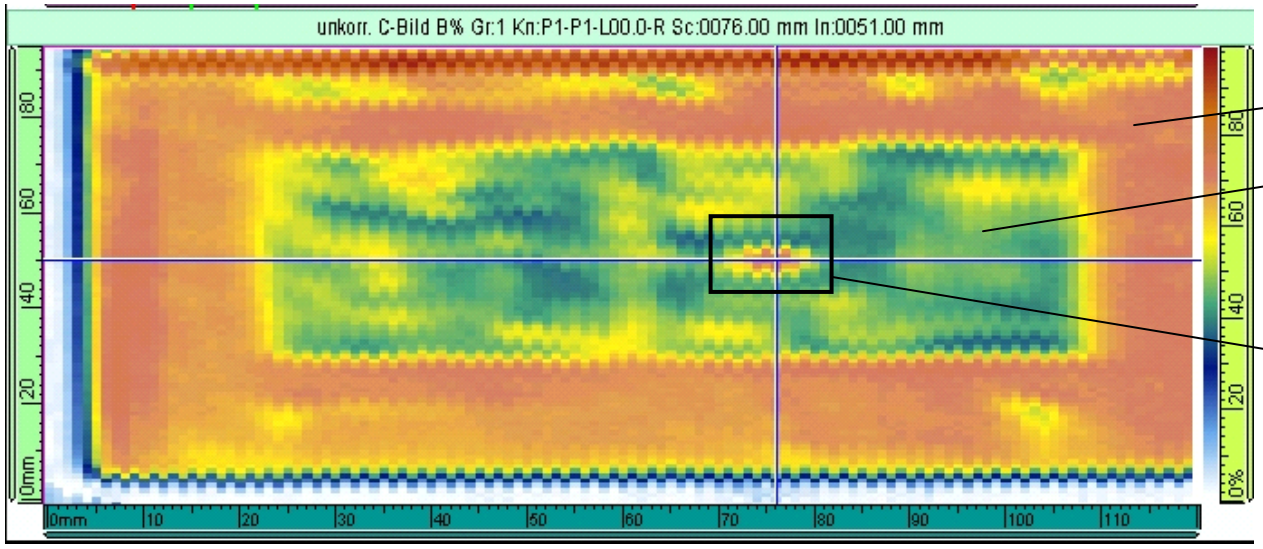
- PU adhesive requires careful preparation of specimen to avoid moisture.



- Foam could reduce strength of a joint and has to be detected!

➡ Different type of relevant defect !

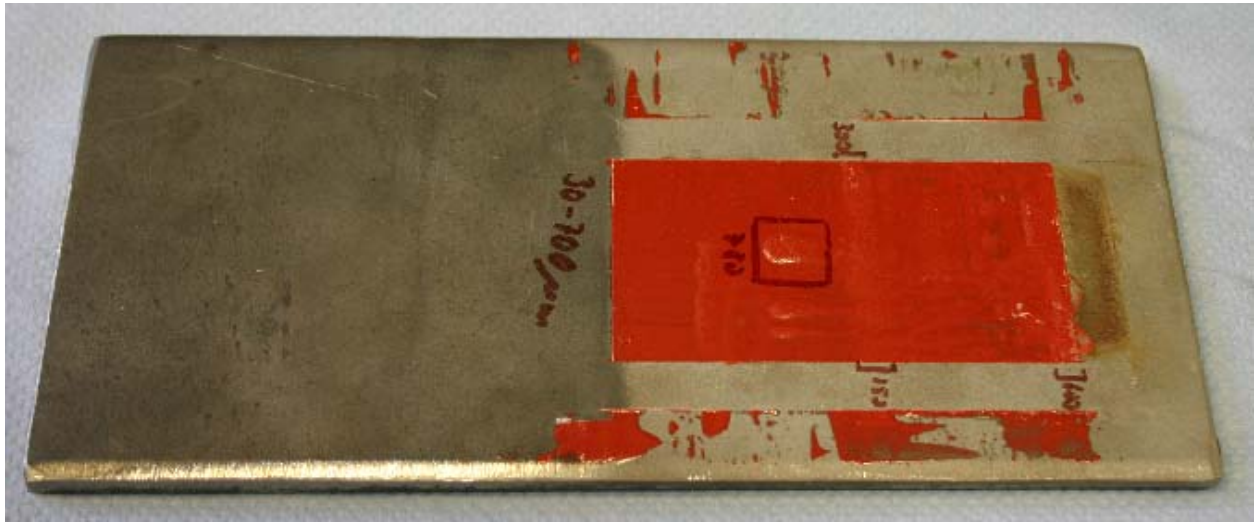
Foam



air

adhesive

foam area

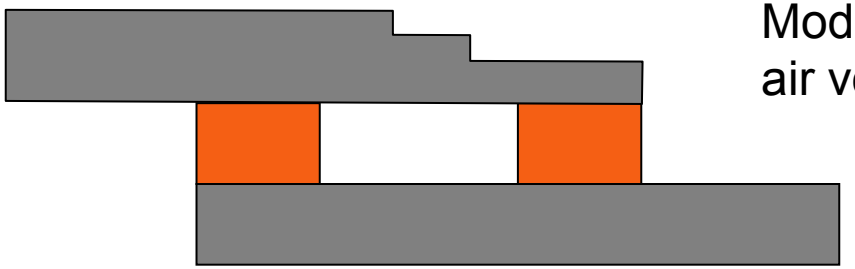


- Foam area behaves similar to air.
- It can be detected in advesive layer.

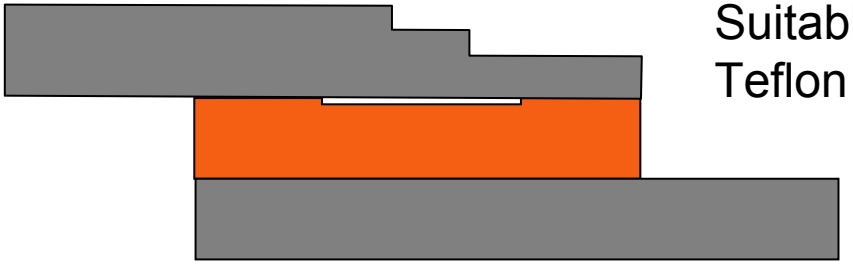
Influence of wall thickness: Step wedge

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

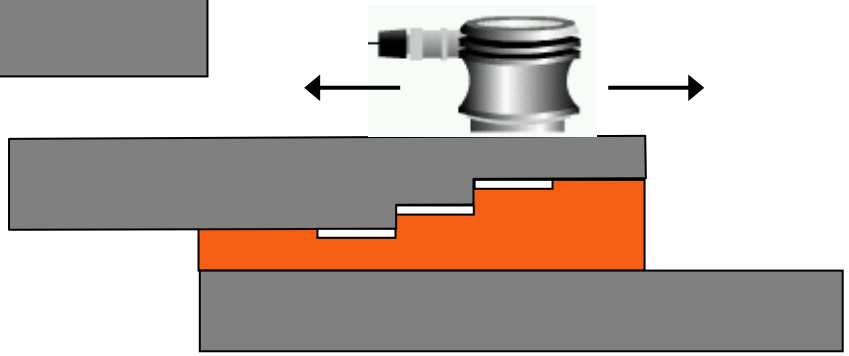
- Does the technique developed work for tubes with different wall thickness?



Model of interest:
air void covered with step wedge

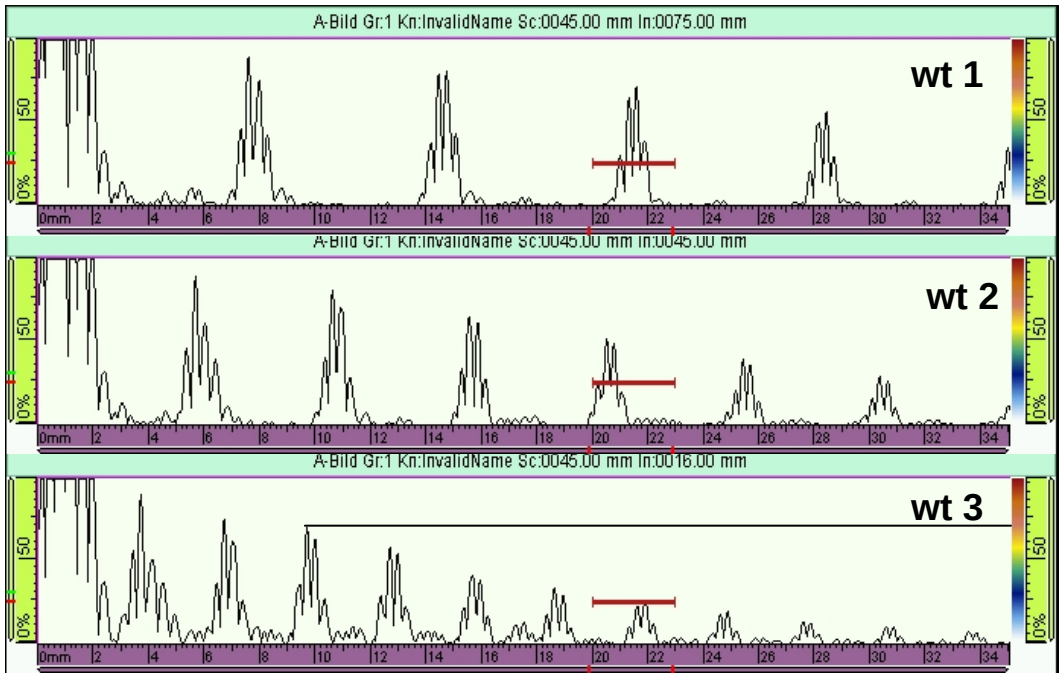


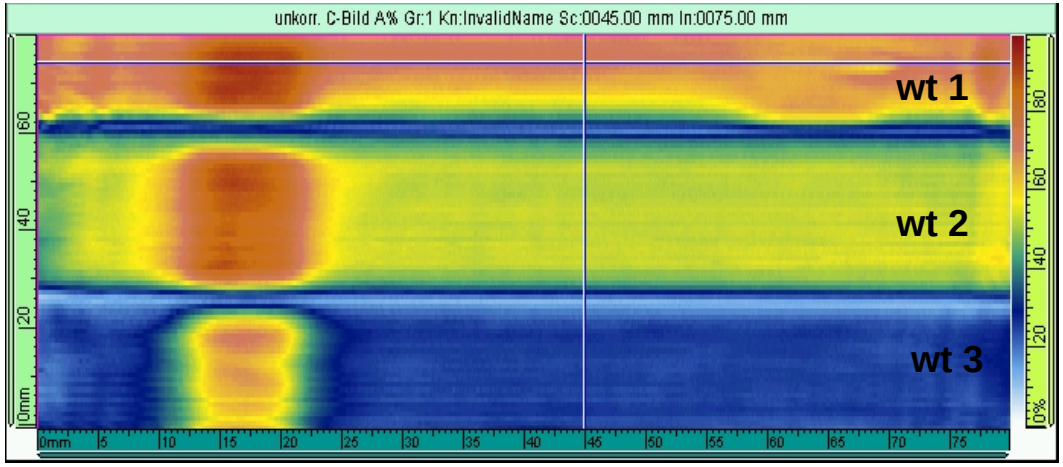
Suitable replacement:
Teflon layer attached to upper plate

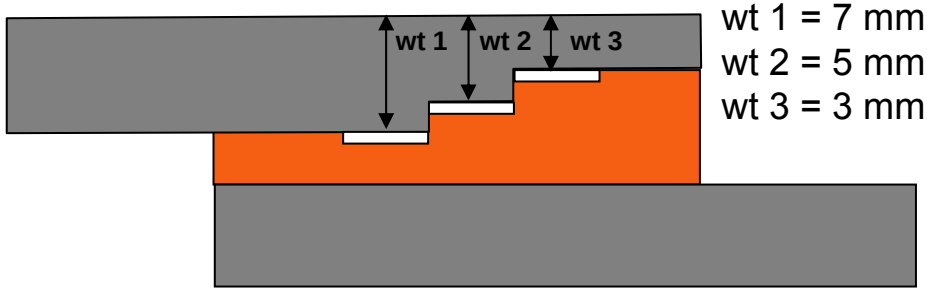


Practical considerations:
Step wedge on inner surface

Influence of wall thickness: Step wedge







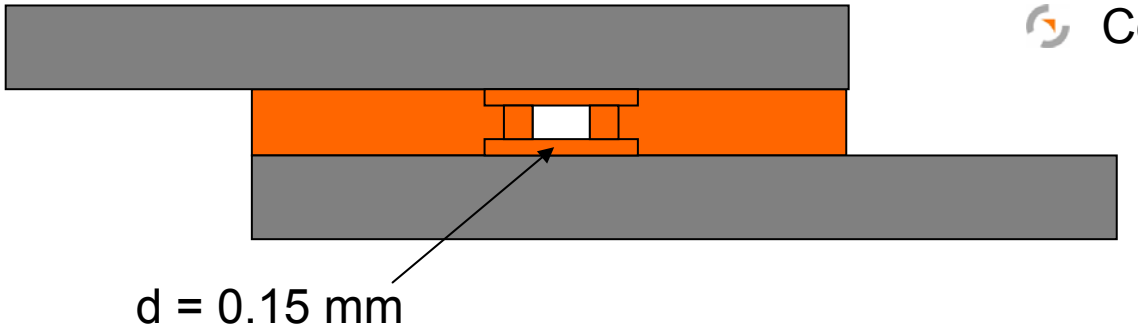
wt 1 = 7 mm
wt 2 = 5 mm
wt 3 = 3 mm

- Defect is clearly detectable in each case
- Decrease of amplitude is different for air and adhesive → main contribution to signal amplitude is dissipation of energy to adhesive rather than attenuation in steel layer
- Follow 3rd (or 4th) echo: only small variation of amplitude in adhesive → variations in wt are uncritical

Real adhesively bonded samples

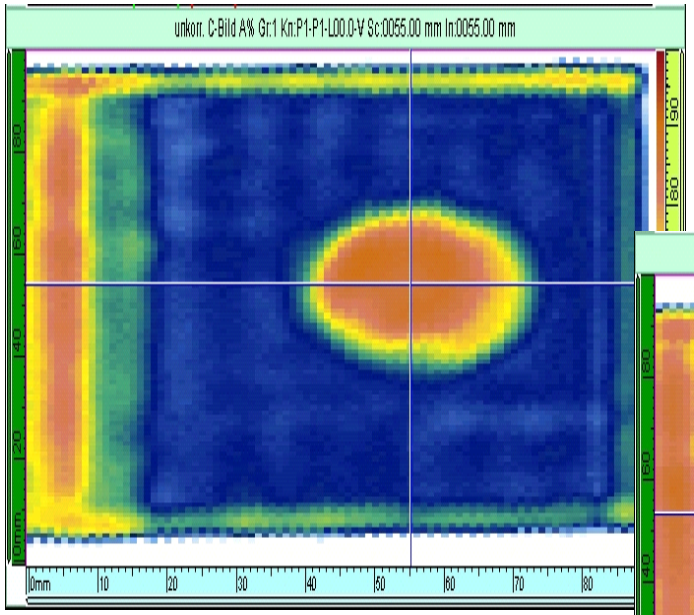
SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

- In real samples a thin adhesive layer is present around an air void.
- Comparable test defects were made.

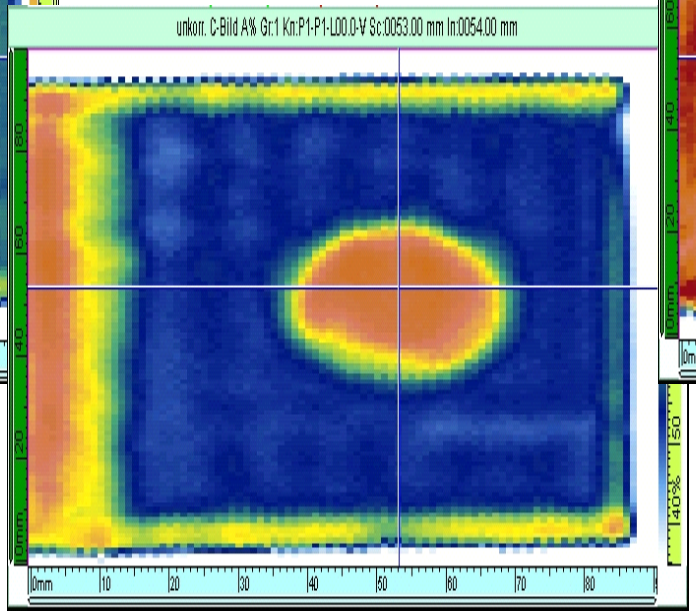


Frequency dependence

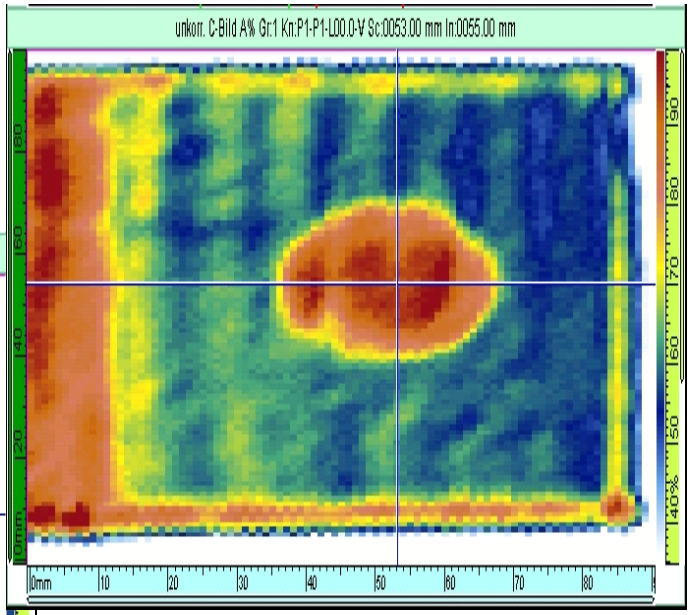
SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group



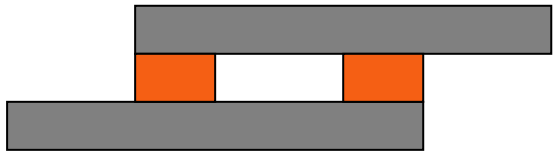
LB33, 2 MHz



LB33, 5 MHz

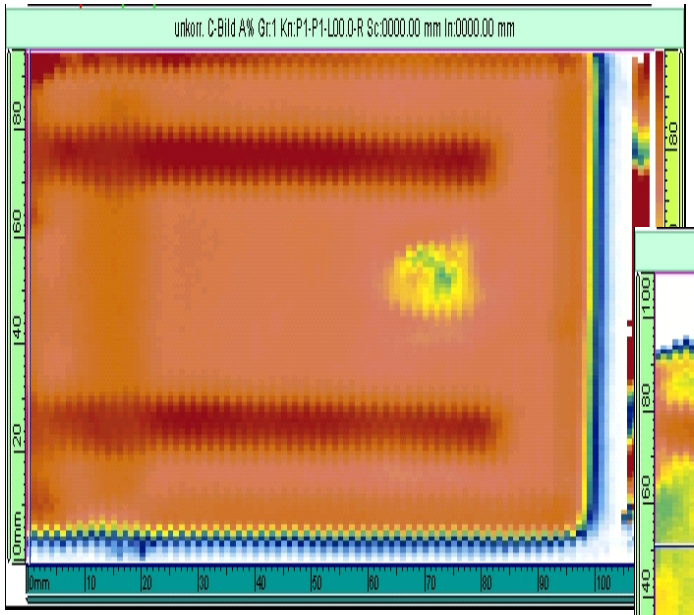


LB33, 10 MHz

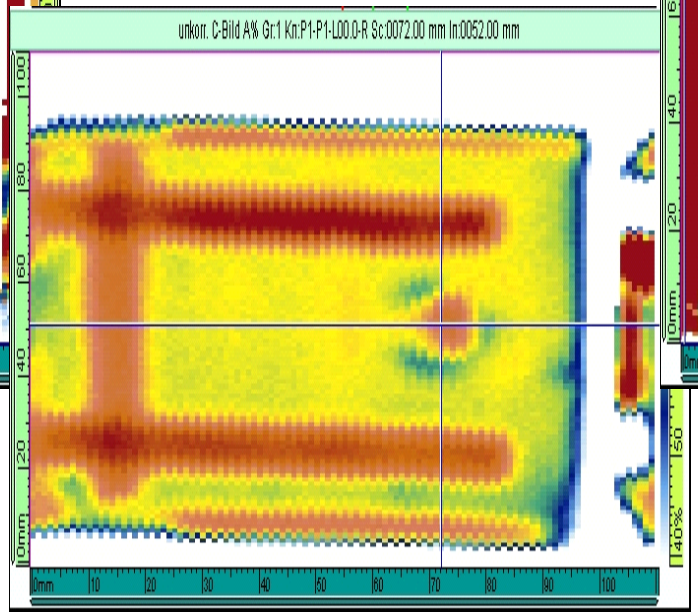


- Almost no difference, only little differences in sharpness are visible.
- Scanning resolution: 1 mm.

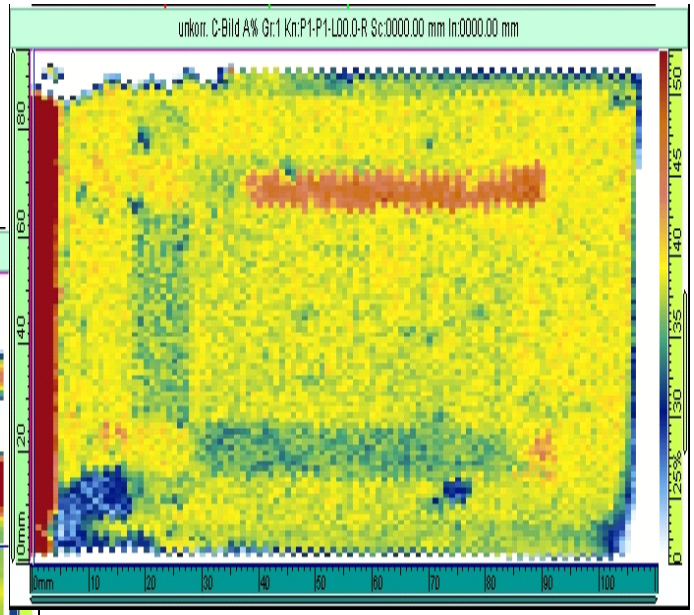
Frequency dependence



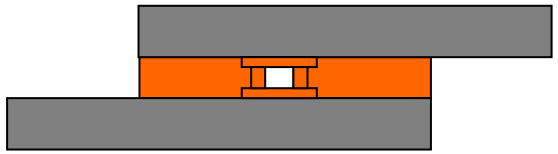
LBL, 2 MHz



LBL, 5 MHz

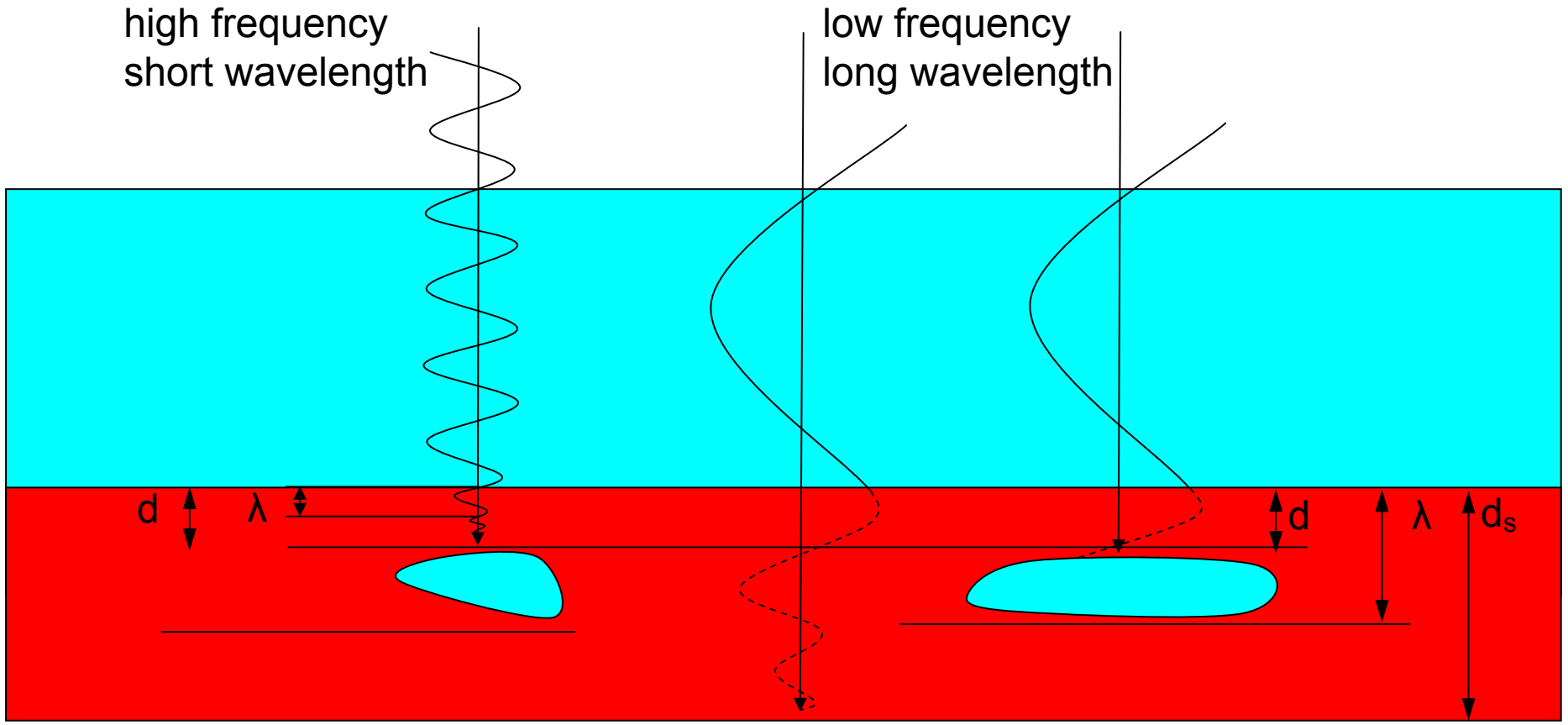


LBL, 20 MHz



- Why is air void at all detectable?
- Why significant dependence on frequency particularly for high frequencies.

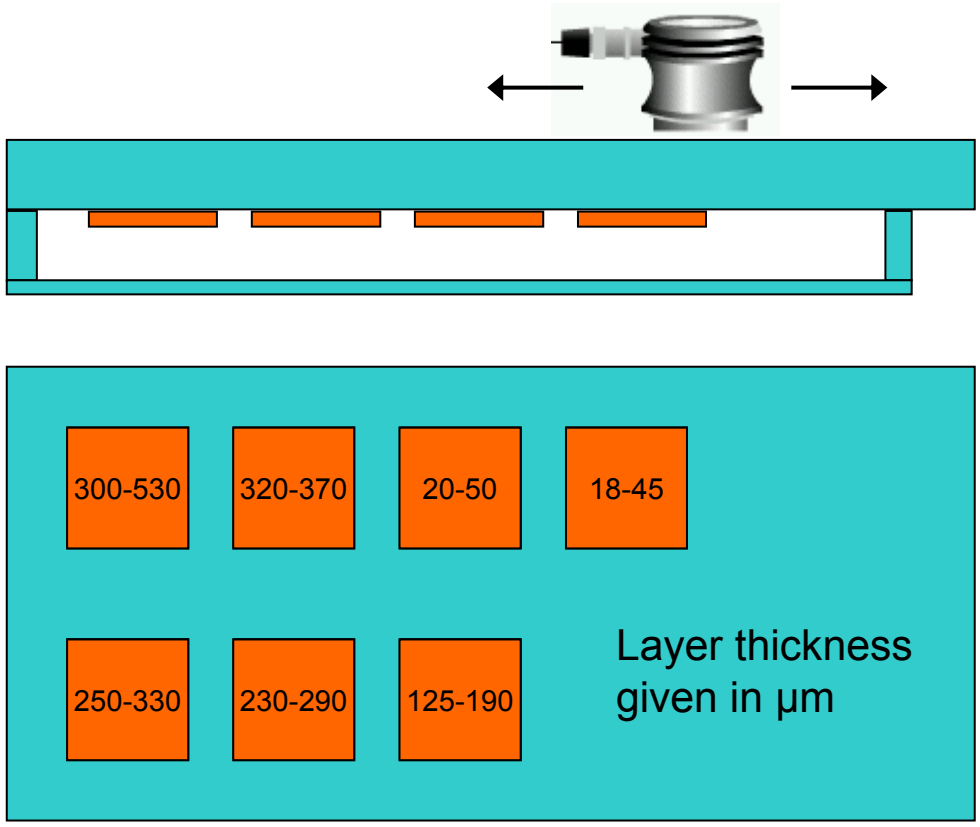
Model considerations



- Interference of waves reflected from interface and from void.
- Strong attenuation in adhesive for higher frequencies.
- Wavelength in adhesive: 2 MHz: 1.0 mm 5 MHz: 0.4 mm 20 MHz: 0.1 mm

Thin layer thickness

- To investigate the relation thin layer thickness ↔ wavelength, a test sample was prepared.

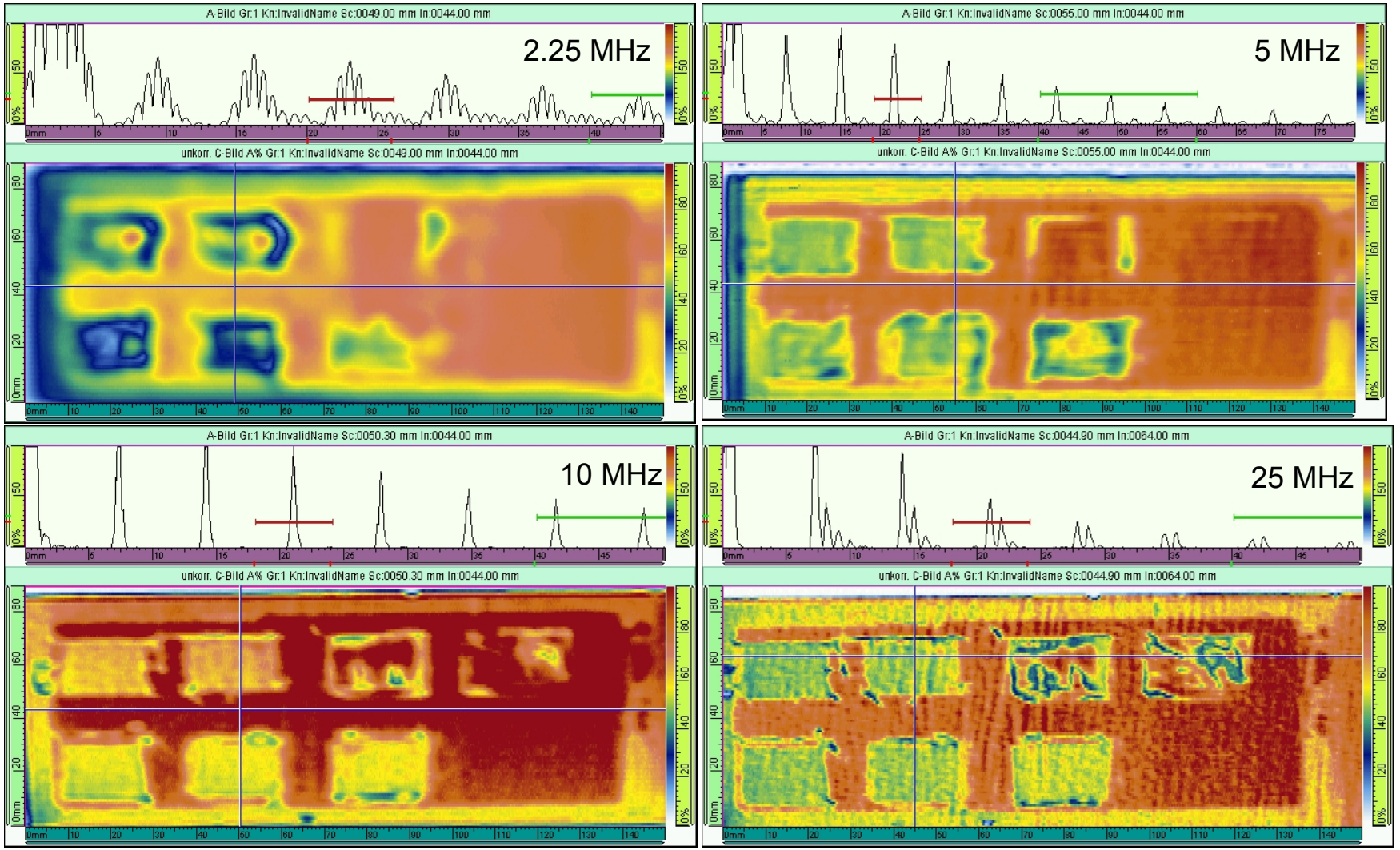


No ‘thick’ adhesive layer present.

Comparison to air backing.

Thin layer thickness

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

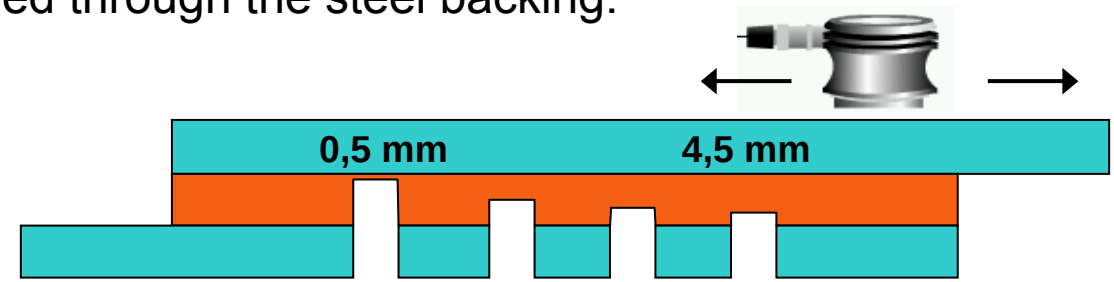


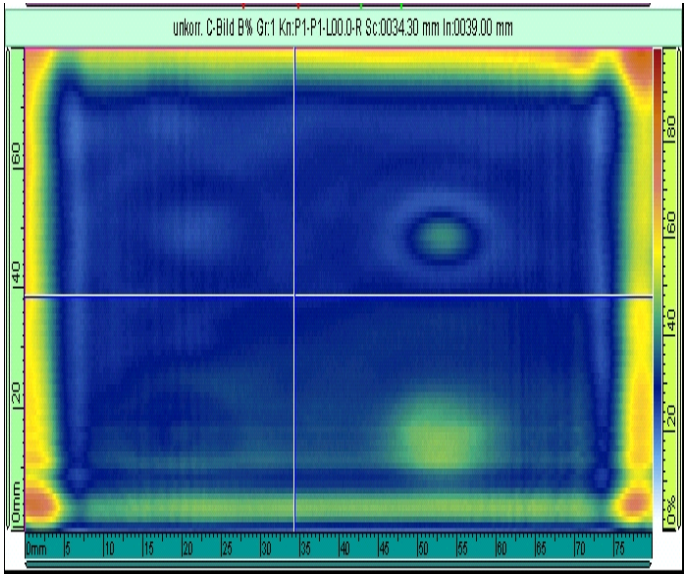
- Thin layers are invisible for low frequencies.

Thick layer thickness

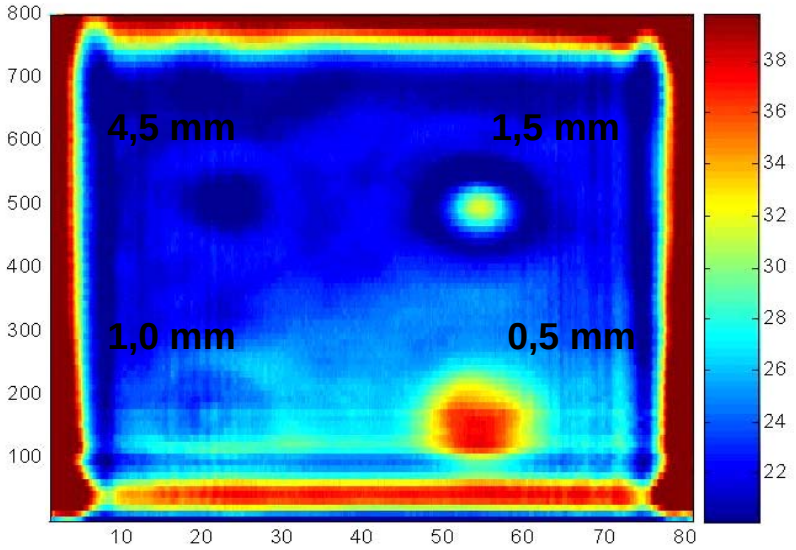
SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

- To investigate the relation thick layer thickness ↔ wavelength, flat bottom holes were drilled through the steel backing.



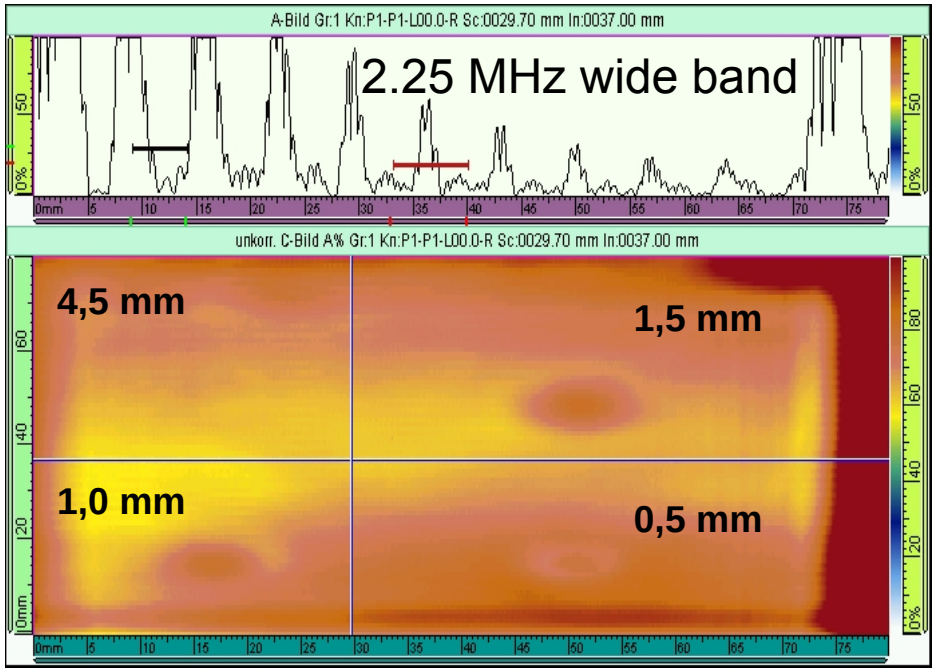


as measured

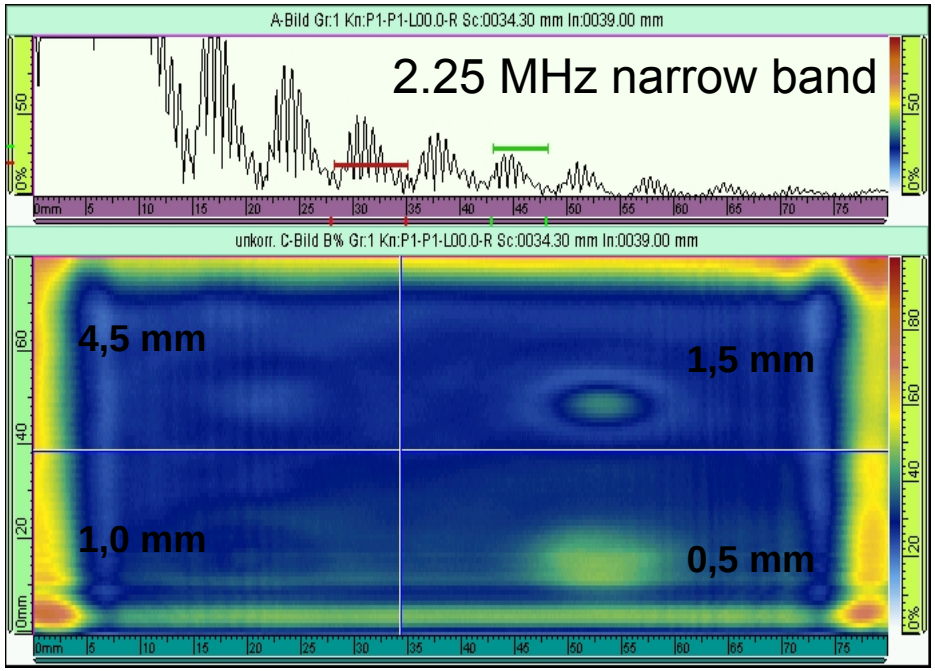


data processed

Thick layer thickness

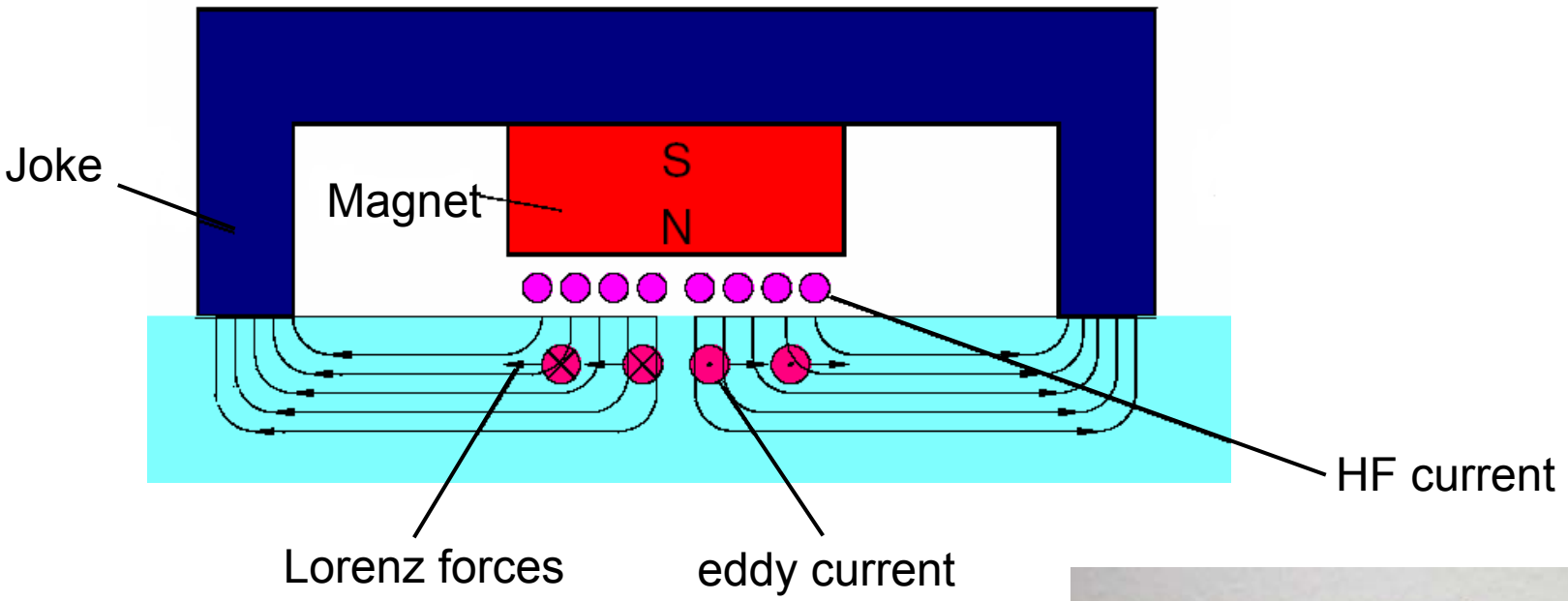


- 4.5 mm flat bottom hole is not visible with ‘normal’ transducer head.



- With narrow band head the pulse is longer. Interference is possible, but contrast is low.

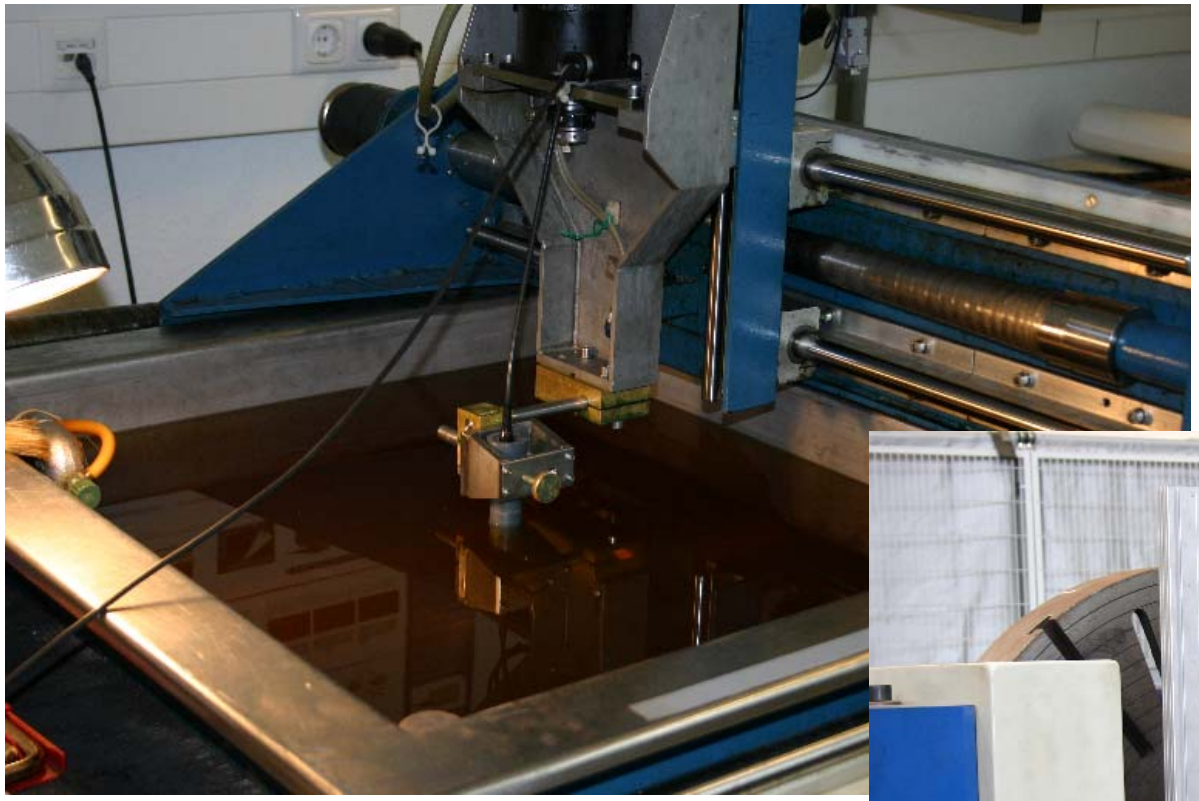
EMAT-Technique



Properties of EMAT-inspection:

- No coupling medium required.
- More sensitive to disturbances.
- Generation of transversal waves.

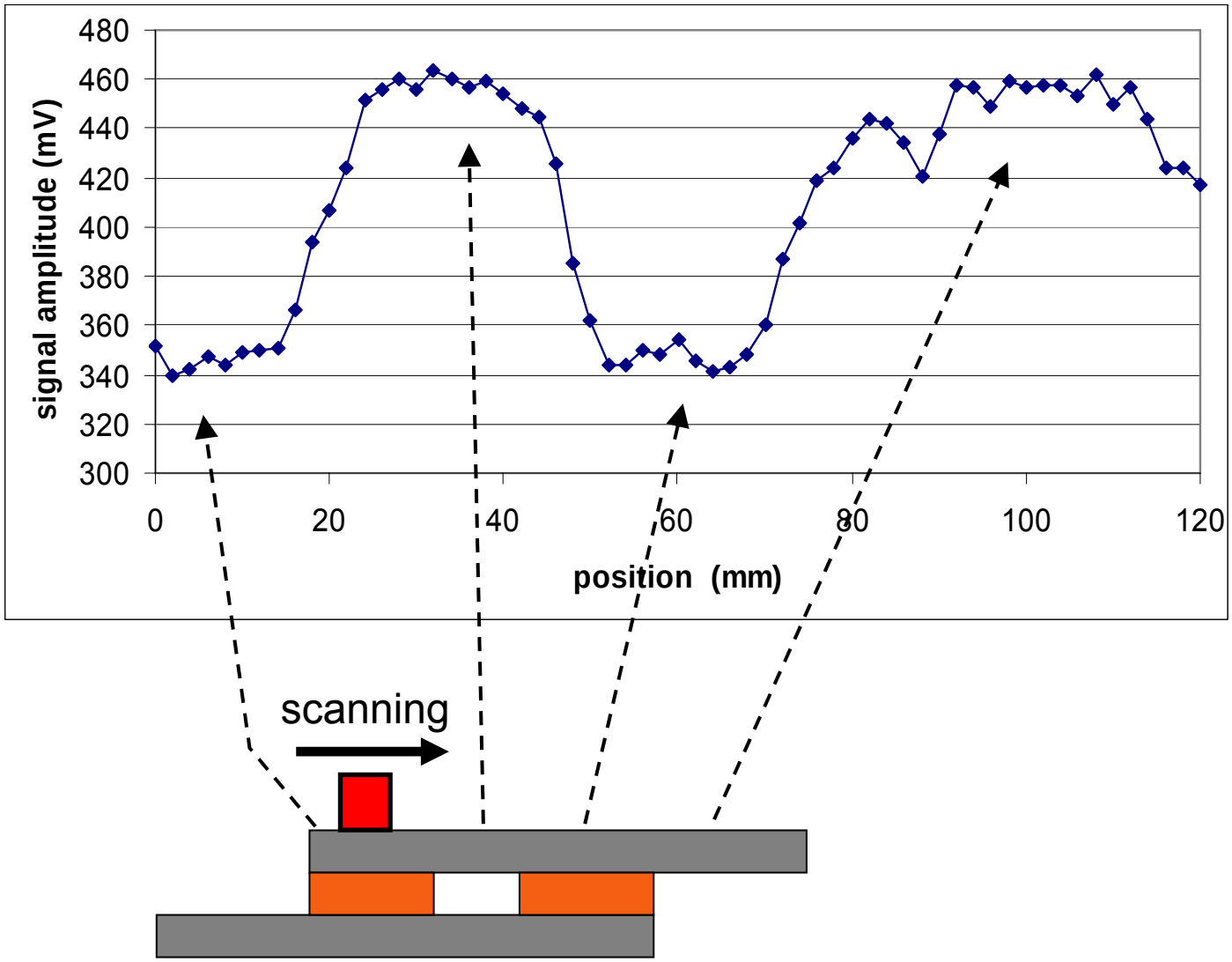
Piezo <-> EMAT-Technique



typical piezo setup

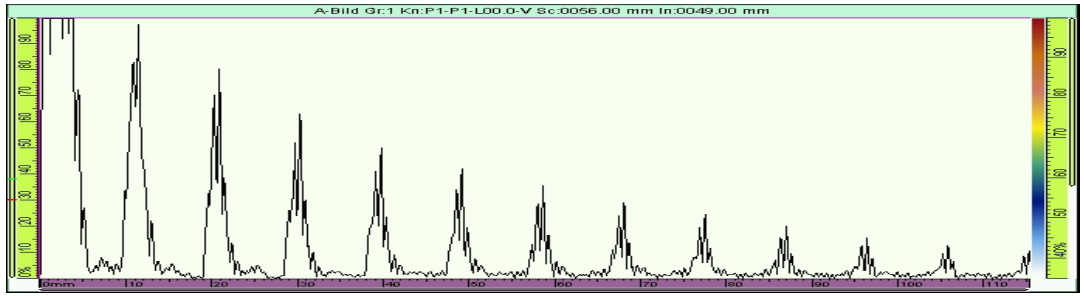
typical EMAT setup

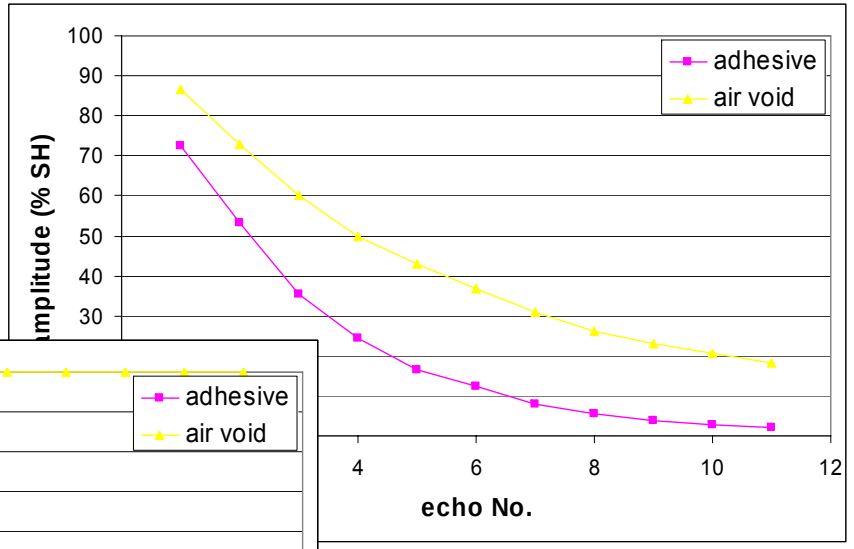
EMAT-Technique

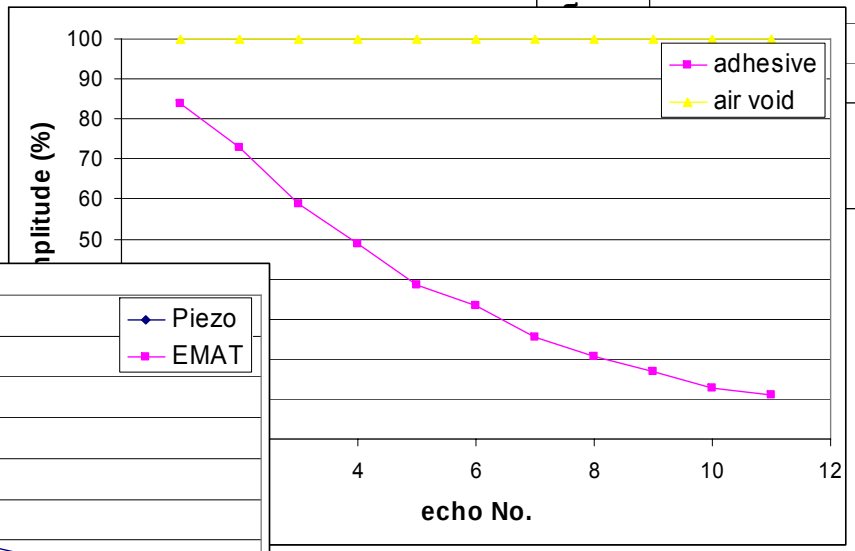


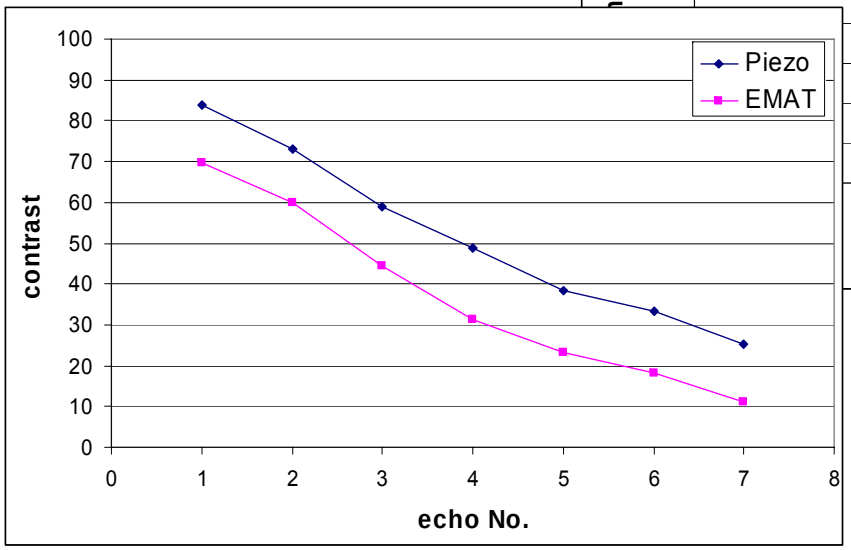
- EMAT technique offers advantages in the field.
- Air void is clearly detectable.
- Lateral resolution is reduced due to coil size (9 mm).

Higher Echoes



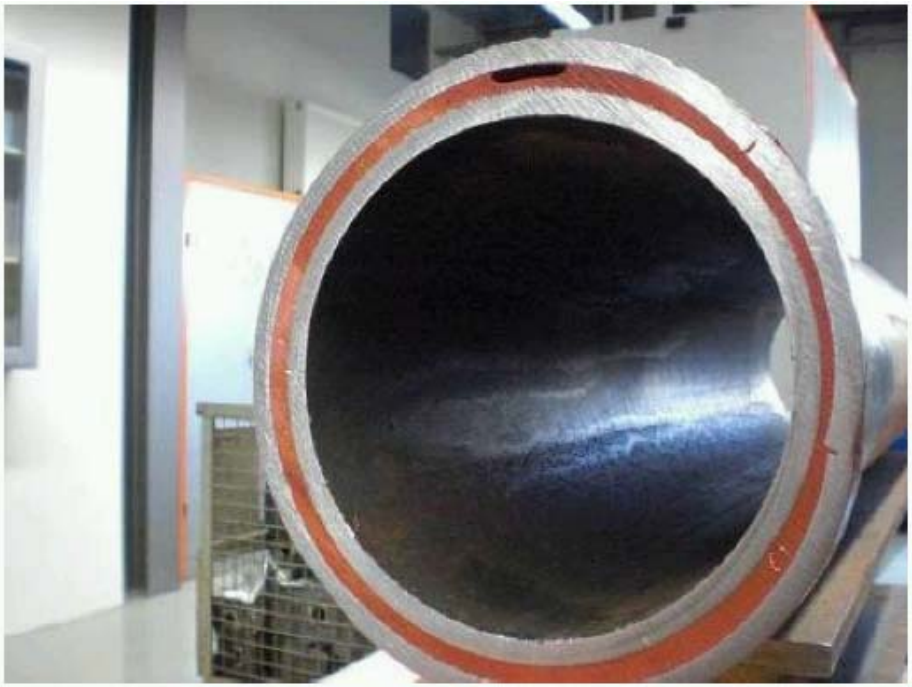






- Use of higher echoes gives advantage of higher sensitivity.
- Attention: noise level

Bonded tubes

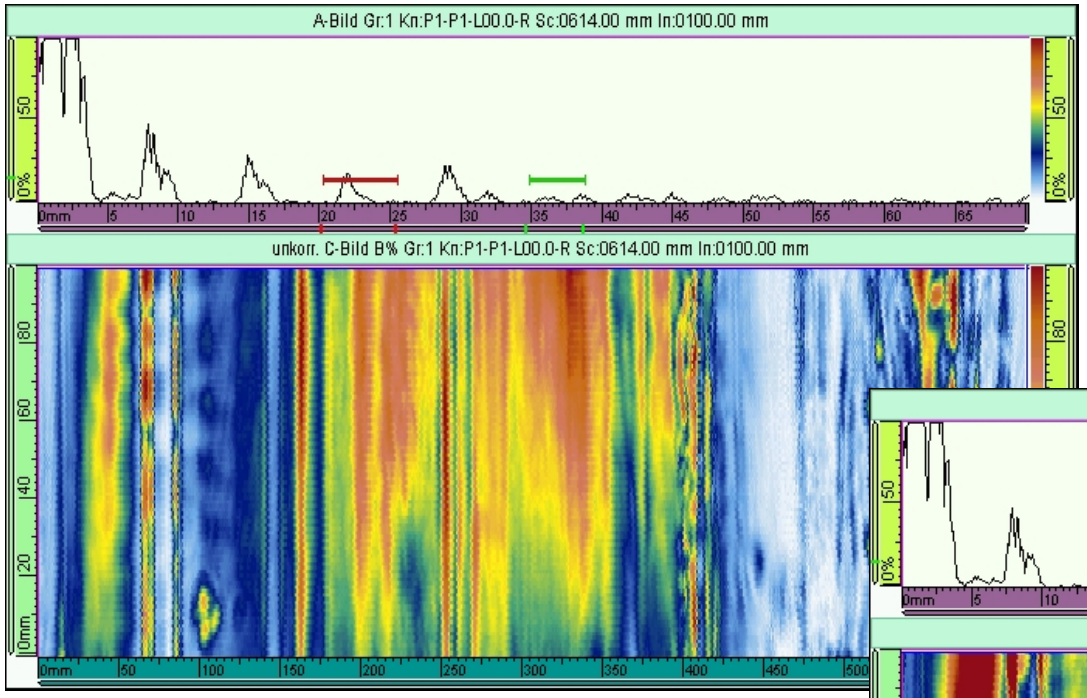


- Next step is investigation of bonded tubes.
- First test generated a large air bubble in the adhesive layer.

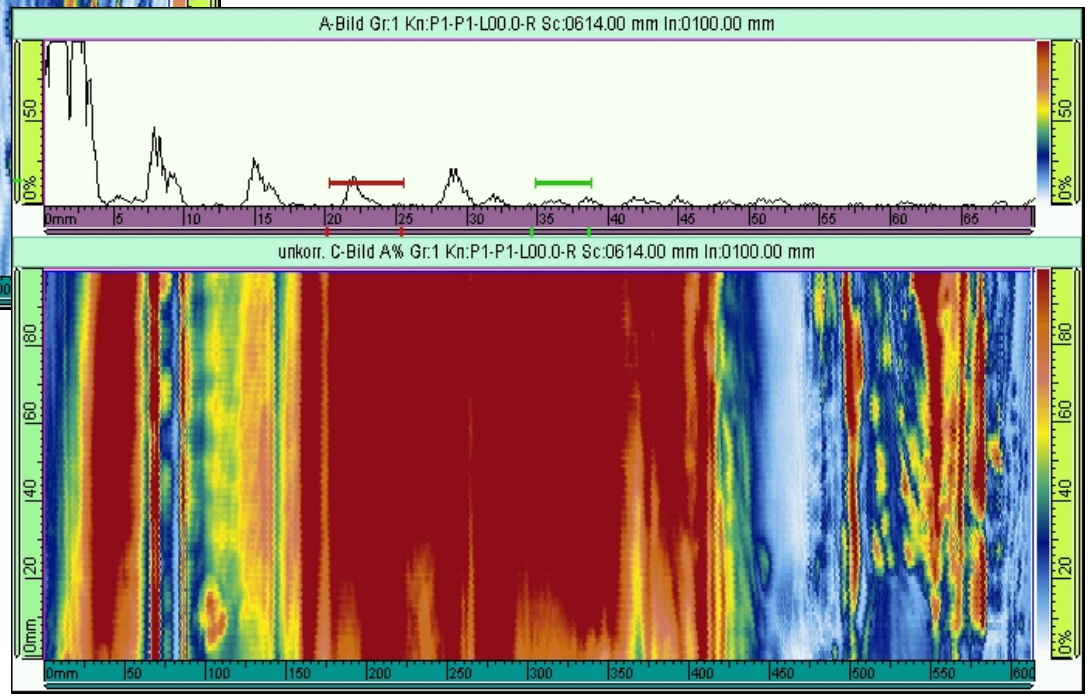
Inspection of bonded tubes

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

Piezo technique



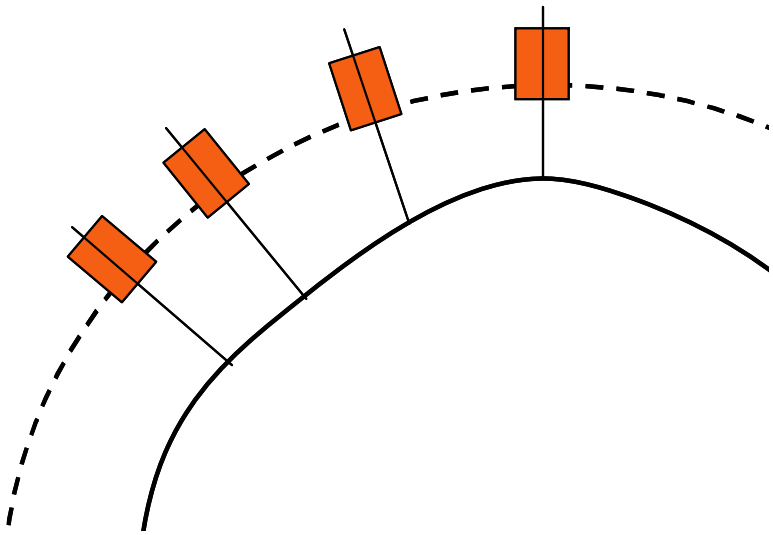
5 MHz 3rd echo



5 MHz 5th echo

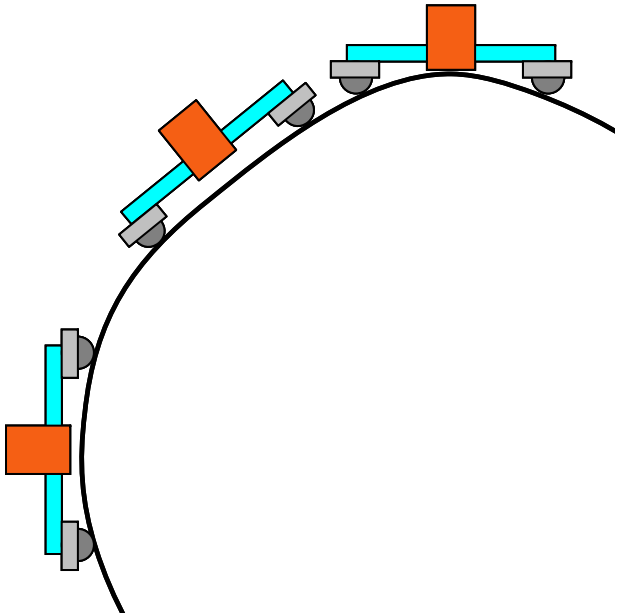
- The large defect is not detectable !!!

Tubes with out-of-roundness



Piezo technique:

- Head ↔ surface distance is changing.
- Angle of incidence is changing.



EMAT technique:

- Head ↔ surface distance is changing !!
- Double influence: magnetic forces and strength of eddy currents.

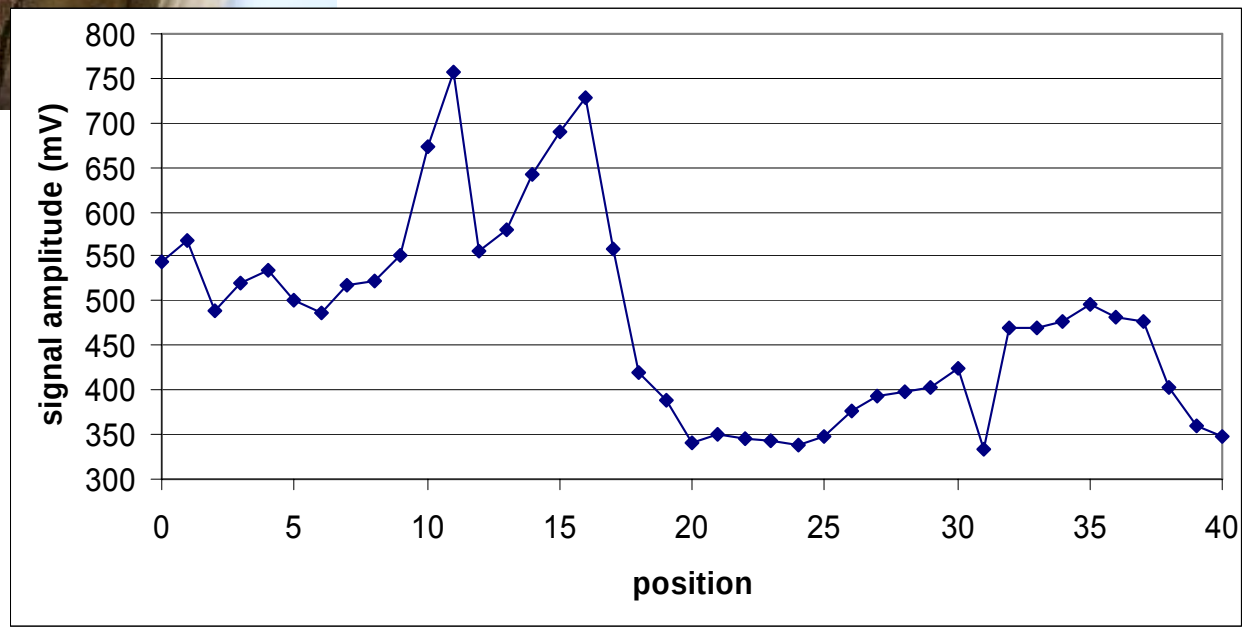
Manual scanning of EMAT: first tube

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

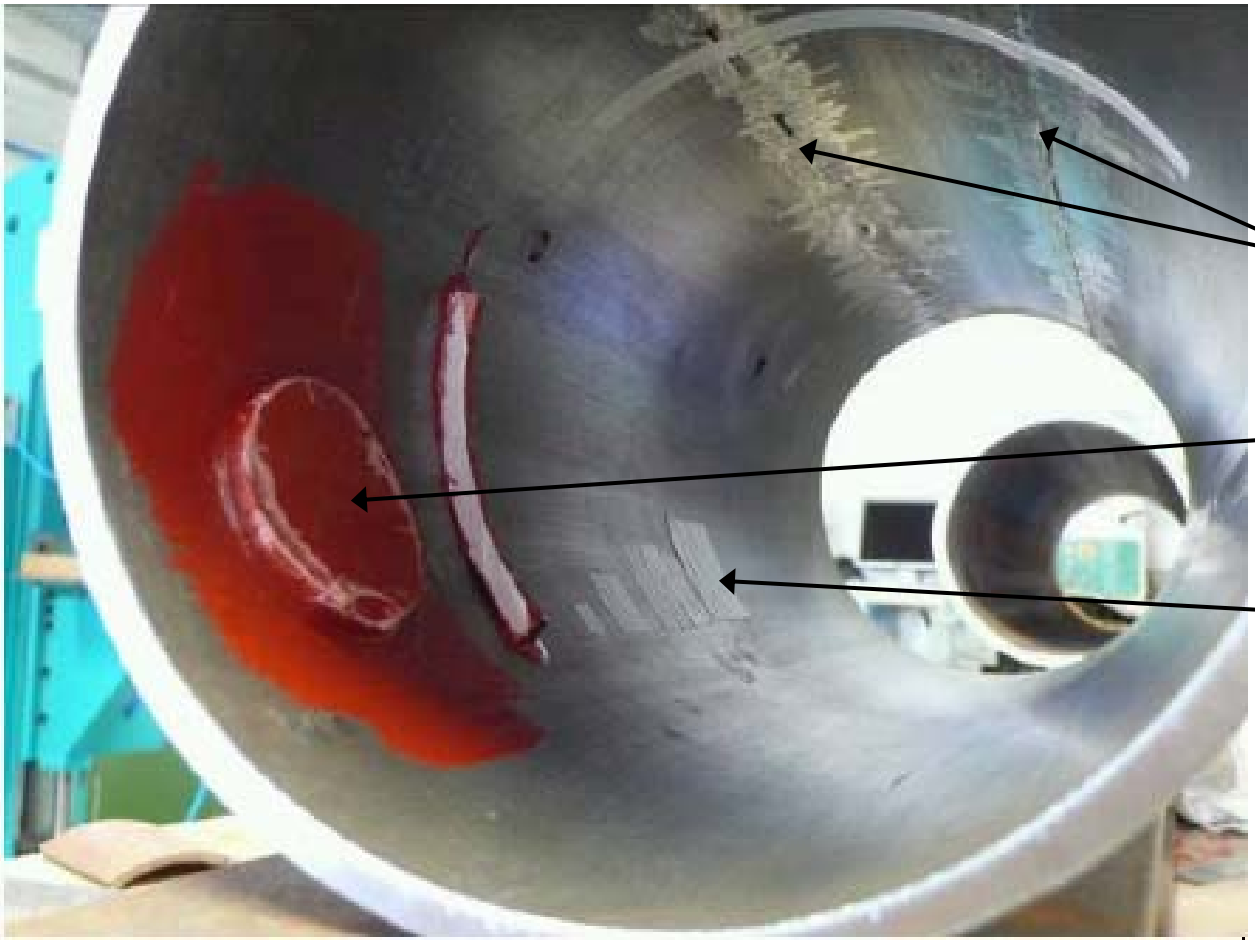
EMAT technique

first tube

- Large defect is detectable if distance variations are eliminated.
- Additional drill hole can be seen as drop in amplitude.



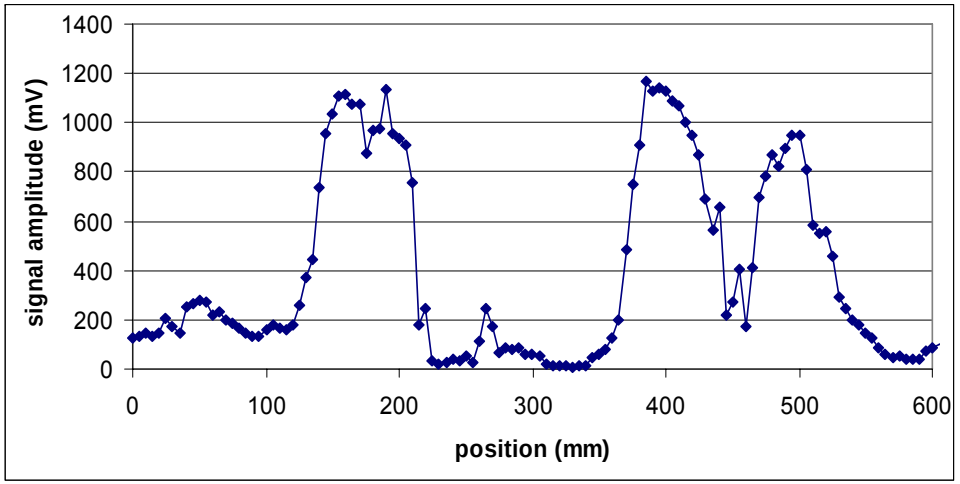
Manual scanning of EMAT: test tube



- Weld seams were ground off extensively on outer surface.
- Same difficulties on automated inspection.

Manual scanning of EMAT: test tube

EMAT technique

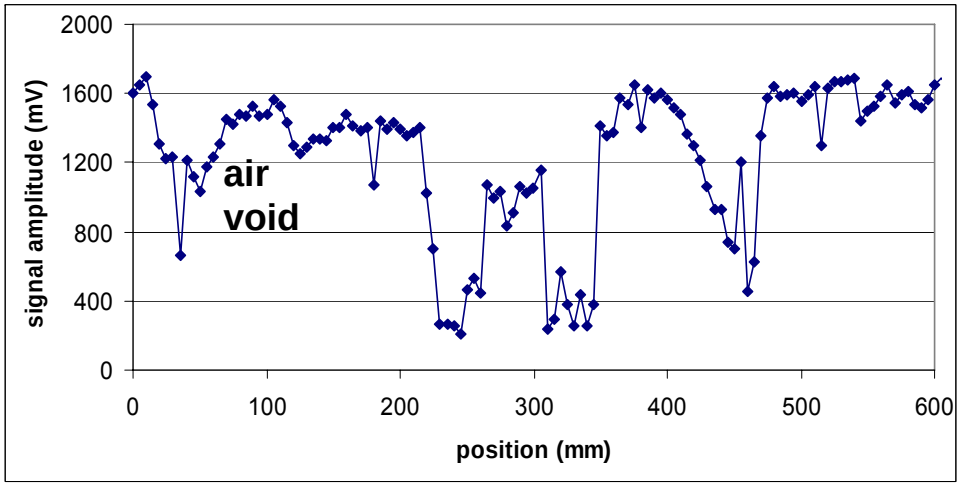


Inspection with carriage

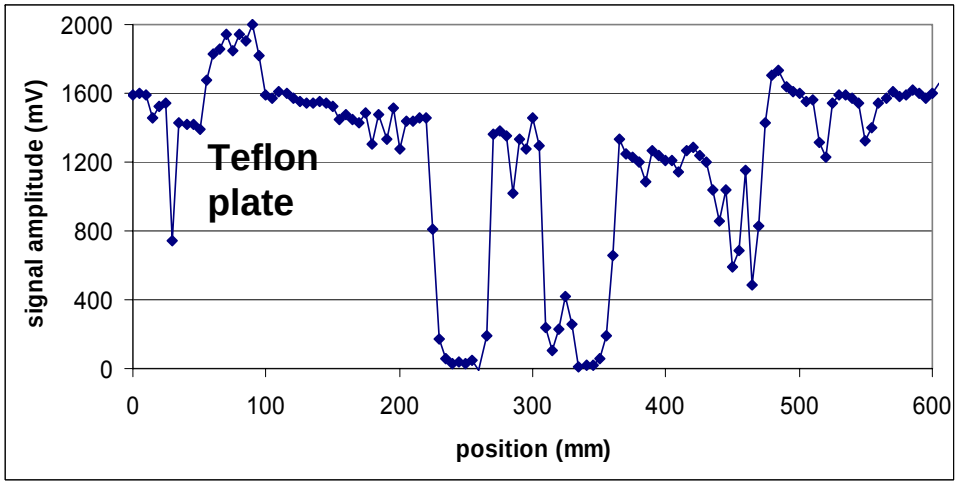
- Defects are detectable.
- Areas of weld seam are not inspectable.
- No significant difference between cured and wet adhesive.
- Tube will be machined.

Inspection in direct contact

cured adhesive



'wet' adhesive

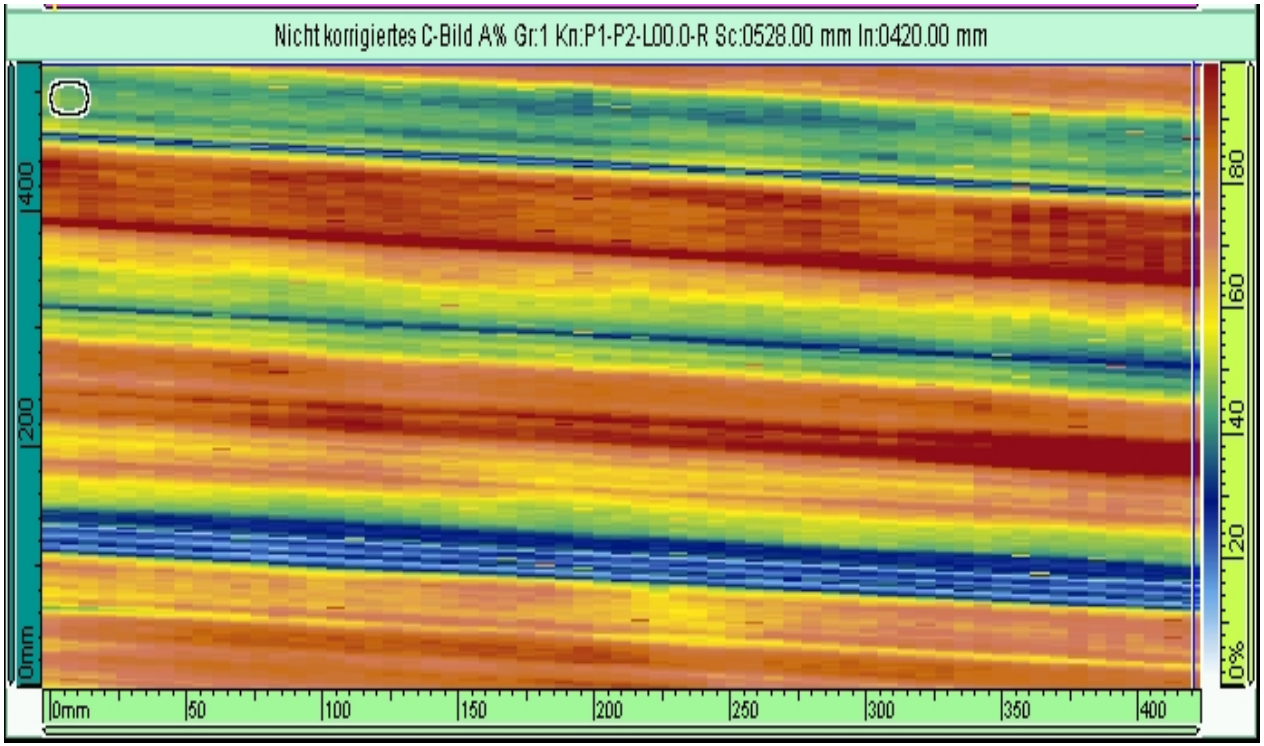


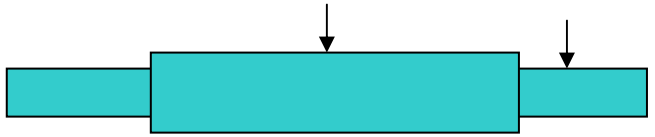
Inspection of ‘naked’ tube

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

- Automated inspection of sleeve with EMAT did not work due to out-of-roundness.
- Inspection of single tube beside sleeve was tested.

EMAT technique





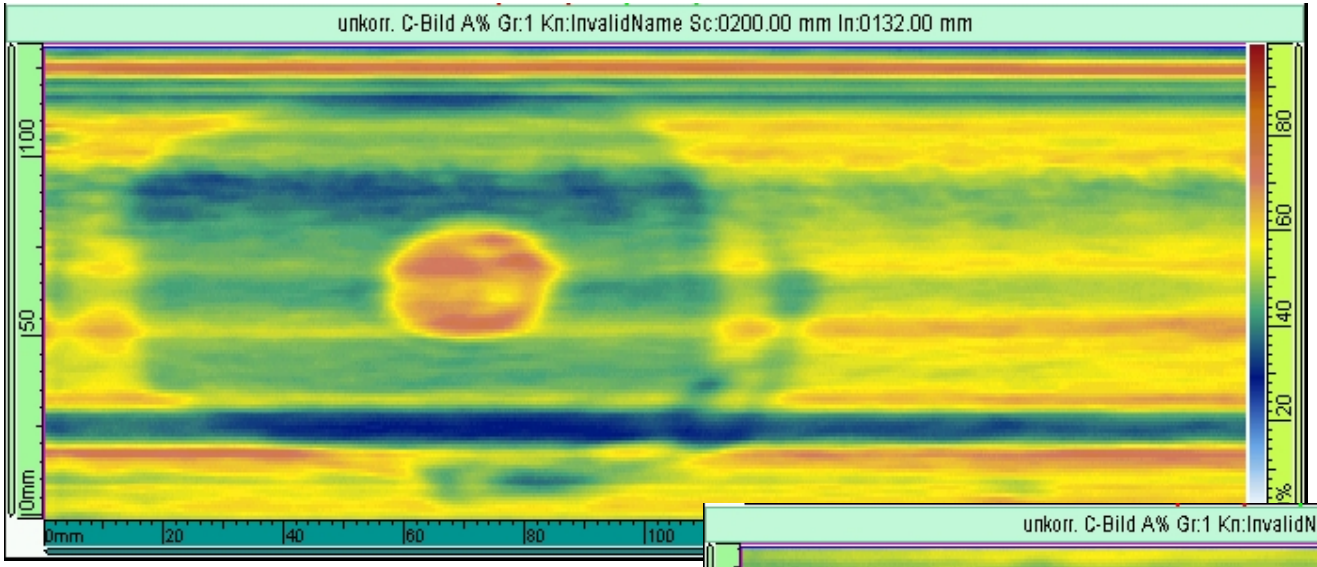
- Small variations due to wt changes and little deviations from perfect roundness.
- Weld seam clearly visible.

Artificial air voids: Piezo technique

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

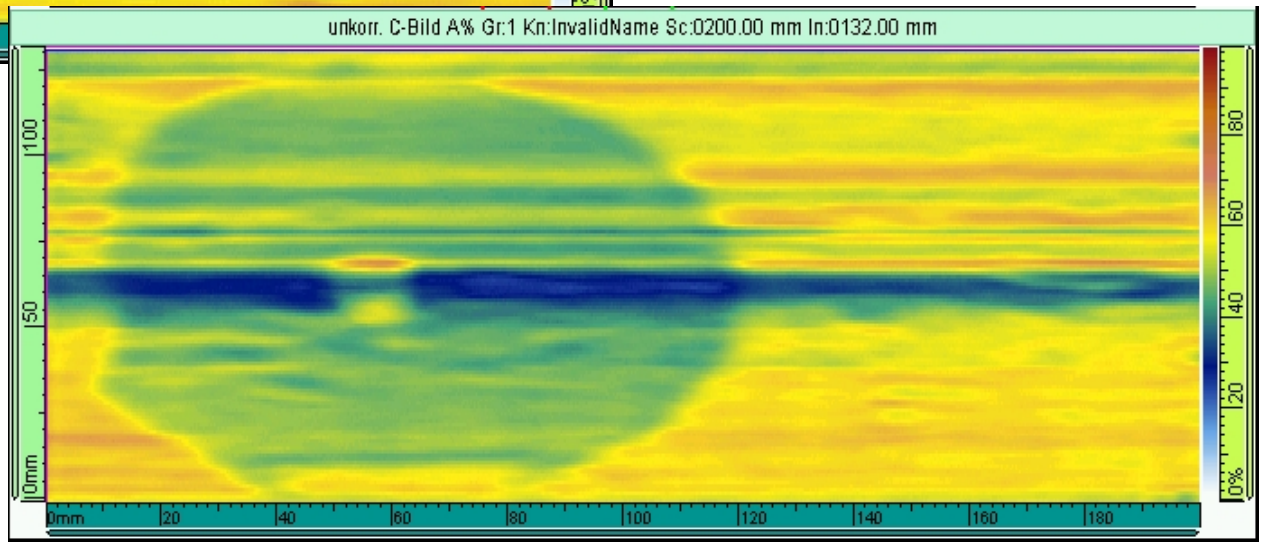
- Manufacture of two artificial air voids.

Piezo technique

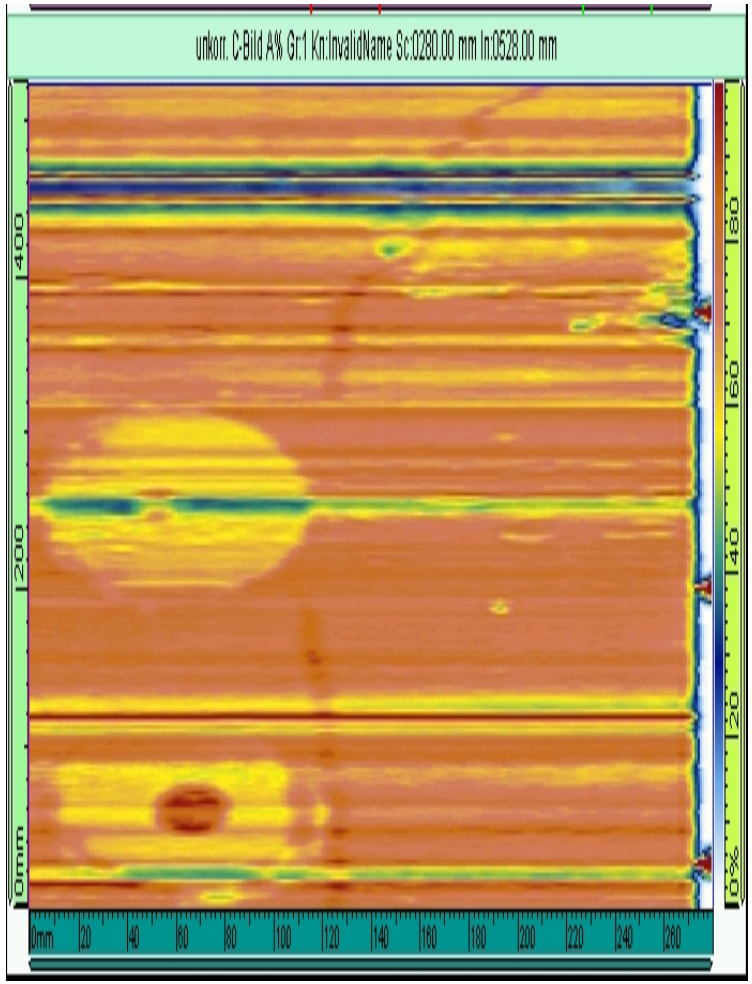


simple
air void

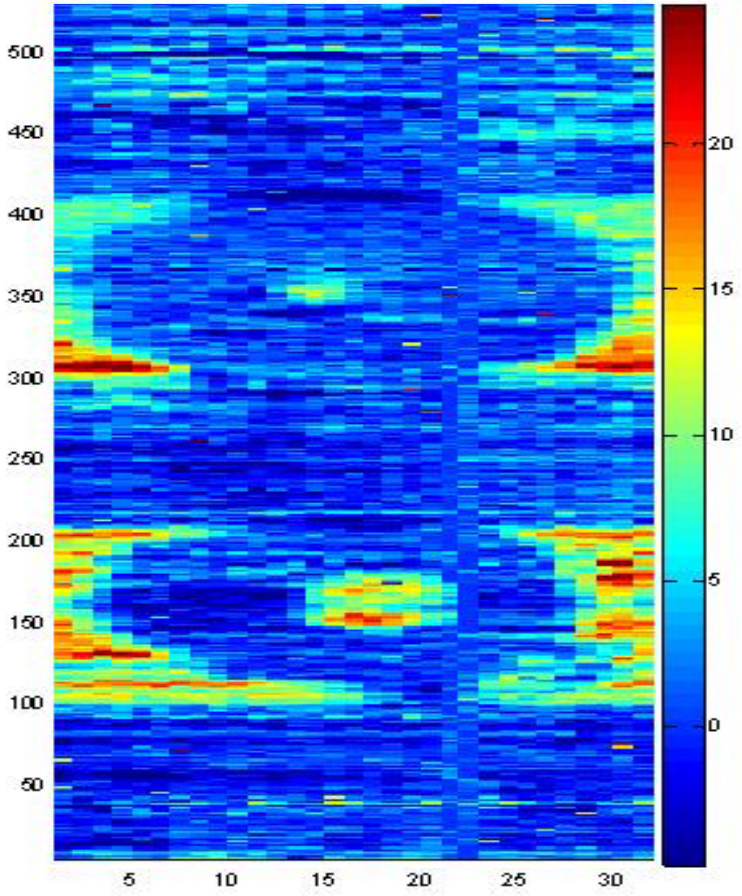
air void with
additional layer



Artificial air voids



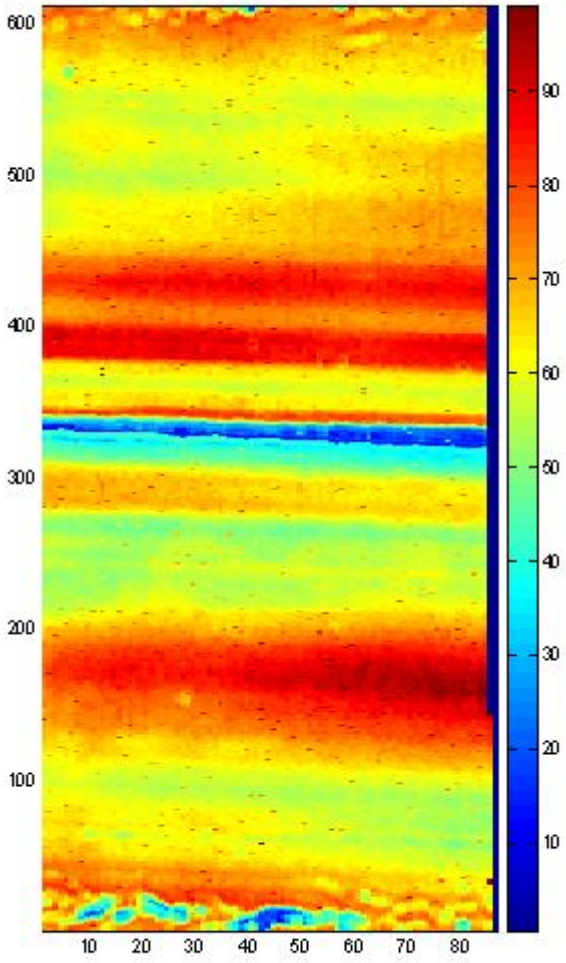
Piezo technique

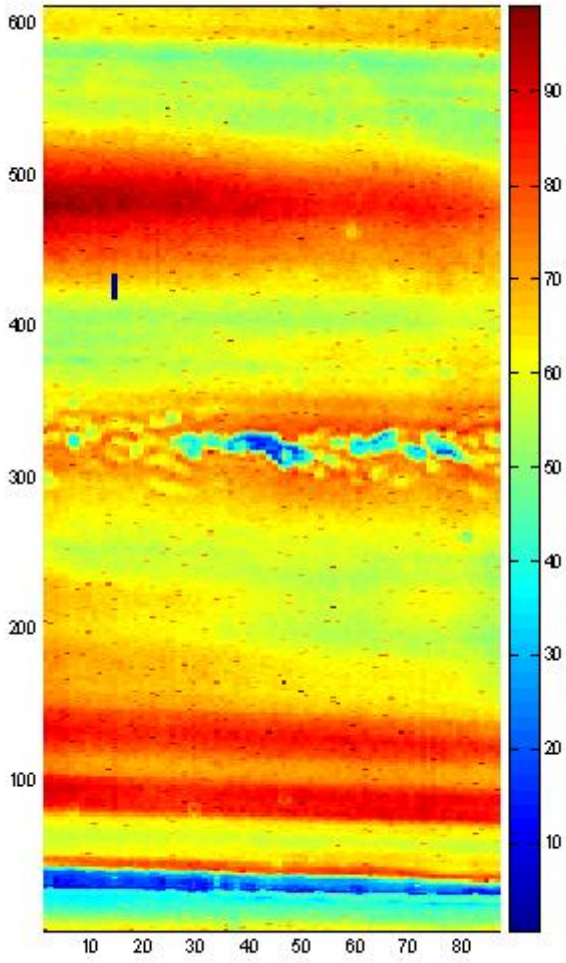


EMAT technique
data processing

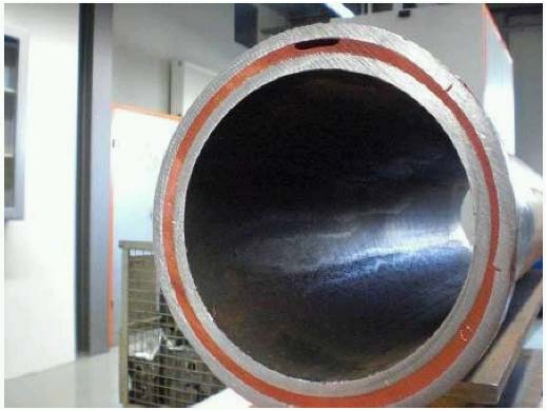
New sleeves

EMAT technique





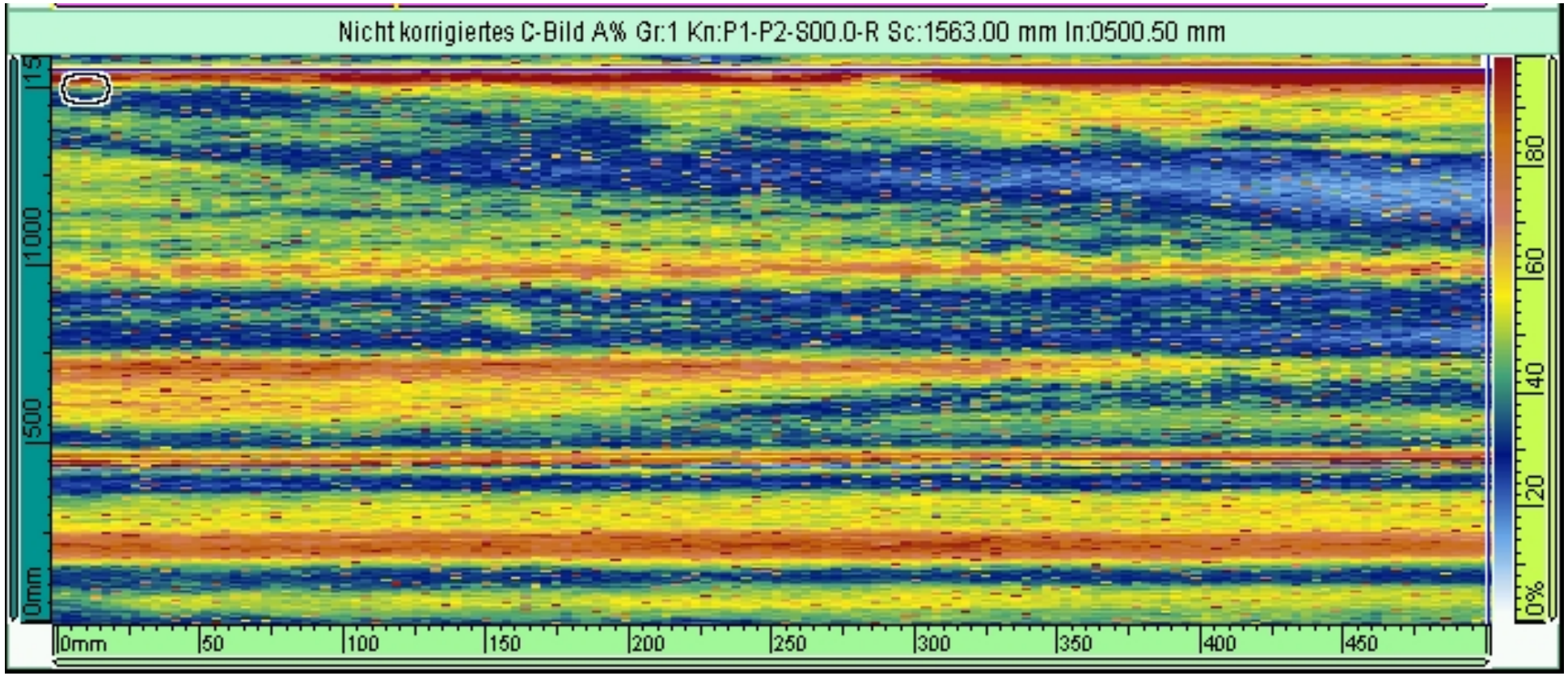
- New sleeves were ordered from external supplier.
- Weld seam still not inspectable.
- Additional not inspectable line visible.
- <u>Solution:</u> place these lines to 3 o'clock and 9 o'clock positions.



Large diameter tubes

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

EMAT technique



- Inspection showed large variations in signal.
- Preceding preparation necessary to ensure reliable inspection.

Summary

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

Results from plates

- Used effect has it origin in transfer of energy to adhesive, not attenuation in steel
- Real defects have thin covering adhesive layer
- Inspection is possible with low frequencies
- Use of higher echoes increases sensitivity
- No. of echo usable is limited by noise level

Results from tubes

- Out-of- roundness gives contribution to signal background
- Important is geometry, not variation in wall thickness
- Sleeves must be prepared / machined to ensure reliable inspection
- Weld seam cannot be inspected → 3 o'clock position
- Developed techniques are promising.
- Question: relevant defects?

Take care for good quality sleeves.