THREE DIMENSIONAL EXAMINATION OF DIRECTIVITY PATTERN IN IMMERSION TANK TESTING

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Abstract: High resolution examination of safety-relevant parts in immersion tank testing with focussing probes is forming a main topic of modern non-destructive testing. For the usage of complex reconstruction methods and algorithms, an individual and detailed knowledge about the transmission behaviour of the used probes is essential, as this has a significant influence on the results of data reconstruction.

Especially the knowledge about position and diameter of the focal point is needed to achieve the highest possible sensitivity. Through the individual position of the beam axis within the examined volume, a four dimensional metro logical determination of the acoustical pressure (x, y, z, t) is necessary. With the measured data it is possible to draw interferences about the sound field and acoustical pressure distribution. The presented work realized a method of automatic determination of the beam axis, the position of focal point and the focal diameter to support individual testing setups and transducer characterization.

Introduction

Focussing probes are, concerning their higher spatial resolution, increasingly used for high-resolution immersion tank testing tasks. For post-processing algorithms of digital signal processing, image processing and of course modern reconstruction approaches (ex. ultrasonic impulse echo tomography or synthetic aperture focussing technique), a well-known sensor description and characterization is necessary. For example the location of focal point and the sound beam diameter are highly demanded information ([1] and [2]).

The Federal Institute for Materials Research and Testing has developed measurement equipment, set-ups for capturing the sound pressure of non-focusing or focusing probes and several algorithms for automatic evaluation of measured data.

1 Theoretical background

The focal laws concerning ultrasonic transducers are well defined by [3], [4] and [5]. For example the diameter and the focal range of focussed probes could be estimated by eqs. (1) to (3).

$$D_{F,th} = f' \cdot N \cdot \frac{\lambda}{D_0} = f_{aq} \cdot \frac{\lambda}{D_0} \qquad \text{sound beam diameter (focal point)} \qquad (1)$$

$$l_{z,th} = N \cdot f'^2 \cdot \left(\frac{2}{1+\frac{f'}{2}} \right) \qquad \text{range of focal zone} \qquad (2)$$

$$\Delta l_{z,th} = \frac{l_z}{4}\left(1+\left(1-f'\right)^2\right) \qquad \text{leading part of the focal zone} \qquad (3)$$

For testing purposes a 10 MHz focussed transducer, focal point in 125 mm distance, was used to acquire the test data. The corresponding values for focal range were calculated and shown below.

$$f_{aq,th} = 125 \text{ mm} \qquad D_{F,th} = 0.93 \text{ mm}$$
$$l_{z,th} = 42.3 \text{ mm} \qquad \Delta l_{z,th} = 17.6 \text{ mm}$$

For data gathering, the whole region of interest was predefined in the range of 100 mm up to roughly 200 mm with a ball shaped reflector and a high spatial resolution of 100 µm for y- and z-direction and 500 µm.

2 Experimental measurement results

2.1 Measuring arrangement

For the metro-logical determination of the three-dimensional radiation pattern (x, y, z), the echo height was captured and digitized in a four-dimensional arrangement (x, y, z, t). Under usage of a ball shaped reflector and the reflection technique, the echo height in a predefined volume was captured automatically. The main benefit of the single probe arrangement is the possibility of measuring the system response, without any influences by other sensor equipment like a probably limited bandwidth of a hydrophone.

2.2 Signal processing

As Figure 1 illustrates, for each volume point (voxel) a high frequency A-Scan was captured with high resolution in the time domain. After reducing the time series by applying an one-dimensional maximum filter, the measured data leaves the time domain and forms an intersection plane (C-Scan) with echo height distribution with dependency of the current distance. After applying a two-dimensional maximum-filter on each C-Scan, the point of maximum sensitivity can be located easily and forms the sensitivity-function over distance of the tested transducer arrangement. Through the orientation of the sensitivity-function, the acoustical axis of the sound field can be described inside the captured volume by two or more maximum locations (with different distance values) inside the intersection planes.

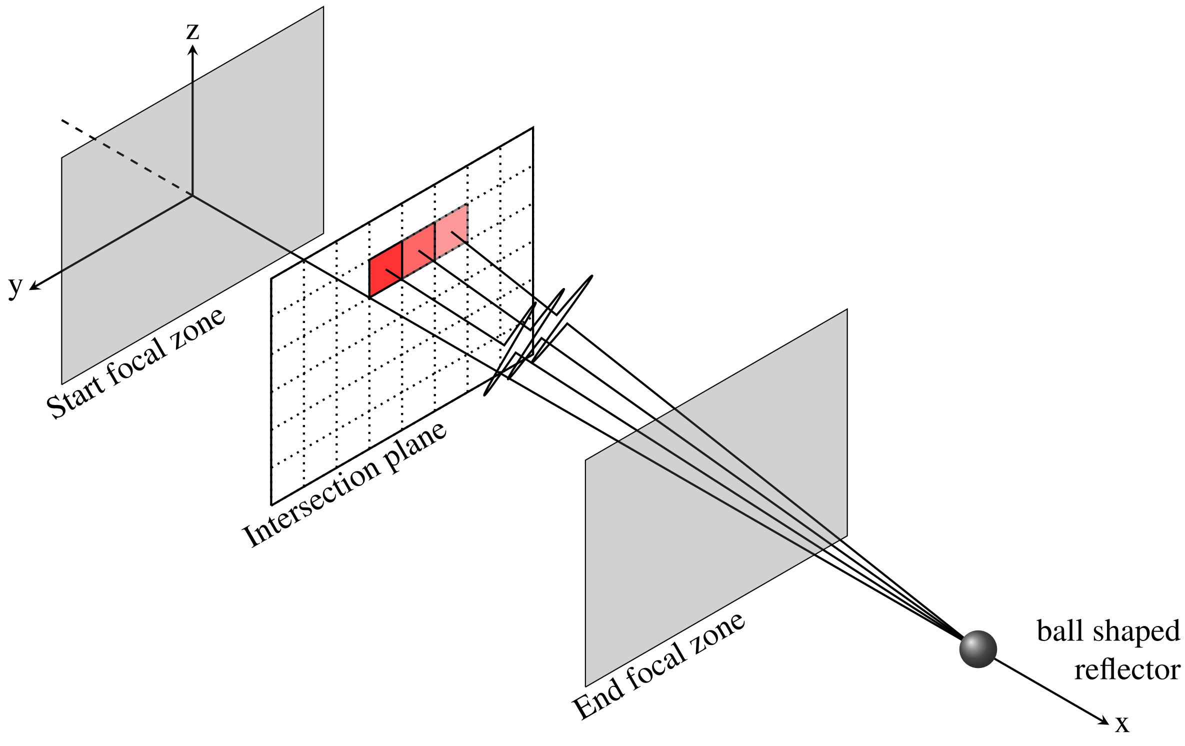


Figure 1: Schematic illustration of measurement arrangement

2.3 Acoustical axis

As described in the last section, each intersection plane covers the two-dimensional echo height distribution over distance. For a raw description of the orientation, at least roll- and yaw-angle must be determined through the location of two points under different distances. Both 6 dB-drops are used to calculate the sound beam orientation inside the captured volume. For a better, one pixel exact, estimation of the sound beam orientation the centre of each distribution is calculated under usage of digital image processing. According to Figure 4 based on the maximum sensitivity of the echo height distribution the 6 dB lower value forms the applied threshold to transform the echo height distribution into a binary image.

After translating the distribution into binary image, the gradients in x- and y- direction were computed under usage of a shape optimized edge filter and the circle detection through Hough Transformation was applied. The Hough Transformation results in a pixel-exact determination of centre-point and radius of the circular shape of the sound beam inside the echo height distribution. With knowledge of each centre-point an automatic pixel-exact calculation

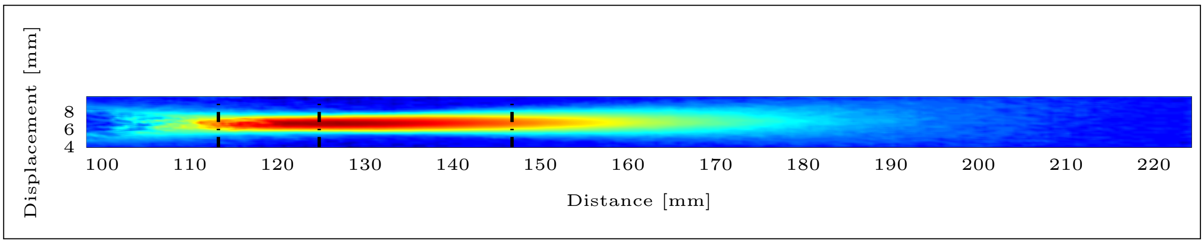
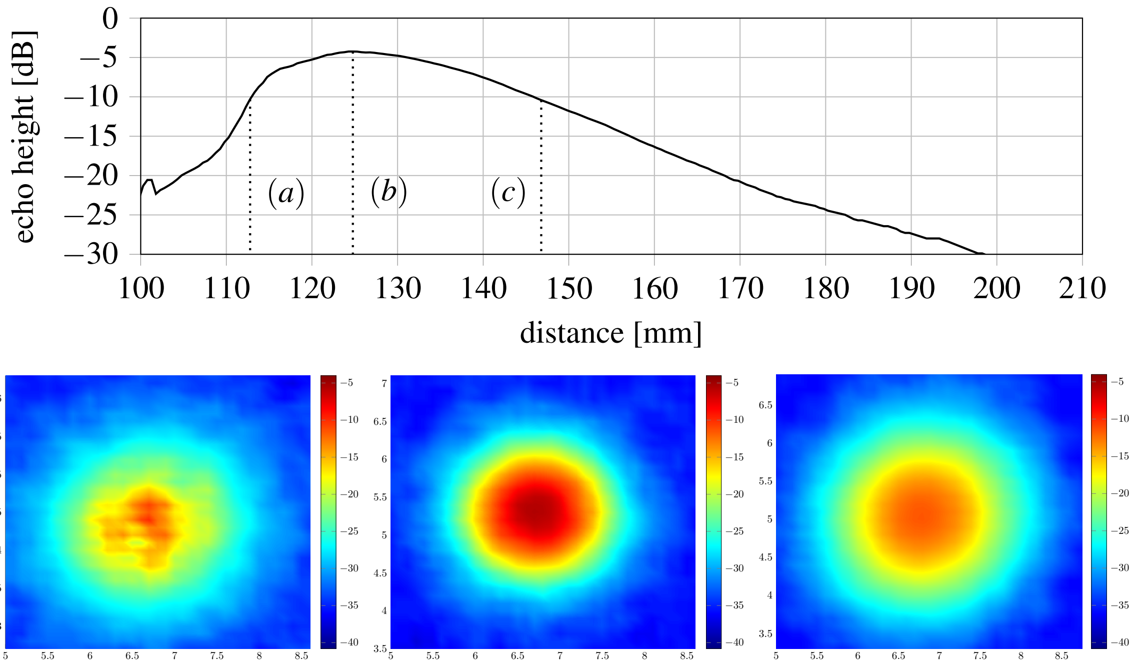


Figure 2: Echo-height distribution over distance



(a) start focal zone (b) focal point (c) end focal zone

Figure 3: Echo height over distance on acoustical axis and corresponding intersections
(a) start focal zone
(b) focal point
(c) end focal zone

of roll-angle, yaw-angle, the acoustical axis orientation and sound beam diameter is possible.

2.4 Measurement results

According to section 1, the estimated values based on the theoretical formulae could be validated with slightly small differences for sound beam diameter and focal point position.

$$
\begin{aligned}
f_{aq,meas} &= 124.3\,\text{mm} \pm 0.5\,\text{mm} & f_{aq,th} &= 125\,\text{mm} \\
D_{F,meas} &= 1\,\text{mm} \pm 0.1\,\text{mm} & D_{F,th} &= 0.93\,\text{mm} \\
l_{z,meas} &= 34\,\text{mm} \pm 0.5\,\text{mm} & l_{z,th} &= 42.3\,\text{mm} \\
\Delta l_{z,meas} &= 12\,\text{mm} \pm 0.5\,\text{mm} & \Delta l_{z,th} &= 17.6\,\text{mm}
\end{aligned}
$$

A quite higher difference (8.3 mm and 5.6 mm) exist between estimated and measured values of focal zone length and leading part of the focal zone.

2.5 Three-dimensional echo height visualization

In addition to the widely used visualizations of sound pressure or echo height distribution as two-dimensional image (fig. 2), the four-dimensional capturing of the echo height allows a three-dimensional illustration of the sound field.

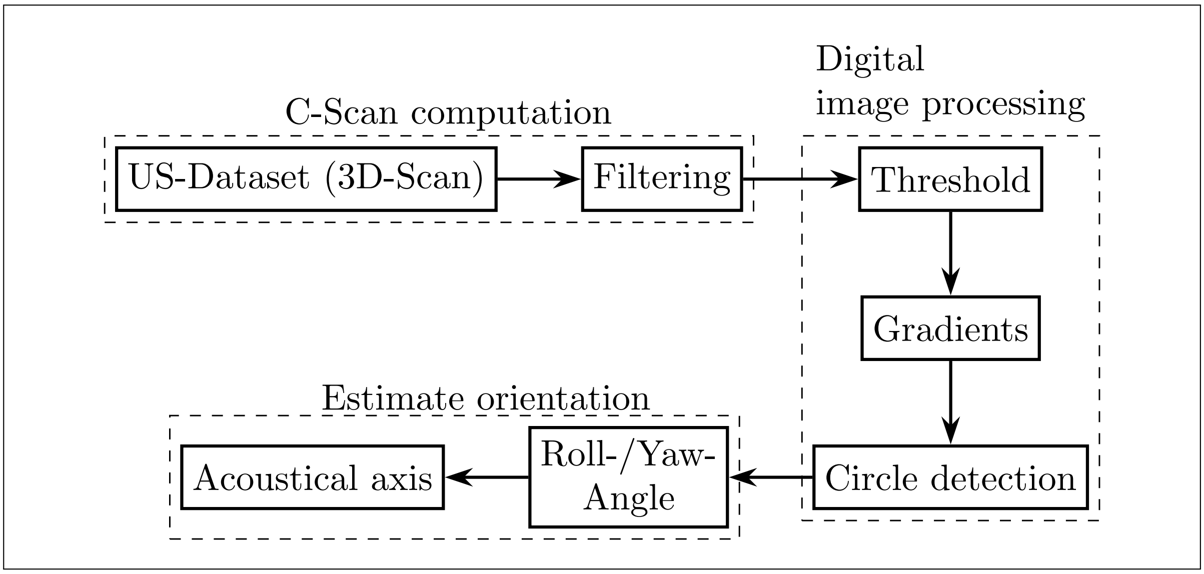


Figure 4: Signal and image processing toolchain

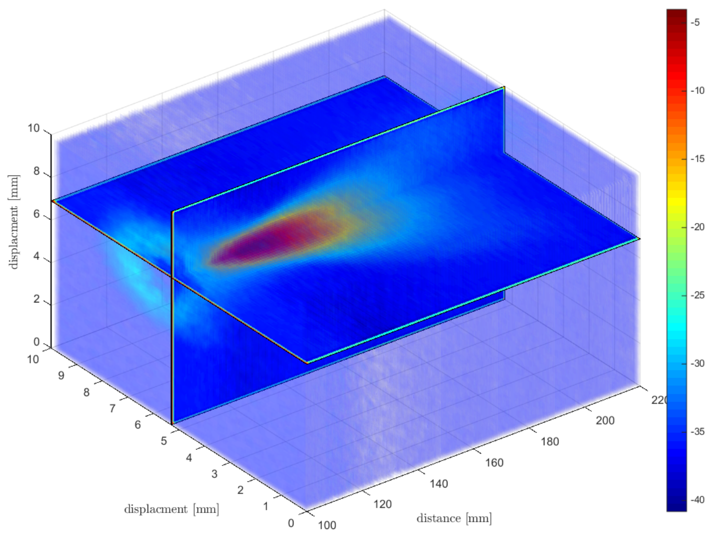


Figure 5: Example illustration of three-dimensional echo height distribution

3 Conclusion

As mentioned before, the four-dimensional capturing of echo height to characterize a focussing ultrasonic probe offers several benefits. By measuring the whole acoustically penetrated volume, any kind of data processing is available. Especially for validation of simulation results a better understanding of complex reconstruction algorithms or a well known sensitivity characteristic helps to provide best results during highly specialized testing arrangements.

The complete automatic data acquisition combined with offline data processing through highly adapted algorithms of digital signal and image processing are providing a full characterization of the tested transducer. For further information about the device, additional parameters like centre frequency, bandwidth or impulse response could be also done automatically.

References

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