

New UT techniques for HTHA detection - lessons from the field

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ABSTRACT

HTHA occurs in an environment containing hydrogen and high temperatures. High temperatures change the atomic form of hydrogen to form methane bubbles into the steel which can turn into cracks. Refinery owners have started additional inspections for HTHA after the component failure that was not anticipated. However, HTHA defects are very small and difficult to detect with conventional ultrasonic testing or other volumetric NDT methods. Recently, new UT techniques have been proposed, including FMC/TFM, TOFD and PAUT. They have been applied in the field and improved based on the experience gained. In this paper, FMC/TFM ultrasonic technique for HTHA inspection will be presented. Data on a component, removed from the field, will be shown and cross-referenced with information from field examination and follow-up investigations. Conclusions will be drawn on the level of success in identifying HTHA correctly.

INTRODUCTION

High Temperature Hydrogen Attack (HTHA) happens in an environment where high temperature and the presence of hydrogen are combined, mostly to low alloy steels. The high temperature causes some of the hydrogen to change into its atomic form, which allows it to migrate into the steel. Inside the steel the hydrogen will react with carbon and form methane, which cannot migrate through the steel and therefore gets trapped in metal, typically as microscopic methane bubble at the grain boundaries in the steel (stage 1). As these bubble start to grow, they will start to coalesce (stage 2) and can finally lead to fissuring and cracking (stage 3). HTHA occurs preferentially in welds and heat affected zones and in material that received no heat treatment.

As a result, HTHA may express itself in various shapes, including decarburization and small voids at early stages, linked voids at intermediate stages and blisters and crack like damage at late stage. Due to the variation in defect shapes, and the small size of early damage, HTHA is a challenging ultrasonic examination task. Until recently, API RP 941 recommended a number of manual ultrasonic techniques that were developed in the 1980s and 1990s ¹. The 2020 update to API RP 941 annex E ² now includes more recent techniques. This paper compares these advanced techniques and presents an approach for optimizing the Full Matrix Capture / Total Focusing Method (FMC/TFM) array techniques for improved detection, characterization, and sizing of early stage HTHA in refining equipment.

OVERVIEW OF AVAILABLE TECHNIQUES

In this section the main properties of the three newly recommended techniques for inspection for HTHA are described. AUBT, being the main historical technique is also treated. Given the properties of early HTHA damage, being small void in the material, it is important that that a technique is sensitive to small defect, while also covering the potentially affected area efficiently. For correct characterization it is also helpful that the technique has a high resolution, to distinguish the anomalies from other reflectors. The four techniques (AUBT, TOFD, PAUT and FMC/TFM) will be treated based on these requirements.

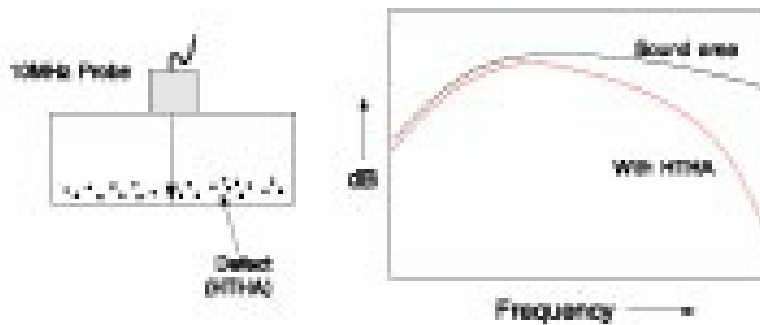
AUBT

The Advanced Ultrasonic Backscatter Technique was developed by Shell in the early 1990's and combined and improved the techniques used until then¹. As a result, AUBT proved to be more reliable for detecting and quantifying damage from HTHA. At the time of development, almost all ultrasonic equipment consisted of a manual probe and an oscilloscope screen. In AUBT this was enhanced with attenuation measurement, velocity measurement and analysis of the ultrasonic frequency (Figure 1). The background to this is, that small voids in the material are very hard to detect directly with this kind of UT equipment, but since they cause multiple scattering, they will lengthen the path along which ultrasound must travel. This is measured as a drop in ultrasonic velocity. Since ultrasound decays faster at higher frequency, this can also be detected as a shift of the maximum amplitude of reflections to a lower frequency. This is illustrated in Figure 1.

Back-Scattering Technique



Spectrum analysis



Velocity Ratio Technique

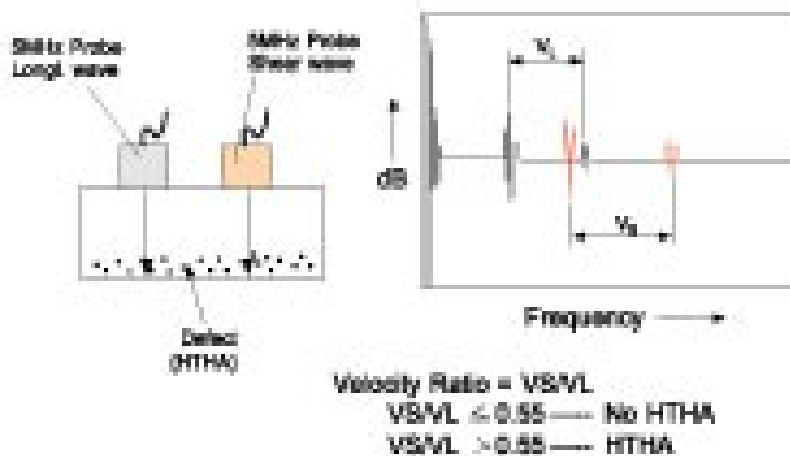


Figure 1 Overview of the main features of the AUBT technique

TOFD / TULA

TOFD involves two ultrasonic probes on either side of the region of interest (Figure 2). The technique makes use of ultrasonic diffraction rather than reflection. Results are displayed on display style which is particular to TOFD and shows indication as hyperbolic arcs. One of the properties of ultrasonic diffraction is, that it is stronger in the through transmission direction and stronger with compression waves than with shear waves. TOFD makes use of both properties.

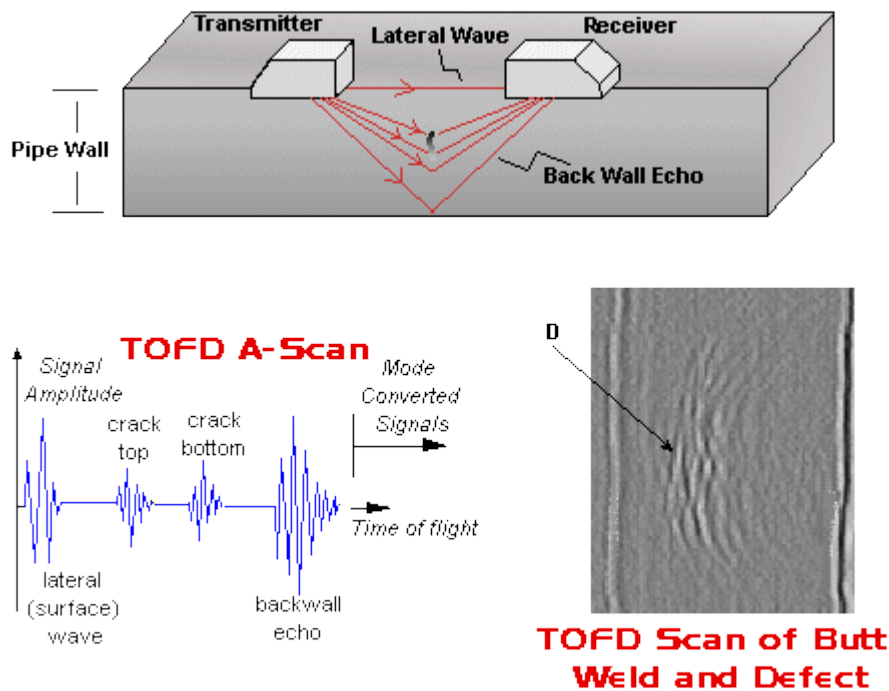


Figure 2 TOFD basic setup and image style

TOFD was developed in the early 1970s in the UK, and has earned a reputation for highly reliable testing, especially in defect detection trials³. However, it also has as controversial side, with opponents pointing to the low signal to noise ratio of signals used for interpretation, and the sizable dead zones near the component surface. While these disadvantages can be compensated for by a well setup system, it is easy to see how they are a limitation in the detection of HTHA, as HTHA typically originates near the inner surface of the material, in which TOFD has a dead zone, and because HTHA reflections are already very small. Nevertheless, TOFD has been used for HTHA inspection⁴, and impressive results have been obtained with specifically engineered TOFD probes for HTHA inspection, such as the TOFD Ultra Low Angle (TULA) probe⁵.

PAUT

Phased Array Ultrasonic Testing has a long history and gained market acceptance once portable units became available in the early 2000s. Phased Array Ultrasonic Testing (PAUT)

uses probes with many small elements with are exited with small time delays. By manipulating these time delays, a phased array probe can steer and focus ultrasonic energy. Usually, this is displayed in a fan display, like maternity echoes are displayed. The main appeal of PAUT is, that the display is very recognizable compared to earlier ultrasonic techniques (figure 3), which often only displayed an oscilloscope trace. PAUT has been used for detection of HTHA ⁶. Theoretically, good resolution is possible in the near field of the array but requires high frequency probes and a large aperture (a large array) ⁷. Additionally, this must be programmed into the instrument correctly as focal laws, which each focus in a small area. Covering of a large area, as necessary in inspection for HTHA, needs highly experienced technicians to correctly setup the equipment for the component dimension. Even then, the equipment is only in focus where it has been programmed, and not outside this area. Small defects, such as early stage HTHA, which are outside the focus area, are easily missed.

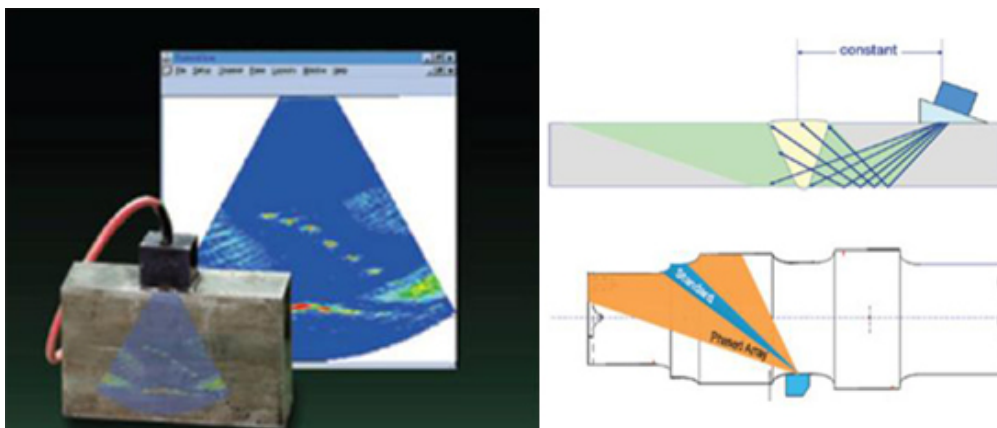


Figure 3 PAUT technique and display style

FMC/TFM

Full Matrix Capture / Total Focusing Method builds on the capabilities of array probes. Instead of programming time delays, as is done with Phased Arrays, the delays are applied afterwards on recorded data. To do this, all possible combinations of transmitting and receiving elements are recorded (the full matrix). Data is then processed as if the array was focussed on every point in the region of interest (total focusing). The result is an image which is intuitive to interpreted and in focus in all the displayed area. The main disadvantage is that the amount of data recorded is much bigger. FMC/TFM has been recently added to the ASME Boiler and Pressure Vessel Code and has been successfully used for the inspection of HTHA ⁸.

As FMC/TFM focuses everywhere in a region of interest it offers optimum spatial resolution along the active plane, which is vital for the detection of small defects such as HTHA. It is still important to optimize the probe parameters (pitch, frequency, wedge...) to minimize this spatial resolution while avoiding grating lobes.

COMPARISON OF TECHNIQUES.

Table 1 shows an overview of the four techniques treated above with their main advantages and disadvantages. While AUBT and TOFD have both been optimized for HTHA inspection, PAUT and TFM have not yet been likewise optimized. In the next section, the main properties