Detection of discontinuities (Item No.: P5160600)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Applied Sciences Engineering	University	Non-Destructive Testing (NDA)	Ultrasounds	Detection of discontinuities

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	2 Hours	2 Students

Additional Requirements:

- PC (Windows)

Experiment Variations:

Keywords:

Ultrasonic echography, Discontinuity, A-Mode, Straight beam probe, Angle beam probe, Reflection, Beam angle, Signal-to-noise ratio

Overview

Principle

The experiment demonstrates the application and performance of various non-destructive test methods with the aid of ultrasound. A test object with different types of discontinuities is used to perform various detection methods. First, the test object is scanned in order to determine which detection method is suitable for which type of defect. Then, the signal-to-noise-ratio is determined for each discontinuity with a straight beam probe, angle beam probe, and a transmitter-receiver probe (TR probe). This is followed by a discussion of the results in view of the selection of the most suitable detection method for a specific task.

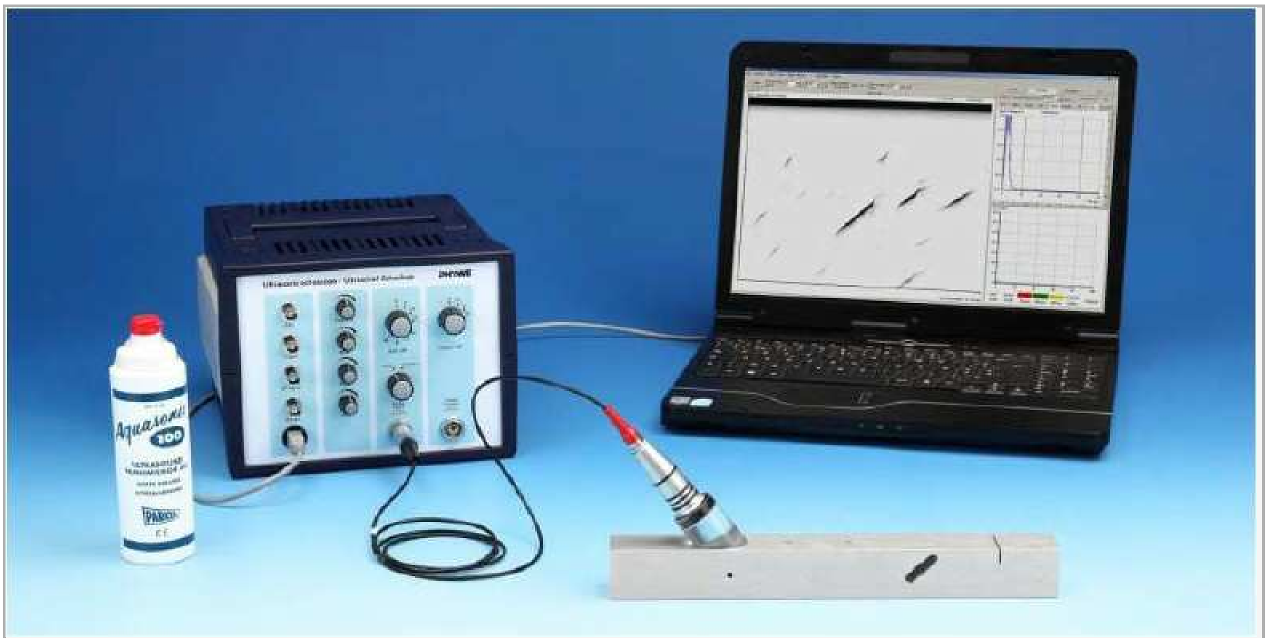


Fig. 1: Detection of discontinuities: experimental set-up

Equipment

Position No.	Material	Order No.	Quantity
1	Basic Set Ultrasonic echoscope II	13924-99	1
2	Extension set: Non destructive testing	13921-01	1
3	Ultrasonic probe 2 MHz	13924-02	1
4	Vernier calliper stainless steel 0-160 mm, 1/20	03010-00	1
5	Ruler, plastic, 200 mm	09937-01	1

Tasks

1. Use a 2 MHz straight beam probe (vertical scanning direction) to define the suitable device parameters at the ultrasonic echoscope. Produce a B-scan of the test object.
2. Assign the various defects (discontinuities) of the test object to the B-scan. Then, determine the signal-to-noise-ratio for each discontinuity in the A-mode.
3. Repeat the above-mentioned tests/measurements on the same test object with an angle beam probe and then with a TR probe (transmitter-receiver probe).
4. Assess and represent the detectability of the discontinuities with the respective test methods.

Set-up and procedure

- Couple the delay line and the TR combination to the ultrasonic probe with the aid of some ultrasound gel. To do so, apply a pea-sized quantity of gel to the centre of the probe surface and attach the delay line or the TR combination. Move the delay line or the probe back and forth in order to distribute the gel evenly on the probe surface. Ensure that no air is trapped in the coupling layer.
- Couple the resulting probe to the test object with the aid of some gel or water. Since, during the measurements, the entire test object will be scanned, it is much easier to use water for coupling.
- Adjust the emitting power ("OUTPUT") and the gain ("GAIN") at the ultrasonic echoscope so that the echo amplitudes can be measured without problems. TGC is not required and it would, in fact, have a negative influence on the measurement of the signal-to-noise-ratio.
- Prior to recording the scans, check whether the signal overshoots at any of the discontinuities.
- Move the probe steadily and slowly over the test object during the scans.
- Ensure that there is always a sufficient amount of water for wetting the surface in order to ensure the consistent coupling of the probe.
- The measurements of the signal-to-noise-ratios of the defects (discontinuities) and the scans are all performed from the side opposite of the crack. Depending on the type of probe that is used, the following discontinuities can be detected (Fig. 2):
  - Cylinder, longitudinal
  - Cylinder, transverse
  - Cylinder, vertical
  - Circular disk, horizontal (blind hole)
  - Crack, oblique
  - Crack, vertical

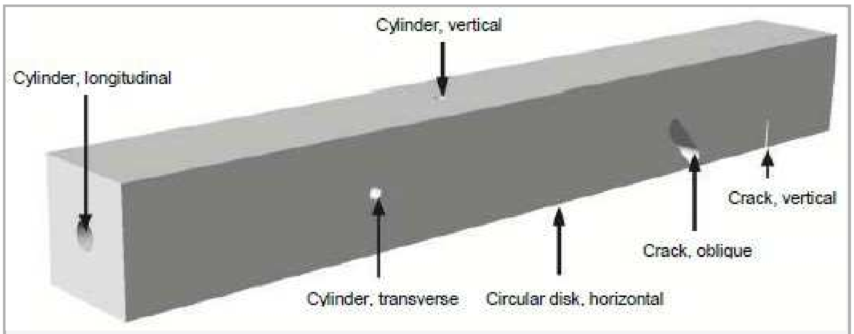


Fig. 2: Aluminium test object with different discontinuities

Straight beam probe:

- Couple the 2 MHz straight beam probe to the test object with the aid of some water. Move the probe on the test object in order to get a general idea of the signal amplitudes of the individual discontinuities and to select suitable emitting and gain settings.
- Then, activate the "B-mode" in the software and produce a sectional image (B-scan) of the test object. To do so, start the image recording process with "Start" and move the probe slowly and steadily over the test object.
- When the probe reaches the end of the test object, stop the scan with "Stop".
- Vary the colour scale and zoom settings in order to optimise the sectional image.
- The image already enables the viewer to estimate which of the discontinuities can be detected well, poorly, or not at all with the straight beam probe. What can be noticed immediately in the sectional image that was produced with the straight beam probe (Fig. 3) is the strong bottom echo and the large number of multiple reflections. The bottom echo is interrupted at each of the discontinuities or it has a low amplitude even if the discontinuity does not produce an echo like the vertical cylinder or oblique crack, for example. In this respect, the bottom echo can be very helpful for the analysis of test objects provided that the test objects have suitable geometrical shapes that enable the evaluation of the bottom echo.

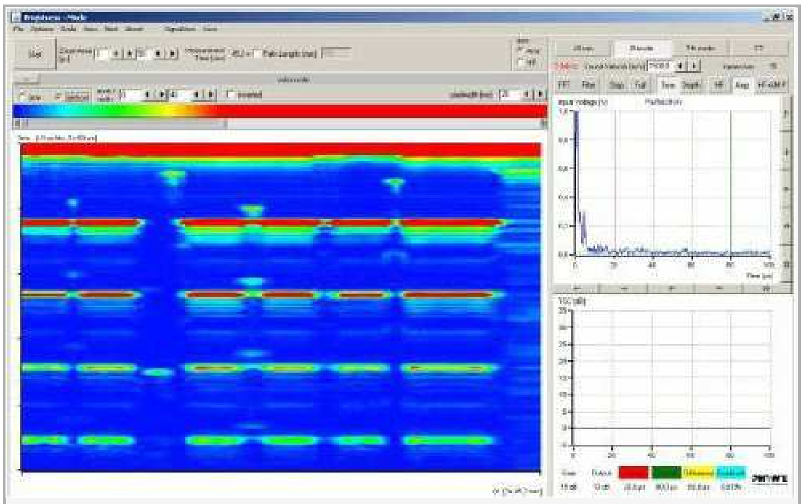


Fig. 3: Sectional image of the test object with the straight beam probe

- Save the sectional image and switch back to the "A-mode".
- Now, measure the signal amplitude and the noise amplitude of each of the discontinuities (Fig. 4 and 5). To do so, position the probe at a discontinuity and determine the maximum signal amplitude. Ensure that it is actually the signal of the discontinuity in question in order to avoid misinterpretations. The upper end of the oblique crack, for example, displays a very strong reflection signal. This, however, has nothing to do with the reflection on the oblique surface, which is why it must not be interpreted as an echo at the oblique crack.

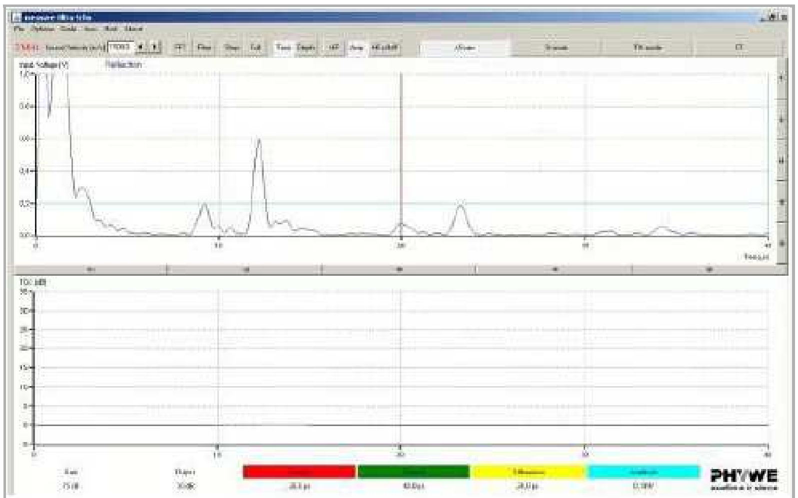


Fig. 4: Measurement of the signal amplitude at the vertical crack with the straight beam probe

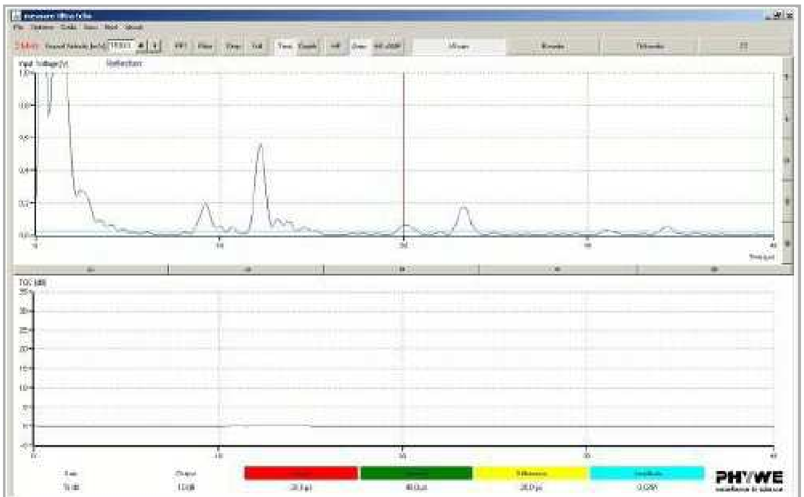


Fig. 5: Measurement of the noise amplitude at the vertical crack with the straight beam probe

In order to perform the measurement, move the horizontal measurement cursor to the maximum of the signal amplitude and then to the maximum of the noise signal.

Again, the precise interpretation of the signals is of the utmost importance, since often smaller multiple echoes may be interpreted as noise. Moving the test object slightly to and fro helps to determine whether it is noise (which would not change during the movement) or small echoes.

Angle beam probe 38°:

For the measurement with the angle beam probe, couple the delay line to the probe as described above and position the resulting probe on the test object. The tip of the angle beam probe points in the scanning direction. Then, produce a sectional image of the test object as described above (Fig. 6).

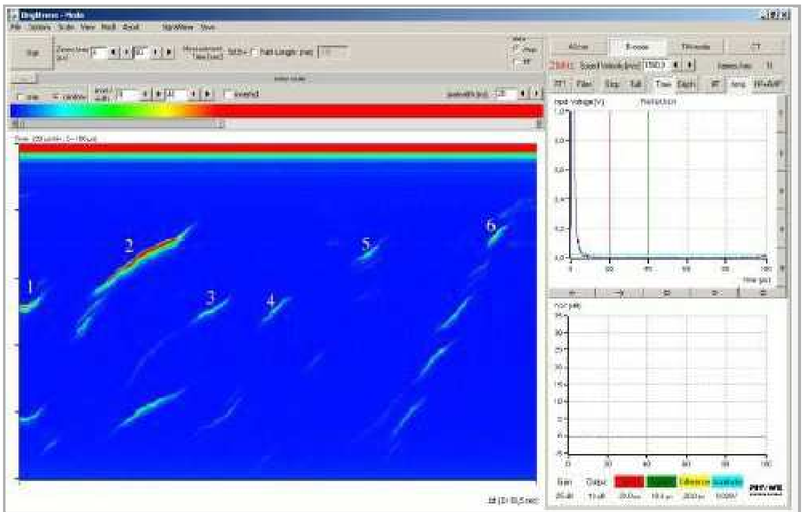


Fig. 6: Sectional image of the test object with the angle beam probe (tip pointing in the scanning direction)

The inclined beam angle makes the interpretation of the sectional image a little more difficult. What can be noticed immediately is that there is no bottom echo. As a result, the boundaries of the test object cannot be discerned. The position and order of the recorded echoes enable the following interpretation:

Echo 1: The strong signal at 1 is the corner echo of the crack and of the test object edge, so that the depth of the object edge can be located in the sectional image. At the right-hand end of the echo, slightly above it, there is another very weak echo that can be interpreted as a scatter signal (TOFD method) of the upper edge of the crack.

Echo 2: At 2, the strong echo of the oblique crack can be seen. The beam angle and the position of the crack cause the strong signal by direct reflection. Slightly below the echo, another, significantly weaker, echo can be seen that is located farther away than the lower edge of the test object, since it was measured at full skip distance.

Echoes 3 and 4: Both echoes are on the same level with echo 1, since they are corner echoes of the vertical cylinder and of the circular disk. The circular disk itself, i.e. the upper end of the blind hole, does not supply any echo with measurable amplitude. This is why this discontinuity is also perceived as a cylinder.

Echo 5: This is the echo of the transverse cylinder, approximately at a medium depth.

Echo 6: The vertical circular disk (base of the blind hole) can be detected with the aid of the scatter signal at the upper edge. The cylindrical wall of the hole does not produce any echoes.

In greater depths, there are several other echoes that are either caused by multiple reflections, or these are the echoes at full and double skip distance.

If the probe is turned 180° with regard to the scanning direction, the resulting sectional image changes considerably, and this is why it is not interpreted here. This does show, however, that the alignment of the probe is decisive for the test result (Fig. 7).

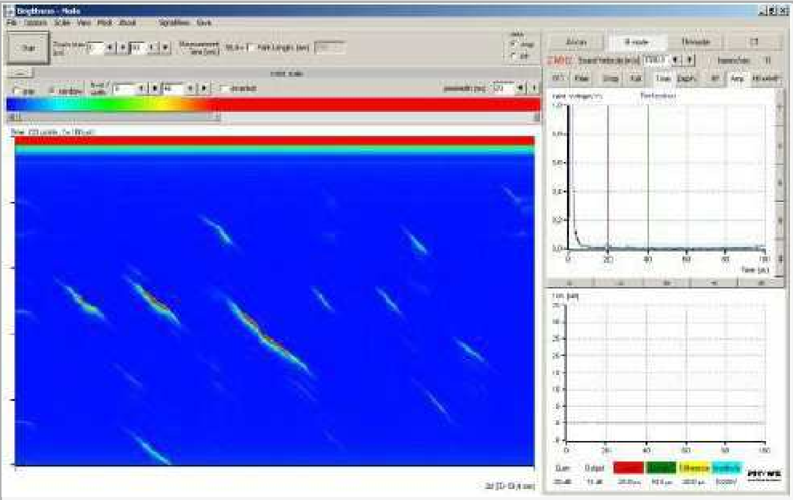


Fig. 7: Sectional image of the test object with the angle beam probe (tip pointing away from the scanning direction)

After the recording of the sectional images, switch back to the A-mode and measure the echo amplitudes of the various echoes. The sectional image that was recorded beforehand is very helpful for locating and interpreting the individual echoes. The exact calibration against the echo maximum is absolutely indispensible for the measurement of the echo amplitudes since, with an inclined beam entry angle, the influence of a potential miscalibration is strongly increased (Fig. 8 and 9).

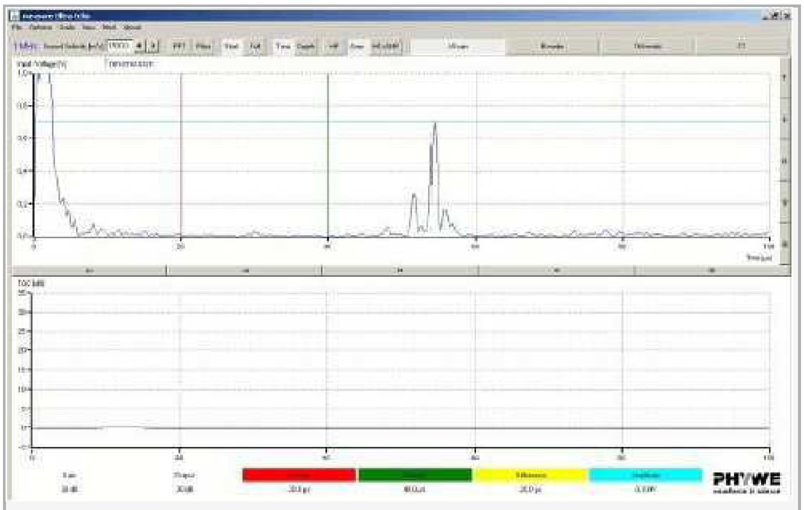


Fig. 8: Measurement of the signal amplitude at the vertical crack with the angle beam probe

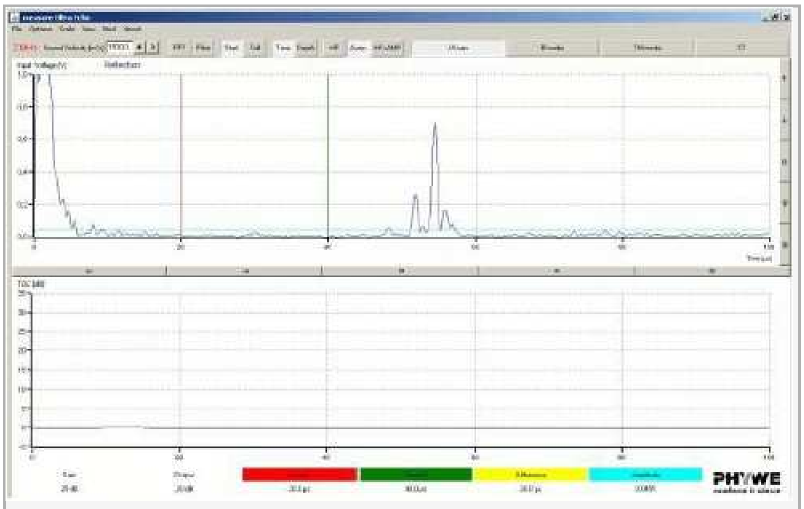


Fig. 9: Measurement of the noise amplitude at the vertical crack with the angle beam probe

TR probe:

The TR probe is obtained by combining two 2 MHz probes with the TR delay line. In this case, too, the optimum coupling with ultrasound gel is of the utmost importance. Select the TRANSMISSION mode at the ultrasonic echoscope. Following the selection of suitable device settings, produce a sectional image of the test object with the TR probe as described above (Fig. 10).

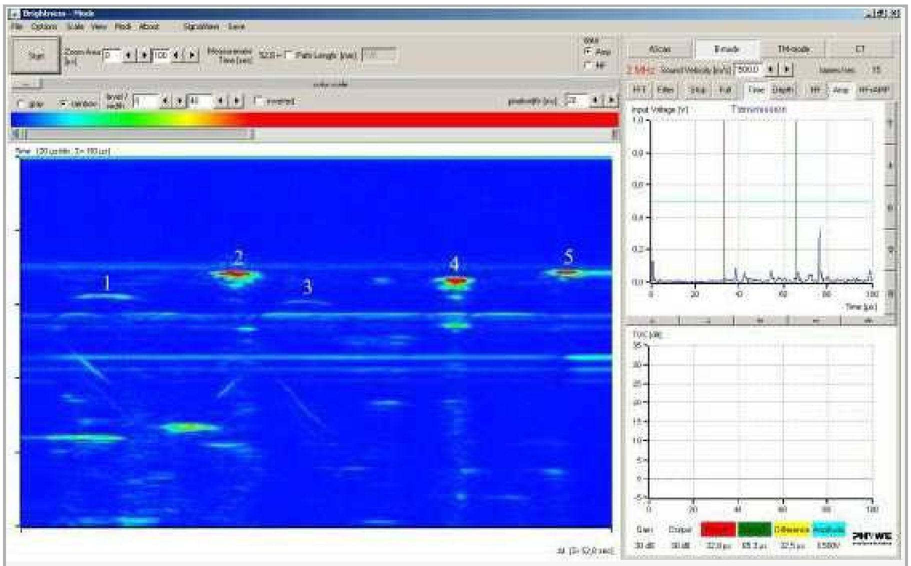


Fig. 10: Sectional image of the test object with the TR probe

- Sectional images that are produced with TR probes essentially show scattering discontinuities, since direct reflection echoes can only be obtained from a certain depth. This depth depends on the sound velocity and geometry of the TR probe.
- Multiple reflections and transverse, curved surfaces, however, may lead to echoes that are difficult to interpret.
- The image shows several horizontal lines. These lines, however, are not echoes from the test object. Instead, they are produced by a direct sound transition in the delay line of the TR probe. These echoes also appear when the probe is not coupled to the test object, so that they can be easily identified.
- Echo 1: At the upper edge of the vertical crack, the ultrasonic waves are scattered in all directions, thereby creating a signal at the receiver probe. The signal amplitude, however, is small compared to reflected echoes, since it is caused by scattering. The scatter echo can be observed over a longer scanning distance. This effect is caused by the width of the sound beam that is also displayed.
- Echo 2: This is the sound reflection at the curved upper edge of the oblique crack. Since this echo has nothing to do with the actual character of the discontinuity, it will not be taken into consideration.
- Echo 3: The conditions that apply to the horizontal circular disk are similar to those of the vertical crack. The signal amplitude, however, is smaller since the circular disk only has a small expansion.
- Echo 4: The transverse cylinder generates a strong echo due to its extensive, curved surface.
- Echo 5: The vertical circular disk also has a curved surface that reflects the sound in numerous different directions, which in turn leads to a strong echo.
- After the recording of the sectional images with the TR probe, switch to the A-mode and measure the echo amplitudes of the described echoes. With this probe, too, the exact calibration against the echo maximum is absolutely indispensible for the measurement of the echo amplitudes. Ensure additionally that you measure the correct echo. Errors can be caused easily by the incorrect assignment of the signal peak to the wrong discontinuity (Fig. 11).

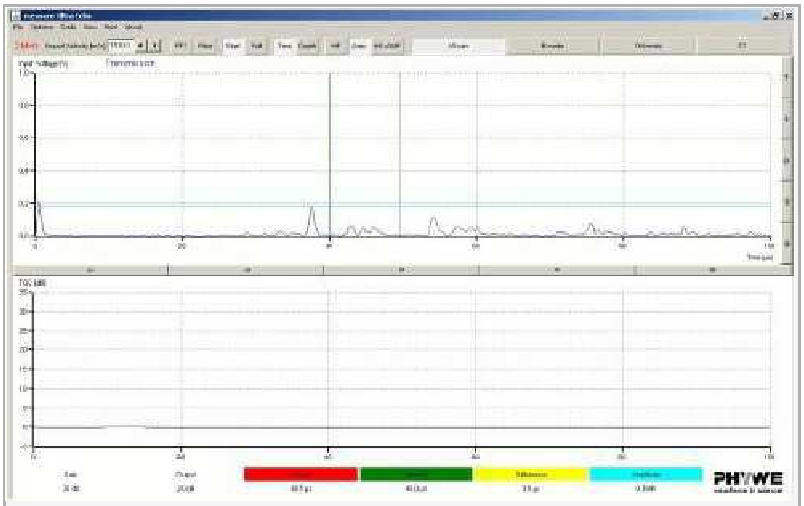


Fig. 11: Measurement of the signal amplitude at the vertical crack with the TR probe

When measuring the noise amplitudes, ensure that the small echoes that are caused by the TR delay line are also interpreted as noise, since only those echoes that lie above this signal level can be evaluated (Fig. 12).

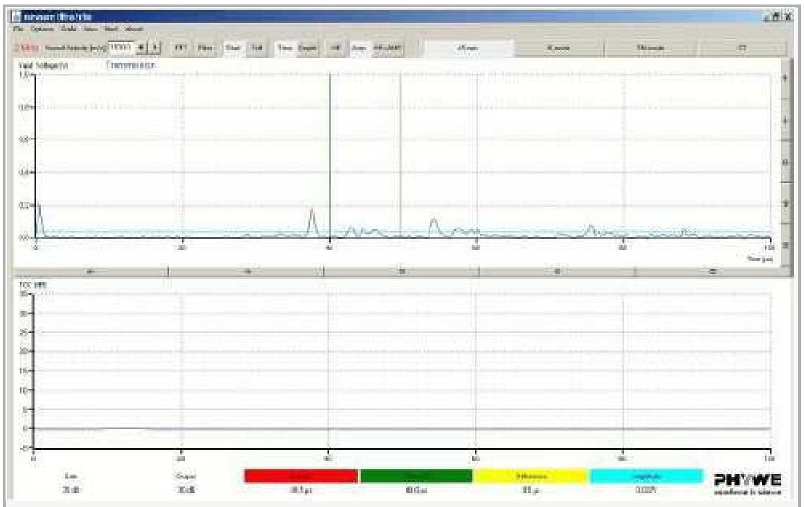


Fig. 12: Measurement of the noise amplitude at the vertical crack with the TR probe

Important

Never use alcohol or liquids with solvents to clean the delay line or the TR combination. Gel residues can be removed with some washing liquid, water, and perhaps a soft brush.

Theory and evaluation

Evaluation

During non-destructive testing with ultrasound, the geometry of the test object as well as the position and orientation of the discontinuities require sound to be introduced and to be received from different directions. The direction of incidence is always measured by referring to the surface normal. The direction of the incident waves leads to three classes of detection methods: normal (vertical), inclined, and orthogonal direction of incidence (scanning direction). The received signal amplitude depends on the type, size, and orientation of the discontinuity. Two fundamental interactions between the discontinuity and the ultrasound can be distinguished: reflection (strong interaction) and scattering (weak interaction). For the reliable detection of a discontinuity in the test object, the selected detection method must provide a sufficient signal-to-noise-ratio:

$$A = 20 \log U_s / U_r [\mathrm{dB}] \quad (1)$$

with U_r as the noise amplitude and U_S as the signal amplitude. Specific recording thresholds are defined for the detection limits of the individual discontinuities and detection methods. Since the ultrasound echoes of real discontinuities are usually a mixture of reflection and scattering, detection thresholds that are too low can easily lead to misinterpretations. In order to detect discontinuities with strong interactions, the sensitivity of the ultrasonic echoscope must be adapted with the aid of idealised test reflectors. Typical test reflectors are circular disks (blind holes), cylinders (through-holes), back surfaces, and corner reflectors (grooves) with different geometrical orientations.

During the measurement of the various amplitudes, the problems concerning the evaluation of ultrasound signals at discontinuities become very obvious. The correct alignment of the probe with regard to the discontinuity has a strong influence on the signal amplitude. If the positioning is not good, the echo signals can easily fall below the detection limit. In addition, the separation between noise signals and useful signals is often difficult, since some discontinuities produce numerous small echoes due to scattering effects or multiple echoes are superimposed by other discontinuities.

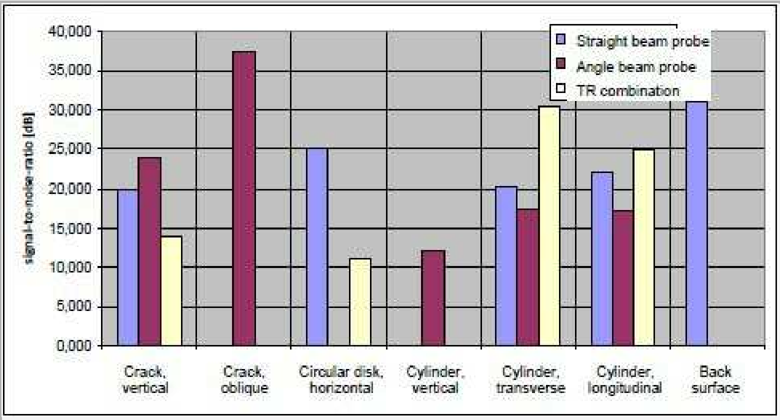
First, the sectional images are analysed and then the signal and noise amplitudes of the measuring points are measured (Table 1).

Table 1: Signal-to-noise-ratios for various discontinuities in an aluminium test object

	Crack, vertical			Crack, oblique			Circular disk, horizontal		
	Signal	Noise	SNR	Signal	Noise	SNR	Signal	Noise	SNR
Straight beam probe	0.184	0.019	19.721				0.393	0.022	25.039
Angle beam probe	0.704	0.045	23.887	0.813	0.011	37.374			
TR combination	0.184	0.037	13.932			0.000	0.120	0.034	10.954

Cylinder, vertical			Cylinder, transverse			Cylinder, longitudinal			Back surface		
Signal	Noise	SNR	Signal	Noise	SNR	Signal	Noise	SNR	Signal	Noise	SNR
			0.270	0.026	20.328	0.333	0.026	22.149	0.79	0.022	31.104
			0.195	0.026	17.501	0.434	0.060	17.187			
0.120	0.030	12,041	0.745	0.022	30.595	0.453	0.026	24.822	0.307	0.052	15.423

The results show clearly that different types of discontinuities also required different types of detection methods (Fig. 14). The inclined surface of the oblique crack, for example, can only be detected with the angle beam probe. The back surface only provides a signal if the straight beam probe is used. Smaller discontinuities such as material fissures or small inclusions (horizontal circular disk) can only be detected with the TR probe by an evaluation of the scatter signals. For the assessment of the measurement results, however, the fact that the discontinuities in the test object are idealised discontinuities must be kept in mind. In real life, a vertical crack would be hardly detectable with the straight beam probe. The signal measured here has been reflected on the surface that was produced by saw. The traverse or longitudinal discontinuities in the test object (traverse and longitudinal cylinders) can be detected reliably with all of the probes.



ig. 14: Detectability of various discontinuities in an aluminium test object as a function of the test method

Vertical cylinders are the most difficult to detect, since only the small corner echoes at the bottom of the test object can be captured with the angle beam probe.