Ultrasonic Detection of Hydrogen Induced Cracking (HIC) in Oil and Gas Industry

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Abstract

Advanced NDT techniques have been developed for detection and characterization of critical damage mechanisms in metallic structures in the oil & gas industry, such as chemical/mechanical corrosion, fatigue cracks and hydrogen induced cracking. This paper presents the actual performance of such techniques, for on-stream inspection of pressure vessels in wet H₂S service suffering from Hydrogen Induced Cracking (HIC) or Stress Oriented Hydrogen Induced Crack (SOHIC). The different requirements for the inspection of each mechanism HIC/SOHIC and monitoring techniques are discussed.

Case-study applications of Phased Array Ultrasonic testing technique, combining rapid inspection and long-term or continuous monitoring performed on vessels of the oil and gas industry is presented. The advantages and limitations for real-life industrial applications are, also, discussed.

INTRODUCTION

A common damage mechanism of equipment in the oil & gas industry, is hydrogen induced cracking (HIC). This type of structural damage typically appears in equipment that undergoes a wet H₂S service in elevated pressure and temperature profiles. The degradation of structural integrity in the presence of HIC may advance slowly or rapidly depending on the operational conditions. If not detected and subsequently quantified and mitigated, this might lead to sudden catastrophic failure, resulting in the loss of personnel, equipment and having a major impact on the operational costs.

There are numerous case studies resulting from catastrophic failures of equipment documented in the literature [1], as well as various inspection guidelines that present, in great detail, the different stages and morphologies of this type of damage [2]. Recent advances of advanced ultrasonic phased array (PAUT) non-destructive techniques made possible the early detection of such damage in great detail. Due to the increased probability of detection (POD) and flaw sizing capabilities of this technique, on-stream monitoring and comparisons can be also applied [3], assessing potential damage growth and resulting in information about the rate of degradation of the damaged equipment and Fitness-for-Service (FFS) studies of those high risk areas.

In this work, two case studies are presented. In both cases, damage had been fortunately detected in early stages. The application of further on-stream monitoring techniques and procedures will, also, be presented and discussed.
ULTRASONIC DETECTION OF HIC

HIC damage appears typically in three stages/forms. These are, hydrogen blisters, sparse laminar in-plane discontinuities and as large clusters of in-plane discontinuities that sum up to a surface breaking structure. Detailed information about each category is presented below.

Hydrogen blisters may form as surface bulges on the ID [2], the OD or within the wall thickness of a pipe or pressure vessel (Figure 1). The blister results from hydrogen atoms that form during the sulphide corrosion process on the surface of the steel, that diffuse into the steel, and collect at a discontinuity in the steel such as an inclusion or lamination. The hydrogen atoms combine to form hydrogen molecules that are too large to diffuse out and the pressure builds to the point where local deformation occurs, forming a blister. Blistering, results from hydrogen generated by corrosion, not hydrogen gas from the process stream. Internal blisters are characterized by laminar (in-plane) cracking without some associated through-thickness crack linkage.

![Figure 1 – Blistering resulting from Hydrogen Attack](image1)

Hydrogen induced cracking (HIC) is characterized by an in-plane step-wise cracking with and may results in a through-thickness crack linkage [2] (Figure 2). This type of damage typically occurs in carbon steels that are exposed to hydrogen sulphide, cyanides, hydrofluoric acid and in general in chemical compounds that can charge atomic hydrogen into the steel. The atomic hydrogen combines and forms hydrogen molecules at non-metallic inclusions or other imperfections. These are too large to diffuse through the steel, thus this build-up of internal hydrogen can result in HIC.

![Figure 2 – Laminar In-Plane HIC damage](image2)

Stress Oriented HIC (SOHIC) is defined in [2] as follows (Figure 3): “Array of cracks, aligned nearly perpendicular to the stress, that are formed by the link-up of small HIC cracks in steel. Tensile stress (residual or applied) is required to produce SOHIC. SOHIC is commonly observed in the base metal adjacent to the heat-affected zone (HAZ) of a weld, oriented in the through-thickness direction. SOHIC may also be produced in susceptible steels at other high stress points such as from the tip of mechanical cracks and defects, or from the interaction among HIC on different planes in the steel.” The hydrogen charging phenomenon is the same as that which causes HIC.

![Figure 3 – Stress Oriented HIC damage marked with red ellipse](image3)
This type of damage, when inspected with single crystal ultrasonic probe, either straight or angled, appears to have all the characteristics of a typical crack or laminations. Therefore it is easy to misclassify these indications as non HIC in service damage, appearing as minor or non-significant. In order to mitigate the risk of misclassification of this type of damage, higher vertical and horizontal resolution per thickness is needed. Ultrasonic Phased Array (PAUT) equipment, such as the Omniscan MX2 Flaw detector (Figure 4) [4] typically provides varying levels of inspection customization regarding the focusing needs and angular span and resolution.

![Omniscan MX2 Flaw Detector by Olympus](image)

**Figure 4 – Omniscan MX2 Flaw Detector by Olympus [4]**

Different focusing depths or planes, as well as different angular beams with sub-degree resolution can be used simultaneously providing higher resolution in both the horizontal and vertical axis. Real-time representations (Figure 5) offer fine and detailed visual information about the detected indication as well as various inspection parameters needed for its characterisation. Typical setups include a set of two angular linear or sectorial scans in combination with one set of straight beams in order to cover the whole area of interest with ultrasonic waves.

![Olympus Omniscan MX2 Real Time Representation of HIC indications](image)

**Figure 5 – Olympus Omniscan MX2 Real Time Representation of HIC indications**

The most critical inspection factor is the interpretation of the various indications as acquired by multiple set of A/B/C Scans combined with Sectorial or Compound Scans. Relevant guidelines for identification as well as Fitness-for-Service (FFS) evaluation are given in part 7 of API 579 [2]. Combination of PAUT inspection under the guidelines of the API inspection code result in a rapid inspection timing with increased POD, as well as rapid evaluation and comparison of results for subsequent FFS studies.

In the remainder of this study, two (2) case studies of HIC damage in amine absorbers under wet H₂S service will be presented. In both cases, HIC indications were observed during routine inspection and subsequent higher resolution scans were obtained as part of a continuous monitoring scheme with subsequent FFS studies of the comparative results.
CASE STUDY 1 – Amine Absorber Column of 91mm thickness

During a routine internal visual inspection, multiple blisters were observed in one of the courses of a ~90mm thick amine absorber column. Ultrasonic inspections with manual and automated systems were applied to sample regions from the outer shell surface (Figure 6).

![Figure 6 – Typical Surface Sample of Automated C-Scan inspection.](image)

Results of these inspections revealed multiple clusters of lamination-type indications. However, the straight beam probes only, could not provide the additional information that was required, in order to assess the morphology of the indications with higher detail (Figure 7).

![Figure 7 – Typical Indication as appeared in Automated C-Scan inspection.](image)

High resolution scans with PAUT were performed in weld areas and in shell areas where the biggest clusters of lamination-type indications had appeared. The increased detail offered by the PAUT inspection resolved the nature of these indications as HIC damage. A typical real-time representation is shown below (Figure 8).

![Figure 8 – HIC Indication as visualised from two side simultaneous PAUT inspection.](image)

Subsequently, 100% PAUT scanning was performed on the specific course of the column and results (upon proper preparation) were also used for an FFS study. To allow operation until
preparation of a substitute vessel, a continuous PAUT monitoring scheme was applied in order to assess the criticality of the indications under service conditions and to provide early warnings about their size change trend.

![Image](image1.png)

**Figure 9** – Sample HIC Indications maximum depth measurement during a 6 month service

Monitored indications were found to have very small depth variations as the vessel was under its normal service.

**CASE STUDY 2 – Amine Absorber Column of 60mm to 67mm thickness**

In the specific column, exhaustive PAUT scans were performed in the parts that were under direct wet H₂S service. This included a conical part and two course areas adjacent to it. Almost full coverage, excluding obstacles and attachments, was achieved.

![Image](image2.png)

**Figure 10** – Typical Surface Sample of PAUT C-Scan inspection. Showing sparse clusters of HIC damage

Composite results of C-Scan showed sparse spatial clusters of indications (Figure 10). High detailed PAUT inspection with combined angular and straight beams successfully revealed that the specific clusters were not just typical lamination inside the metal but an early stage of HIC damage that ranged from blisters to in-plane clusters of lamination-type clusters identified under the guidance of the appropriate inspection codes as HIC damage. Highly focused angular scans were applied on these clusters (Figure 11) in order to extract sizing information for the FFS study. Due to the fact that this column is an essential part of the refining process and cannot be easily taken out of service, a long-term PAUT monitoring scheme was applied in order to assess and compare potential size growth of these indications. In total, more than 20 indications/clusters are monitored at certain intervals and size trends are generated. This provides an early warning of the criticality of the monitored indications. Results are also rapidly prepared for FFS study in order to assess the vessel under service conditions.
Figure 11 – Sample of highly focused angular scans for size metrics extraction. In-plane morphology of typical HIC damage is shown.

LIMITATIONS

The Phased Array technique is an ultrasonic technique that is derived from the conventional ultrasonic pulse-echo inspection method; hence it experiences the same limitations as conventional Pulse - Echo Ultrasonic technique. Specifically, for a successful detection of a discontinuity, the scanning beam and the principal direction of the discontinuity must be perpendicular to one another. However, in the case of planar indications, it is possible to detect the back-scattered, diffracted signals from the edge of discontinuity even if the orientation of the defect is not perpendicular to the beam axis. Typically, the main limitation that may prohibit the extraction of useful results is the surface condition. The highly focused beam can easily be scattered in the presence of rough surfaces resulting in a poor horizontal and vertical resolution, especially if higher gain setting as used.

CONCLUSIONS

Utilizing the extreme versatility of the phased array equipment, highly detailed qualitative and quantitative information can be rapidly extracted. This is not only limited to HIC damage but to other types as well. The apparent abundance of information that is acquired during scanning, can be easily tailored for various inspection schemes to be customized and subsequently applied. Usually, the superset of the PA data sets allows for an instant visual assessment during field testing and offers enhanced POD of various indications and especially critical ones. Post-test analysis and extraction of results using various evaluation guidelines, for example FFS evaluations, can be performed rapidly, allowing results from larger areas to be incorporated to the evaluation in less time. Increased productivity is guaranteed; that is larger areas in the same time, due to the simultaneous multiple phased beams that the equipment is capable to project. Regarding health and safety, major risks that can result in catastrophic failures are greatly mitigated if continuous monitoring schemes are applied either as standalone or part of a greater inspection scheme.

REFERENCES