ULTRASONIC DETECTION OF CRACKS IN PRESSURE TUBES

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Abstract

Results of the ultrasonic inspection of pressure tubes sometimes are not satisfactory due to inability to detect shallow and narrow cracks. It is therefore worthwhile to develop some special and at the same time simple ultrasonic methods for tubes examination, which could significantly improve inspection capabilities. Combined technique, employing two transducers working in parallel, allows "seeing" crack simultaneously at different angles. The large normal beam probe due to various angles and directions of flaw insonification allows detecting the crack and sometimes even "depicting' its shape. Combining obtained data, one can "reproduce" crack shape and orientation, as well as assess its dimensions. Using special software it is possible to generate an isometric (3D) image of a crack.

1. Introduction

Ultrasonic Testing (UT) is a commonly used method for pressure tube (PT) inspection. Various techniques are employed for tube examination in order to detect, characterize and size different flaws including cracks. Typically the pulse-echo (PE) and pitch-catch (PC) techniques are used for tube testing to detect, characterize and size flaws located within the tube wall, on the inside diameter (ID) or outside diameter (OD). (Sometimes terms ID and OD are used in context of the inside and outside surfaces, respectively). Usually the normal beam (NB) longitudinal waves and angle shear waves are commonly employed for the PT inspection.

However, sometimes the results of the inspection are not satisfactory due to insufficient sensitivity and/or inability to detect and characterize a crack. It happens, because cracks are usually tight and sharp, therefore UT waves reflected from cracks are very weak. Moreover, even such weak UT responses from cracks are usually masked by much more strong UT responses from flaws, where these cracks were initiated from. It is particularly difficult to detect, characterize and measure delay hydride cracks (DHC), because typically DHC are tight and filled with oxide, therefore they are almost transparent for UT waves used for inspection.

The objective is to investigate ability of various UT techniques, probes, and software to detect and assess different types of cracks (fatigue, overload, and DHC) initiated from various flaws. The goal is to detect various cracks and determine their orientation, shape, and depth.

2. Experimental setup

All experiments described below were performed on the PT specimens containing various types of cracks. Calibrated UT system and computerized scanning rig with rotary and three axial motions were employed for experiments. The UT system includes Winspect™ data acquisition software, a SONIX STR-8100 digitizer card, and a UTEX UT-340 pulser-receiver. Transducers with different center frequencies (10, 15 and 20MHz), various diameters (from 0.375" to 1.375") and focal lengths (from 25 to 100mm) were used for testing.

Different techniques and probes were used to allow "seeing" the flaw at various angles and from different directions. Obtained images were interposed (combined). As a result, one gets a number of rather simple methods, which allow detecting, characterizing and sizing even the small flaws (cracks); and this significantly improves sensitivity, resolution, and reliability of the inspection.

3. Shear wave three-skip PC technique at large incident angle

A new possibility for flaw characterization involves a modified circumferential PC technique, performed at large incident angle 27^0 and containing three skips of the UT wave within the PT wall, unlike "standard" two-skip (or full-skip) method routinely used in the CIGAR and ANDE systems. By changing the transducer orientation angles, distance between probes in the circumferential direction, and their positions in the radial direction, one can control the incoming beam incident angle, refraction angle, acoustic beam trajectory within the tube wall, number of skips, and angle at which the UT beam impinges on the flaw (i.e. flaw observation angle). After each ID and OD reflection, the angle range within which the reflected waves propagate inside the tube wall, increases, i.e. the UT beam becomes more diverging. As a result, after a few reflections, the beam impinges on the ID and OD within a wide range of angles; therefore it allows "seeing" flaw simultaneously at different angles.

The three-skip PC 2D circumferential B-scan of axial rectangular ID notch with fatigue crack is presented in Fig. 1. Two PC responses (images) represent two sides (left and right) of the flaw tip.

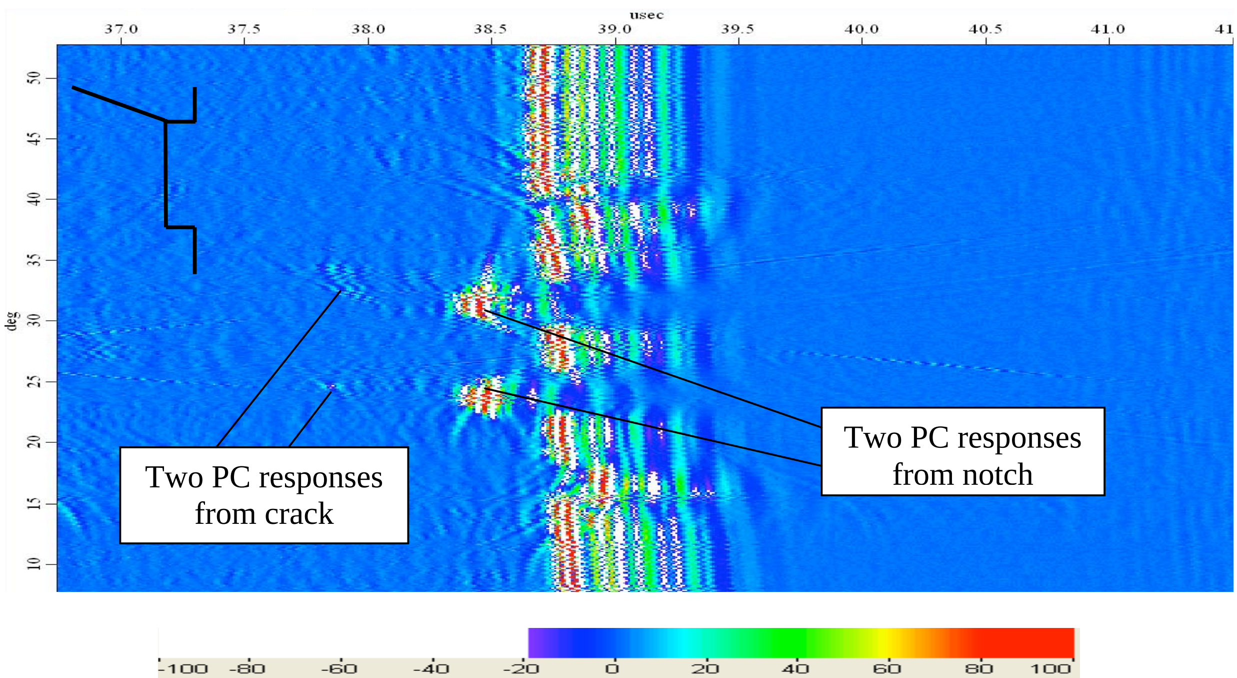

Figure 1. Circumferential shear wave three-skip 2D PC B-scan of axial rectangular ID notch 0.5mm deep and 2.5mm wide with fatigue crack ~1mm deep. Probes: focal length FL=40mm, center frequency f=15MHz, aperture diameter D=0.5", water-path WP=18mm, incident angle $\alpha=27^0$, and distance between probes d=27mm.

Fig. 1 and other similar images obtained during experiments, clearly demonstrate that shear wave three-skip PC technique at large incident angle allows detecting cracks, reproducing notch shape, and estimating notch dimensions.

4. Combination of three different techniques

The ability to combine information, obtained by using different techniques and probes, and then reconstruct the flaw, is the main advantage of the classic tomographic method. To do it, special software should be developed. In order to realize the simplified “quasi-tomographic” technique, one can use a simple method, which combines information from different transducers. One of the ideas is to connect simultaneously two probes (e.g. two circumferentially positioned transducers, clock-wise (CW) and counter-clock-wise (CCW)) to pulser-receiver working in the PE mode.

As a result, both transducers will simultaneously transmit UT signals and both will receive the responses. Each transducer will receive its own signals, reflected from the tube ID and OD, and also signals, transmitted by other probe and reflected from tube surfaces. Subsequently, three techniques will be realized simultaneously: angle CW PE, angle CCW PE, and PC. The obtained “combined” image will contain responses typical for these three techniques; in other words, it will look like three interposed images: CW PE, CCW PE, and PC. This “combined technique” can be performed as 3D or 2D scans at different incident angles and at various probes positions.

Responses from different probes can be easily distinguished. While PC image shows the notch tip, the angle PE responses (the lengths and durations of the CW and CCW reflections from tip and corner of the notch) can be used to characterize two inclination angles of the notch and even tip radius of the notch. Typical 2D circumferential B-scans of different notches with cracks are presented in Figs. 2-4, which clearly demonstrate that combined technique allows detecting and characterizing even tight and shallow cracks.

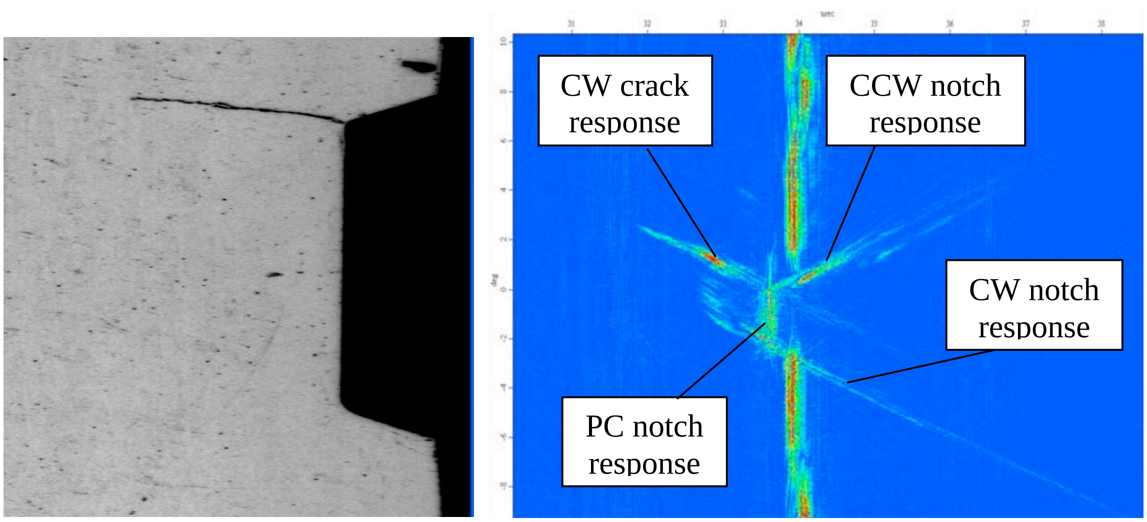

Figure 2. Picture of radial-circumferential PT cross-section and circumferential 2D combined (2PE + 2-skip PC) B-scan of ID rectangular axial notch 2.54mm wide 0.5mm deep with fatigue crack 0.8mm deep. Probes: FL=39mm, f=20MHz, D=9.5mm, WP=19mm, and $\alpha=27^0$. Color scale is shown in Fig. 1

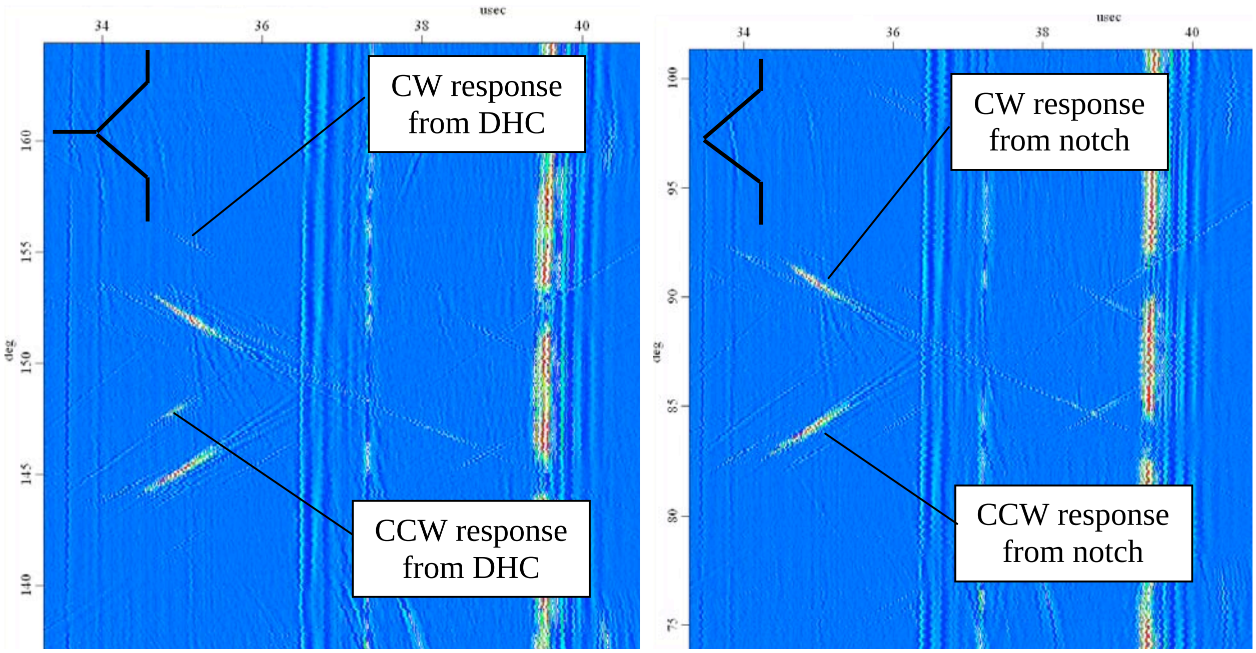

Figure 3. Circumferential 2D combined (CW + CCW + 3-skip PC) B-scans of V-notch (45^0 tip angle and 1mm deep) with delay hydride crack 0.5mm deep and without crack. Probes: FL=40mm, f=20MHz, D=9.5mm, WP=21mm $\alpha=25^0$. Color scale is shown in Fig. 1.

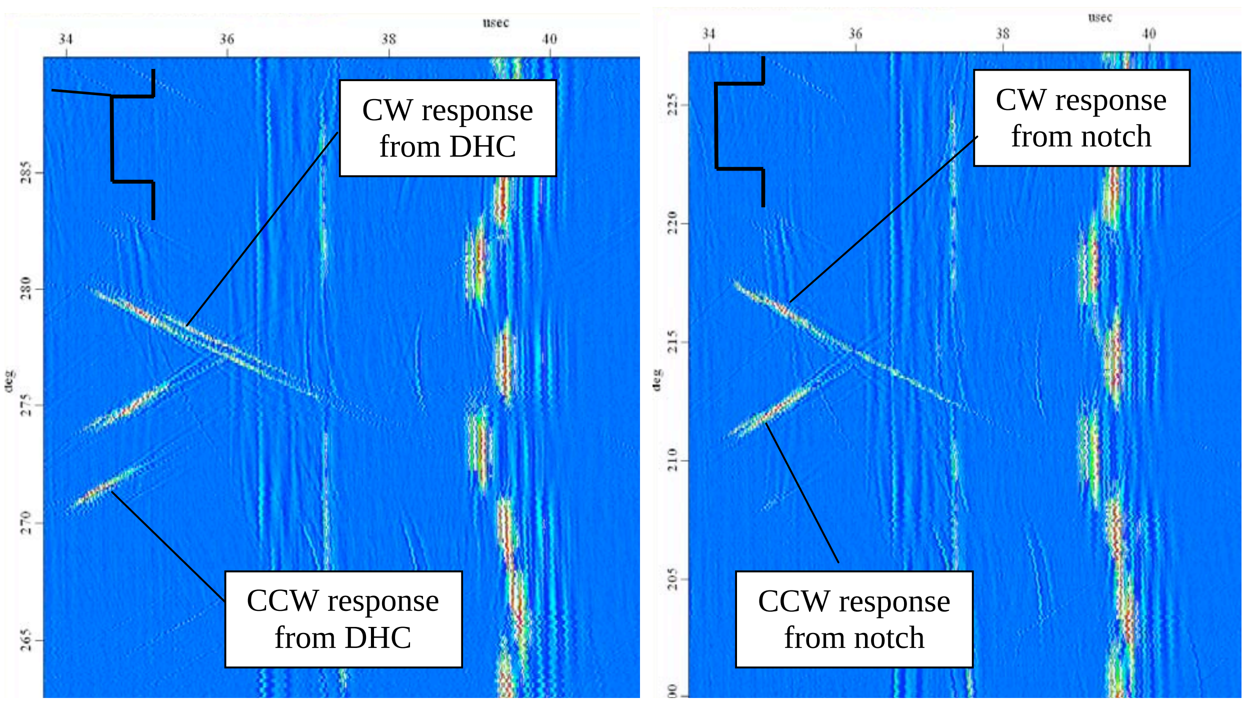

Figure 4. Circumferential 2D combined (CW + CCW + 3-skip PC) B-scans of rectangular axial notch (1mm wide and 0.7mm deep) with delay hydride crack 1mm deep and without crack. Probes: FL=40mm, f=20MHz, D=9.5mm, WP=21mm, $\alpha=25^0$. Color scale is shown in Fig. 1.

5. NB technique with large diameter probe

The NB probe with a large diameter, due to various angles and directions of flaw insonification (particularly after the OD/ID reflections), allows detecting small flaws (cracks), characterizing the flaw and to some extent "depicting' its shape. The large transducer can be presented as a number of small probes stuck together. It means the central part of a large transducer works as a small NB probe, while the peripheral parts of this transducer work as small angle probes in the PE and/or PC modes. That is why one large transducer can insonify flaw at various angles and from different directions. The images of two notches with fatigue cracks, which were obtained employing large probe, are shown in Figs. 5-6. One can clearly see that it is quite possible to detect cracks, "reproduces" the shape of the flaw, and even evaluate flaw width and depth using simple empirical formulae based on the geometrical acoustics approximation.

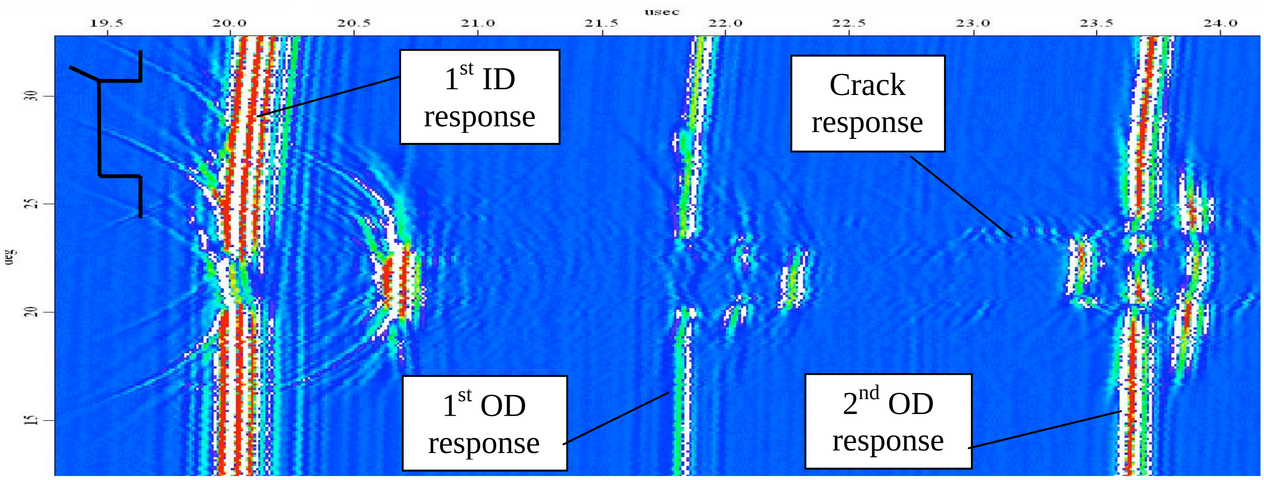

Figure 5. Circumferential NB PE B-scan of rectangular ID axial notch 0.5mm deep and 2.5mm wide with fatigue crack 1.2mm deep at the notch edge. Probe: FL=55mm, f=15MHz, D=0.5", WP=15mm. Color scale is shown in Fig. 1.

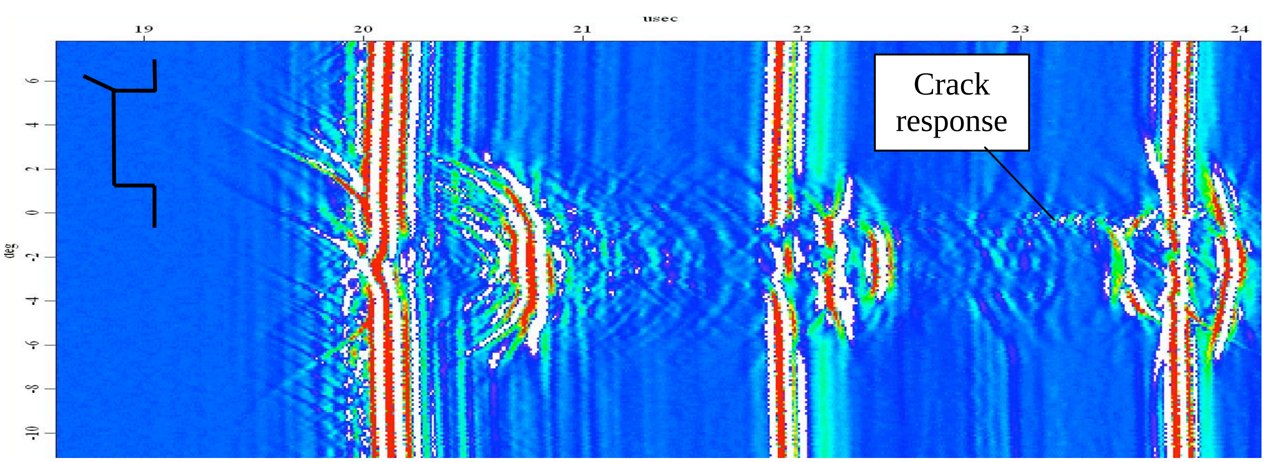

Figure 6. Circumferential NB PE B-scan of rectangular ID axial notch 0.5mm deep and 2.5mm wide with fatigue crack 0.8mm deep at the notch edge. Probe: FL=55mm, f=15MHz, D=0.5", WP=15mm. Color scale is shown in Fig. 1.

6. 3D visualization

Using different images (NB, PC, CW, CCW and others) and empirical formulae, the flaw orientation, geometry, and dimensions can be determined. Special software, that can combine information obtained from different techniques (data fusion), and generate an isometric (3D) image of a flaw, was developed based on the commercial visualization software "Python-3D" and special software to process 3D Winspect files. As a result, based on available 3D B-scans, the 3D time-of-flight C-images can be generated. Some of these images of various flaws with cracks are presented in Figs. 7-10. Recall that these images are based only on information, which the respective Winspect files contain. In other words, although these pictures allow reproducing isometric images of the flaws, rotating them, and looking at them at different angles, they do not have any new information in comparison with Winspect files.

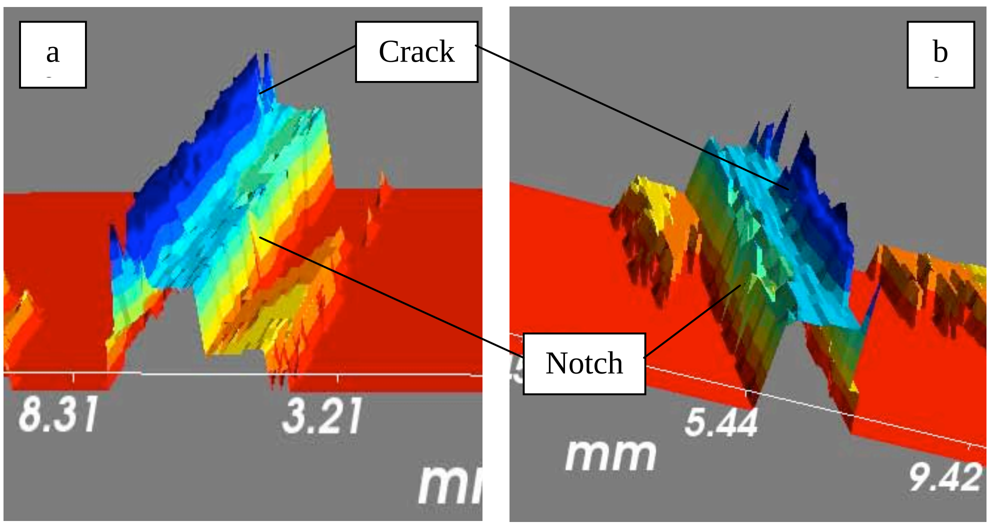

Figure 7. Time-of-flight 3D images derived of 3D PC B-scan of axial rectangular notch 0.5mm deep and 2.5mm wide with fatigue cracks 1mm deep (a) and 0.5mm deep (b). Probes: FL=33mm, f=10MHz, D=9.5mm, WP=20.6mm, $\alpha=25^0$.

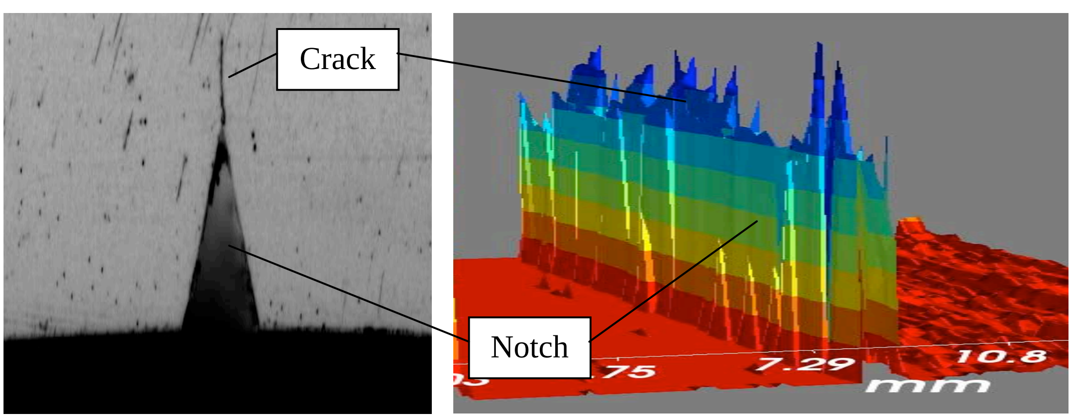

Figure 8. Photograph of circumferential-radial PT cross-section and time-of-flight 3D image derived of 3D combined B-scan of V-notch (1mm deep with 45^0 tip angle) with DHC 0.5mm deep. Probes: FL=40mm, f=20MHz, D=9.5mm, WP=21mm, $\alpha=25^0$.

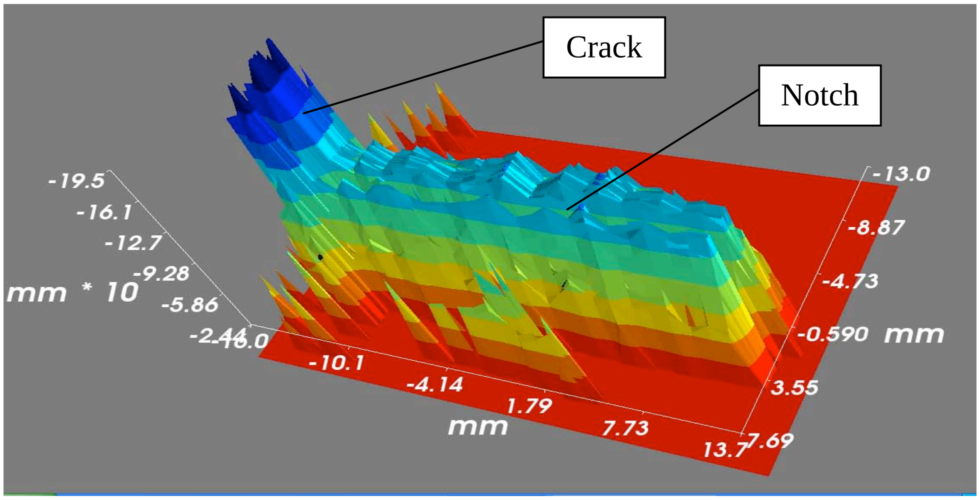

Figure 9. Time-of-flight 3D image derived of 3D combined B-scan of rectangular notch 0.5mm deep and 2.5mm wide with fatigue crack 1.5mm deep. Probes: FL=33mm, f=10MHz, D=9.5mm, WP=20.6mm, $\alpha=25^0$.

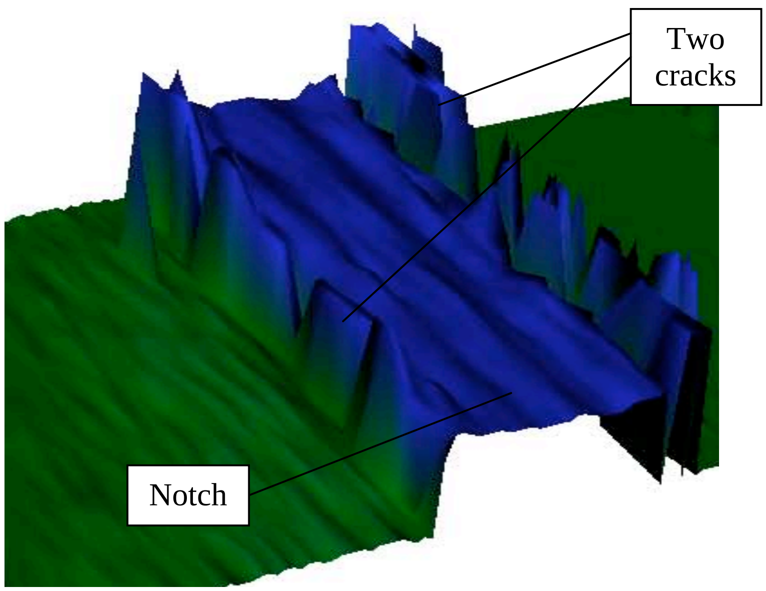

Figure 10. Time-of-flight 3D image derived of 3D combined B-scan of rectangular notch 0.5mm deep and 3mm wide with two DHC 1mm deep and 0.7mm deep, located at the left and right edges of the notch. Probes: FL=39mm, f=20MHz, D=9.5mm, WP=27mm, $\alpha=27^0$.

Figs. 7-10 show that 3D images, based on different inspection techniques, usually provide convenient, accurate and reliable images of flaw with crack. However, if flaw is shallow or narrow, reflection from flaw bottom cannot be reliably obtained, and therefore flaw cannot be fully “reconstructed” and its depth cannot be accurately measured. Moreover, when the responses from cracks are very weak, they can be masked by more strong UT responses from flaws, where these cracks were initiated from.

7. Conclusions

1. Sometimes results of the UT inspection of the PT are not satisfactory due to inability to detect and characterize a crack, particularly a shallow and narrow one. In order to do it, it is necessary to apply different methods and probes, which allow "seeing" a flaw at various angles. In addition, information obtained by using various transducers and methods, should be combined.
2. Three inspection techniques were determined as the most promising ones for crack detection and characterization:
    - Three-skip PC technique at large incident angle.
    - Combined technique (CW PE + CCW PE + PC).
    - NB technique with large probe.
3. These novel techniques give the possibility to detect cracks, "reproduce" the flaw shape, and size the flaw.
4. 3D visualization of flaw images, based on different 3D B-scans, provides convenient, accurate and reliable information data for crack detection, characterization and sizing.