

INDUSTRIAL APPLICATION OF REAL-TIME 3D IMAGING BY SAMPLING PHASED ARRAY

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1. Introduction

The “Sampling Phased Array” technique compared with the conventional phased array approach became very popular in the last years making use of the propagation of elementary waves (Huygens principle) generated by individual elements of the sensor array to reconstruct the composite phased array signal by high-speed numerical computation for any arbitrary, individual angle or physically possible focus depth. As the near field of each individual transducer in the array is that of a ‘quasi’ point source, transducer-near inspection regions are much better to inspect than in the conventional case where the near field is determined by the full aperture of the transducer array. Furthermore, the special IZFP-approach allows a very fast 3-dimensional visualization of inspection objects by combining - slice by slice - 2-dimensionally calculated SAFT-B-images to a 3-dimensional data-cube with a manifold of possible data projections for evaluation and analysis of the inspection results. 3-D-SAFT algorithms taking into account also a modified transducer design with a wide-angular sound beam characteristic in each space direction are under development.

The present paper gives an overview to the basic principles of the “Sampling Phased Array” method and documents its advantages by means of several industrial applications.

2. Sampling Phased Array Technique

In contrast to Conventional Phased Array technique (CPA) which utilizes the physical sound beam steering by electronic transmitter/receiver delay control, the Sampling Phased Array technique (SPA) allows reconstruction of sector image by synthetic composition of elementary wavelets [1, 2]. Thus after one transmitting pulse a sector image containing all angles of incidence can be reconstructed, e.g. by using Kirchhoff Migration algorithm [3]. Thereby, synthetic focusing occurs in every image point (Fig. 1).

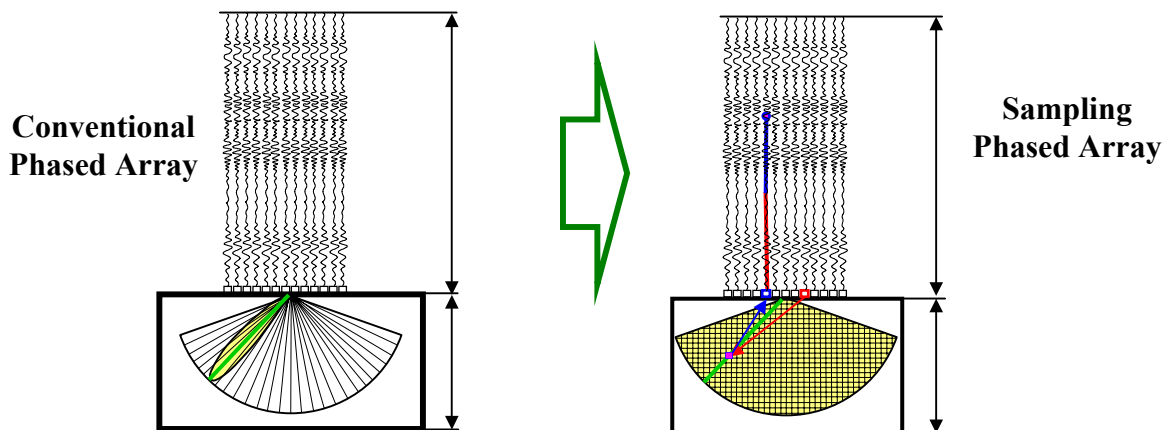


Fig. 1: CPA and SPA principle

For better detection of material flaws in the inspection object by SPA method, ultrasonic transducer with maximal beam spread is used. Due to smaller aperture size of phased array elements in comparison to single element transducer they are especially suitable for synthetic focusing through Sampling Phased Array technique.

The reconstruction principle can be described as follows (Fig. 2). For all probe positions (x), the complete High Frequency signals are acquired for tomographic reconstruction of the inspection volume. Because of the large beam spread, the overlapped echo signals from different reflectors are simultaneously received and saved. The captured volume represents one plane perpendicular to the surface of inspection object. Propagation times from each probe position to each volume pixel on the plane and back are computed.

Similar to the SAFT algorithm, the component (Fig. 1) cross section or volume is divided into pixels producing the image point, see Figure 1.2 below. For each image point, the travel time to the individual transducer elements is computed and the time-related amplitude value is assigned. Figure 2 below illustrates the image reconstruction principle for a single pixel as a function of element location with a hyperbolic distribution of the travel time, and for image reconstruction correlated with the image point location.

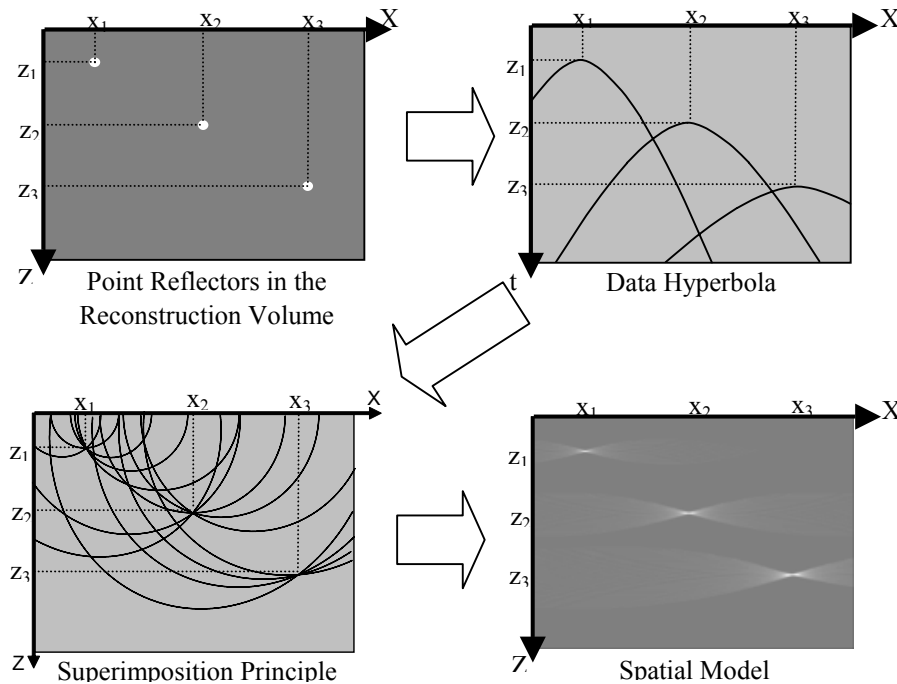


Fig. 2: Reconstruction principle

However, the improved flaw detectability through Sampling Phased Array in a single position of Phased Array transducer is restricted by its near field. Especially, on a large solid components the most of inspection volume is out of probe near field. Thus the effective aperture must be increased and ultrasonic information from different positions must be overlapped for extending the SPA-advantages on entire inspection volume.

Build-up of synthetic aperture allows increasing the focus area in one plane of inspection volume (Fig. 2). Unlike the classical SAFT reconstruction, the SPA method overlaps not single time signals (A-scans), but two-dimensional sector images. By building the two-dimensional aperture, the interslice-tomography can be performed for better three-dimensional spatial resolution in three-dimensional space. Special phased array transducers with reduced element length provide better results due to the good beam divergence in the index direction.

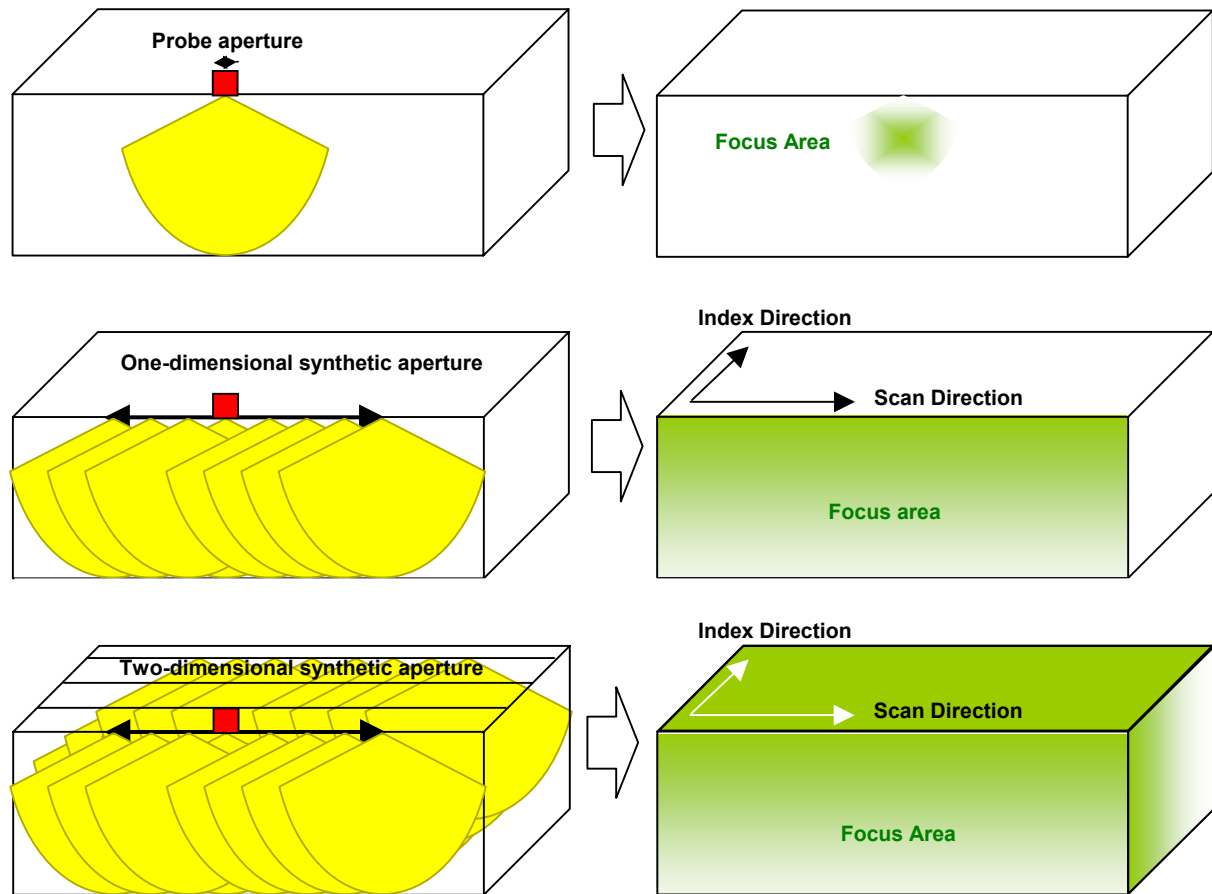


Fig. 2: Build-up of synthetic aperture

3. Industrial application of Sampling Phased Array with 3D imaging

To demonstrate the benefits of SPA technique to Industrial customers, in this current paper we present here some of the results of practical applications of SPA technology.

3.1 In situ casting inspection by mobile SPA unit

Material flaws in castings often possess pure reflectivity. Thus typically large defects like cavities or inclusions can't be correctly evaluated by standard techniques e.g. like according to the DGS-Diagram in pulse-echo mode.

Figure 9, represents ultrasonic inspection results by SPA technique on a massive casting object. The equivalent defect size determined by DGS method with single element transducer (B1S from GE/Krautkramer) corresponds to flat bottom hole of $\varnothing$ 3.5 mm. The real defect size measured by SPA method and approved by metallographic analysis was about 80 x 40 x 30 mm. Three-dimensional tomographic reconstruction of the inspection object allows quantitative evaluation of inspection results. The mobile inspection system consisting of two-axes manipulator with phased array transducer and UT electronics mounted on it. The evaluation station (master-PC) is capable of real time representation of 3D image while scanning is performed. A very fast analysis of material flaws can be provided to the customer either as a mobile service for nonrecurring case, or as an inspection system for daily use.

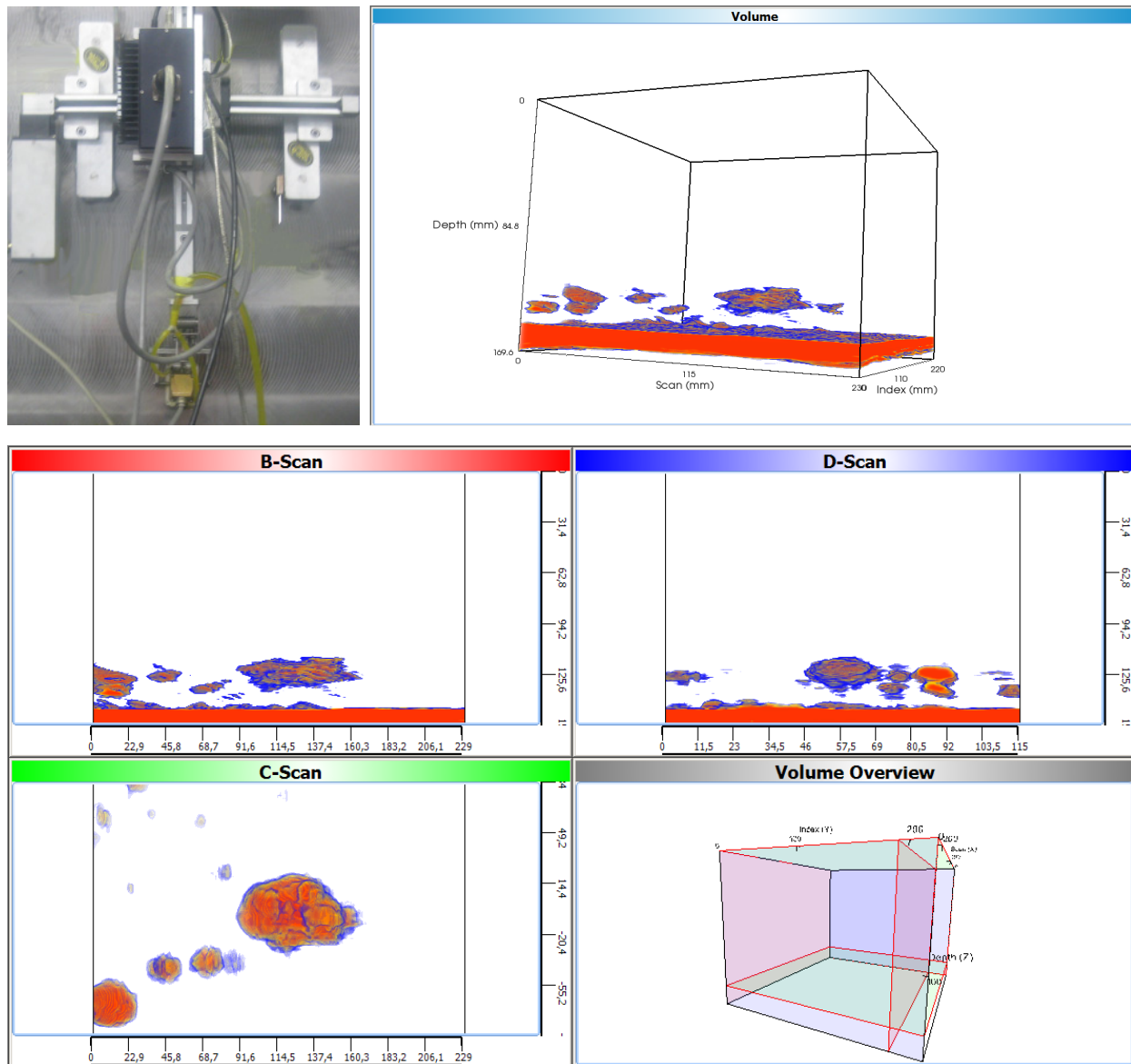


Fig. 3: SPA testing of casting object

3.2 Inspection of thick-wall cladbed weld seams

Forehanded detection and correct sizing of material defects in pressured components can extend its lifetime. Thus, SPA method is the most suitable for accurate analysis of safety-related components [7]. Figure 4 shows the inspection results on a cladbed test specimen with test defect. The scanning was performed by 2MHz phased array transducer from the cladbed side of the specimen (meander scan). The shot distance was 1 mm. The track pitch (index step) was 3 mm. From the B-Scan projection, one can distinguish the upper and lower crack tips. It allows exact measurement of the crack position and its size in the component.

Advantages of SPA method for this inspection task lie in the high spatial resolution due to synthetic aperture refocusing of the data and the subsequent easy-interpretation of inspection results by three-dimensional imaging.

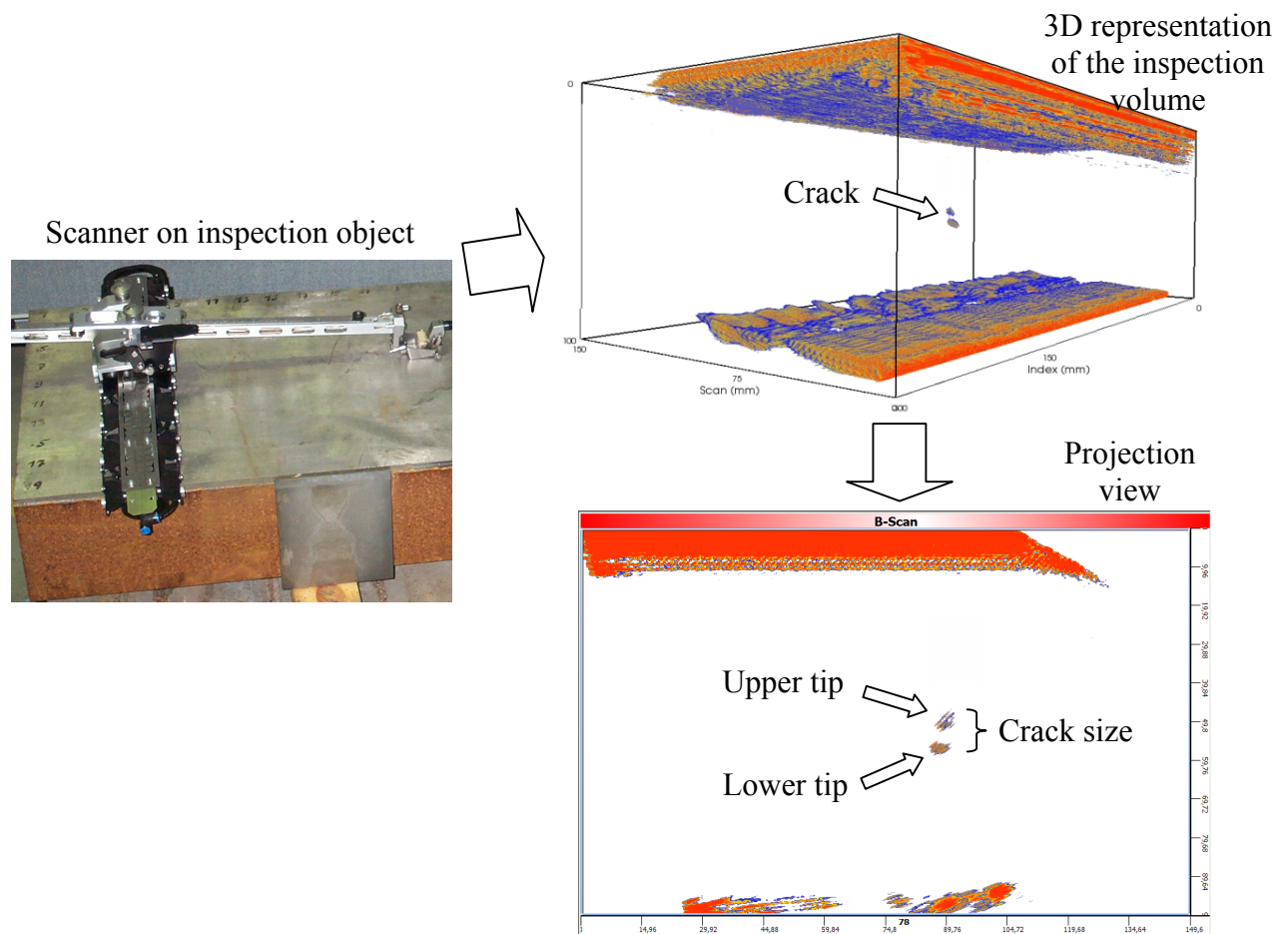


Fig. 4: SPA testing of thick-walled weld seams through cladding

3.3 Testing of CRFP components

The ultrasonic testing of CRFP components has a number of distinct challenges when compared with other applications. Practical use of ultrasonic testing is strongly correlated with the defects prevalent for this type of material, especially lamination, porosity, plastic or paper films, undulations.

Due to lower wall thicknesses and in-plane orientation of material defects, normal probes are often used for ultrasonic testing of CFRP-components. But for complex geometries like Corner joints and T-joint inspection, Phased array transducers can be applied.

The Phased Array testing of light weight components is the state-of-the-art in the aircraft industry since several years. Large inspection area of the components can be optimally inspected by wide phased array transducers with more elements where, the so called linear-scan function option is applied for fast covering of the inspection volume.

SPA technique aids increase in the inspection speed by triggering several virtual probes parallel (parallel cover principle) and also it improves the flaw detectability due to synthetic focusing at every point in the image [6]. Thus the defects in all locations (incl. first and last CFK layer) can be reliably detected for planar and curved geometries (corner joints) followed by the three-dimensional representation of image in real time.

Later an automatic evaluation of inspection results can be performed via signal and image processing to distinguish different types of material flaws, e.g. lamination and plastic films (Fig. 5).

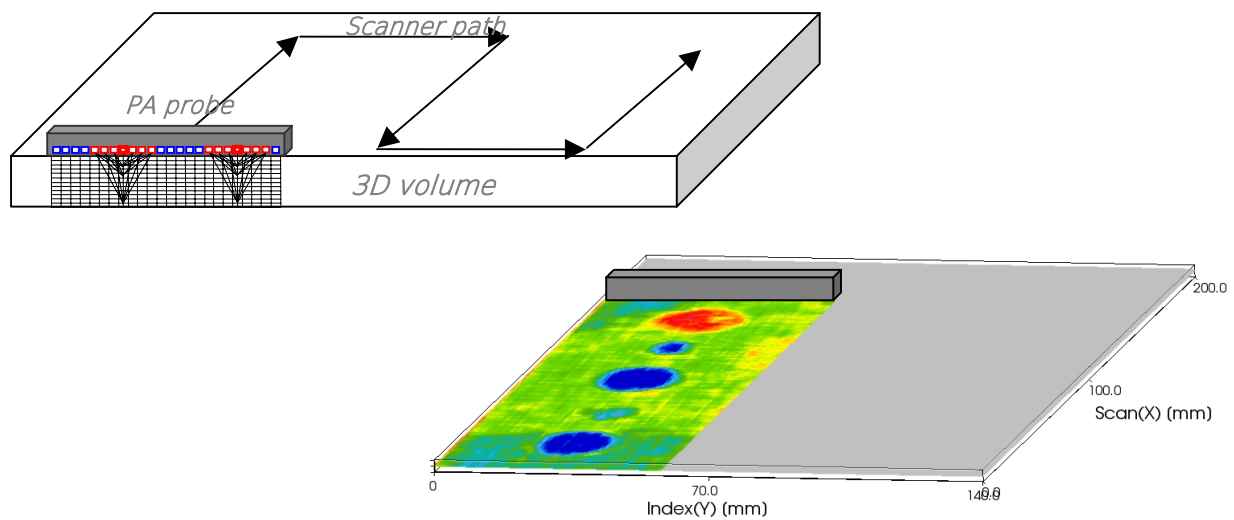


Fig. 5: Data acquisition and reconstruction principle by testing of CRFP components with SPA

Figure 6 represents inspection results of a test specimen with artificial defects by means of SPA in immersion technique. The “3D-Clustering” approach developed by IZFP allows not only faster reconstruction but also to perform various operations like localization and sizing of indications and other preliminary operations like rotating, zooming, changing of views etc, in real time.

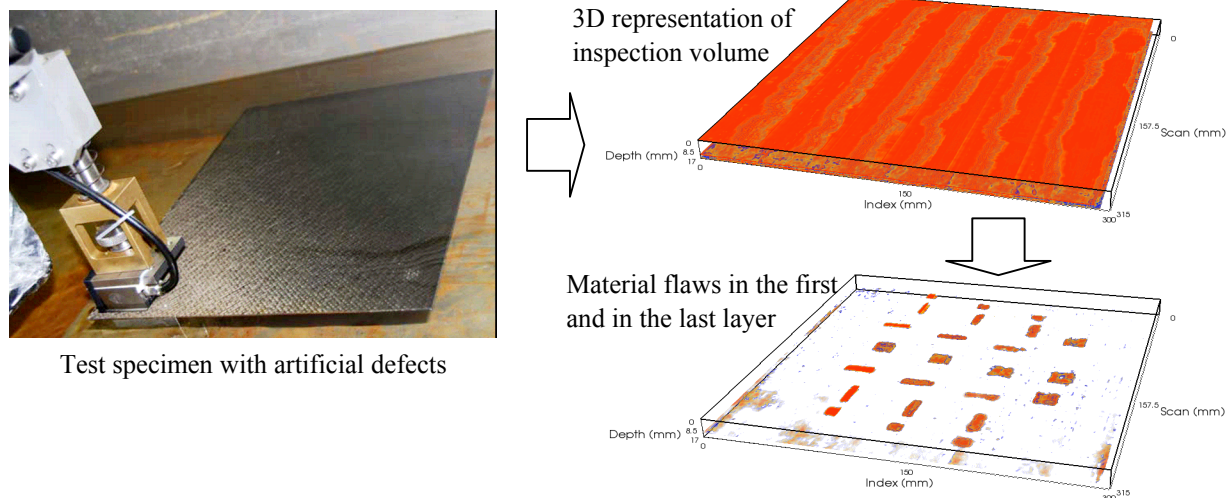


Fig. 6: Inspection of CRFP components by SPA immersion technique

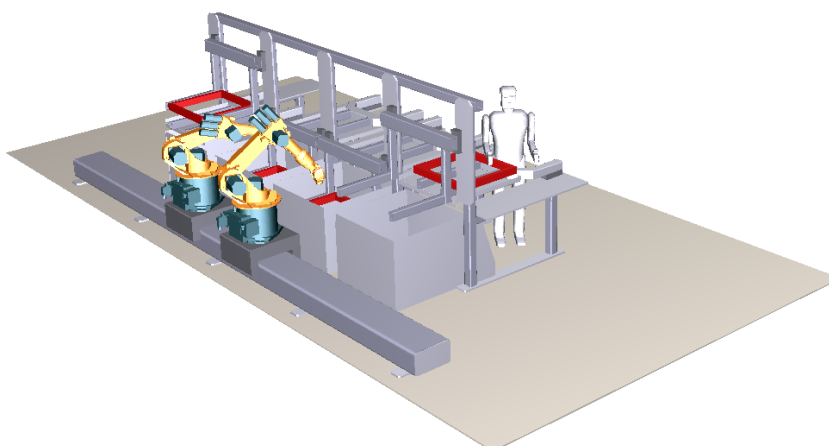


Fig. 7: Automatic inspection set-up for fast testing of CRFP components

Due to higher production speed of modern CRFP components, there is a greater demand for the automated ultrasonic inspection system (SPA) which can perform reliable inspection with higher speed.(Fig. 7).

3.4 Quantitative ultrasonic testing of heavy plates

Ultrasonic testing of heavy steel plates is generally performed in automated multi-channel inspection machines with automatic evaluation of UT indications according to valid codes and standards. For more detailed evaluation of material flaws, Fraunhofer-IZFP has developed a mobile ultrasonic inspection unit MUSE, which utilizes the SAFT principle and provides highly resolved ultrasonic images of the material defects [7]. The system is applied in the off-line analysis of a selected area to analyze

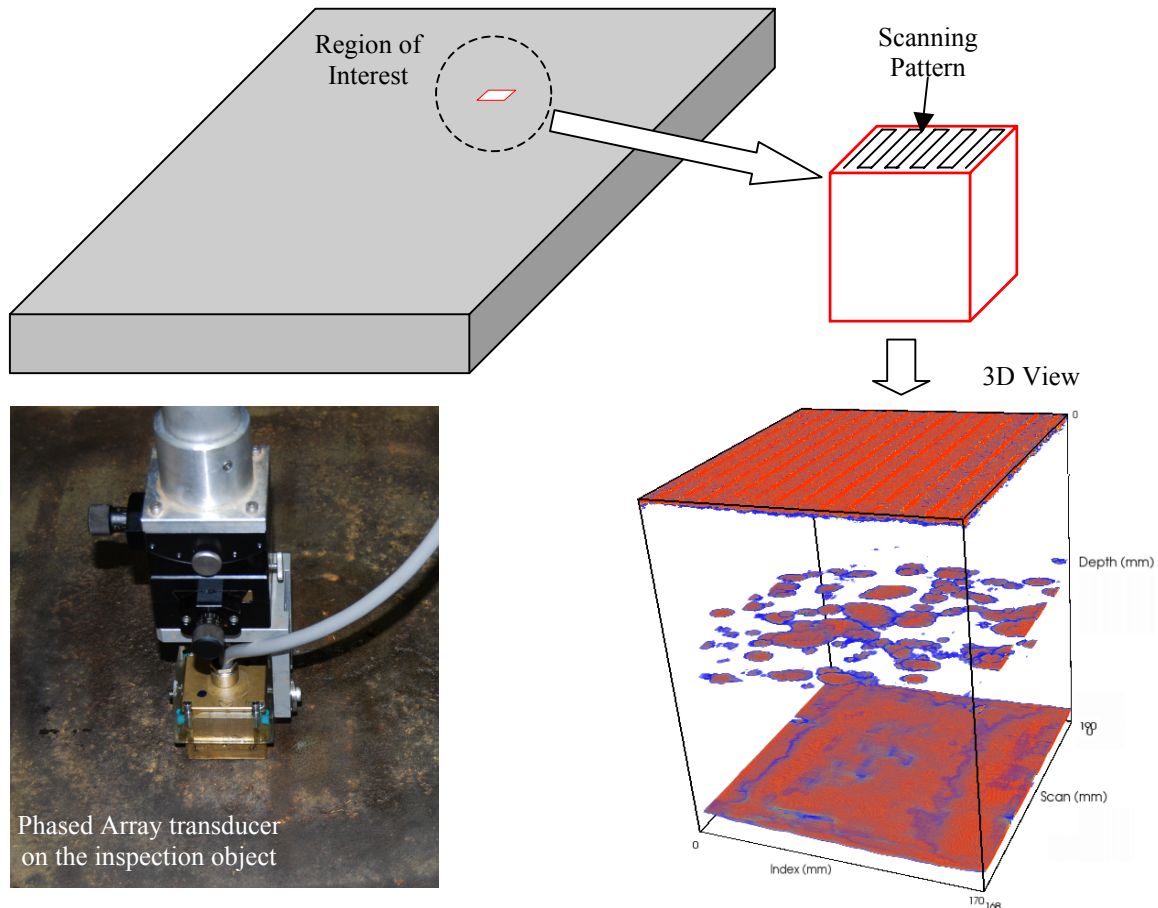


Fig. 8: 3D visualization of material flaws in a rolled plate

The classical SAFT method can be extended to Sampling Phased Array technique, where enormous increase in inspection speed can be achieved. Figure 8 shows inspection results obtained on a rolled heavy steel plate with natural defects.

3.5 Diagnostic of off-shore components made of plastic with metallic elements

Figure 9 shows the results of an UT diagnosis on an off-shore component with embedded steel elements. The goal of the study is to safeguarding the correct position and integrity of the metallic parts for further safe usage of the component.

The inspection task is successfully solved by 3D visualization of the regions of interest (Fig. 9). Due to the strong difference in the acoustic properties of plastic and steel, the metallic elements could be clearly visualized and its function is approved by ultrasonic tomography through SPA.

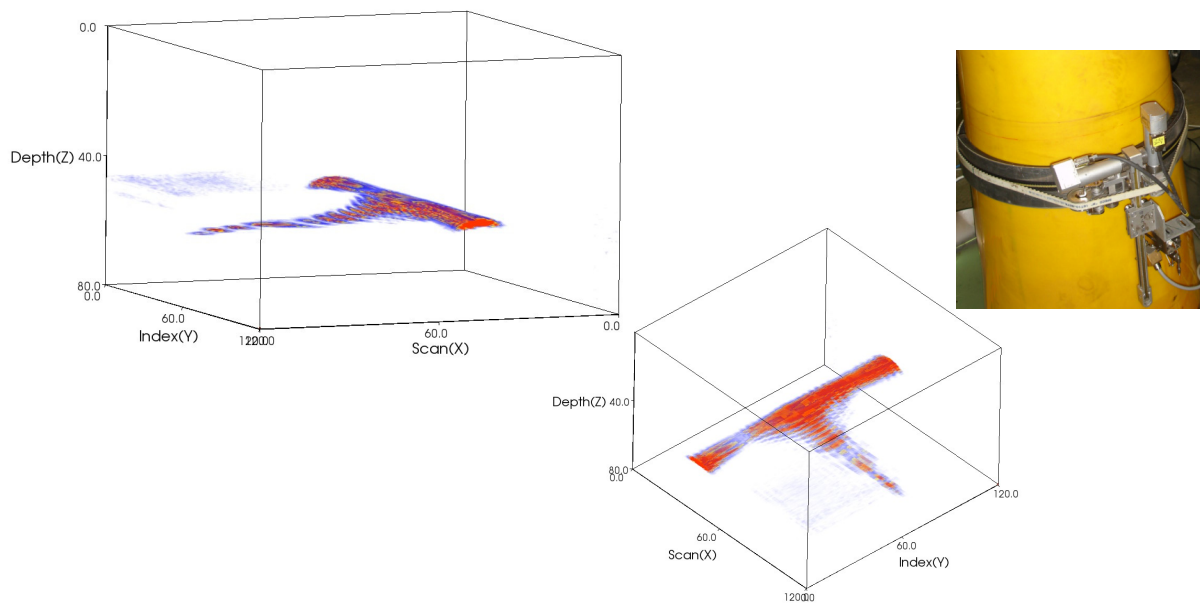


Figure 9: Condition diagnosis of an off-shore component by 3D visualization of steel elements embedded in a plastic body

5. Conclusion

The presented practical applications show the potential advantages of SPA by reliable quantitative high speed imaging.

Fast inspection systems can be used for off-line analysis of safety-relevant components as well as for automated in-line testing in the production process.

Other advantages of SPA technique like improved spatial resolution and signal-to-noise ratio which are due to the synthetic aperture principle, where the focusing in the inspection volume occurs over a large scanning area. This holds especially for testing of solid components where it promises improvement of inspection results in comparison to conventional state of art techniques.

Features of SPA like fast three-dimensional imaging of material flaws in inspection volume is greatest asset for any automatic high speed testing requirements. It has greater potential for testing components with different shapes e.g. with complex geometries where the indications has to be represented in the correct position with higher spatial resolution for appropriate defect sizing. However, such testing asks for extensive apriori knowledge about the inspection geometry like CAD models to correlate with the 3D image reconstruction software result to ensure improved analysis of the ultrasonic data This can be considered as a short-term goal for future development of SPA technology.

5. References

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