Ultrasonic Connected Probe for In-Service Monitoring of Pressure Equipment

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ABSTRACT

In order to guarantee the safety of the gas production plants, Air Liquide conducts NDT inspections regularly closely following the assets' maintenance plans. One high criticality asset is the Pressure Swing Adsorber (PSA), found in the last stages of the hydrogen production process, where product purification takes place. These adsorbers are pressure vessels and need to be inspected for hydrogen enhanced fatigue cracks. The PSA adsorbers are inspected for cracks regularly by INTACT following a dedicated inspection plan. When indications or cracks are found, a Fitness For Service (FFS) assessment is done to determine the stability of the crack, and if stable, propagate the crack over time calculating the number of cycles before the crack reaches its critical size, in other words, the time up until this crack will go through the complete thickness of the adsorber creating a leak. As an output of the FFS assessment, certain cracks could require a close monitoring, with high frequency intervals of inspection, this necessity is what drove Air Liquide R&D and INTACT to partner up to develop the *"Ultrasonic connected probe for in-service monitoring of pressure equipment"*.

INTRODUCTION

The safety of gas production plants is of utmost importance and requires regular inspections to ensure that the equipment is functioning properly. One of the critical components in the hydrogen production process is the PSA, pressure vessels found in the last stages of the process on the Steam Methane Reforming (SMR). The PSAs need to be inspected regularly to detect defects such as cracks or corrosion. Conventional inspection would require stopping site operation, building scaffolding for the totality of the height, which depending on design can be up to 15 meters tall and 6 meters in diameter, grinding of the inspection surface to remove the paint, conducting the inspection manually by 2 operators, and repainting once inspections are concluded.

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Commonly, inspection plans for these high-criticality assets outline a high inspection frequency, resulting in elevated costs associated with logistics, personnel and time and monetary resources required to plan and execute each inspection. This necessity is what drove Air Liquide R&D and INTACT to create a partnership and develop a new methodology to perform the welds inspection and a monitoring technology when the inspection frequency is high.

To respond to the advanced technology for inspection, the solution development was the IBEX crawler, an automated crawler that can be deployed on in-service PSA assets for Phased Array Ultrasonic Testing (PAUT) inspection, using Total Focusing Method (TFM) with INTACT proprietary imaging and software. The inspection allows the control of longitudinal and circular welds, looking for indications/cracks, these results are then analyzed by 3D reconstruction and managed by mechanical integrity assessments proprietary technology, to estimate the residual lifetime of the indications and in consequence, the interval between inspections, when the interval of inspection is too short and a monitoring is required, the solution called "Connected probe" comes in place. The connected probe is an ultrasonic probe able to monitor the evolution of internal hydrogen induced fatigue cracks from the external surface of the PSA.

PSA CONTEXT

The PSA are ferromagnetic assets, mainly A516 Gr 70 with a thickness that can vary between 10mm to 60mm. The adsorbers' dimensions can vary depending on the design and production, with the majority being around 30mm-40mm for the thickness. The PSA's size can also vary, with adsorbers being as large as 1m to 3m in diameter and 5m to 15m in height. The number of welds will also depend on the design and dimensions, typically it is usual to find 3 to 5 circular butt welds, so 2 to 4 longitudinal butt welds along with a top and bottom nozzle.

PSA adsorbers work on pressure cycles throughout their whole life. The pressure cycles go from 0 to 30-40 bar, this depends on the production and design of the plant. In general, the cycle duration ranges between 200-400 to 600-800 seconds. Since these adsorbers are cycling, they are subject to fatigue. And since the adsorbers are in the process of hydrogen production close surveillance and preventive maintenance is necessary. The main risks associated with H_2 PSA units are pressure bursting and flammable gas leaks that may lead to hydrogen fires. The most feared event is the development of a crack from pressure and cyclic fatigue, with the presence of hydrogen being an aggravating factor in crack propagation (see Figure 1).

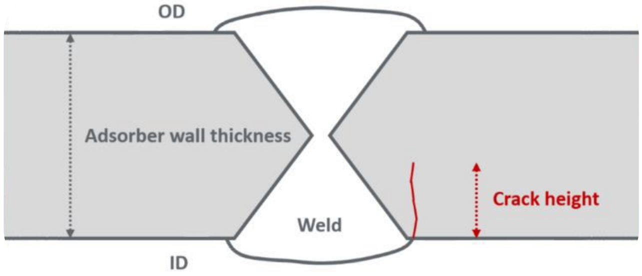

Figure 1. Illustration of typical fatigue crack in butt weld.

In order to ensure the safety and proper functioning of equipment, such as the PSA, regular NDT inspections of the welds are conducted to detect defects such as cracks or corrosion, among others.

When indications or cracks are identified, they undergo a process sizing and characterization by a 3D reconstruction analysis and managed by mechanical integrity assessments proprietary technology to estimate the residual lifetime of the indications and in consequence, the interval between inspections. In cases where the inspection intervals are too frequent and continuous monitoring is needed, a solution known as the "Connected probe" is employed. This probe utilizes ultrasonic technology to observe the progression of internal cracks caused by hydrogen-induced fatigue, doing so from the external surface of the PSA.

CONNECTED PROBE

The connected probe technology consists of a PAUT 64 elements transducer. It is positioned on the outside surface of the equipment, for instance in the PSA, in alignment with the crack. The probe fixation system employs magnetic components to be able to position it and remove it when the monitoring is no longer necessary, the connected probe could be deployed for as long as needed. To ensure the effective transmission of the UT waves, when it is installed, the connected probe is put in position and the ultrasonic coupling is set up as well.

The transmission and reception of UT waves are managed by an ultrasonic electronic card, while the software controls the transducer via the card. To obtain the data, a remote connection is established via wifi, no cable is needed, allowing remote access from various locations worldwide, such as INTACT offices or the control room at the site. Monitoring and data extraction are performed according to the required frequency.

The Connected Probe technology allows the live monitoring of an evolutive crack for in-service ferromagnetic assets. For the general communication protocol for the connected probe technology (see Figure 2).

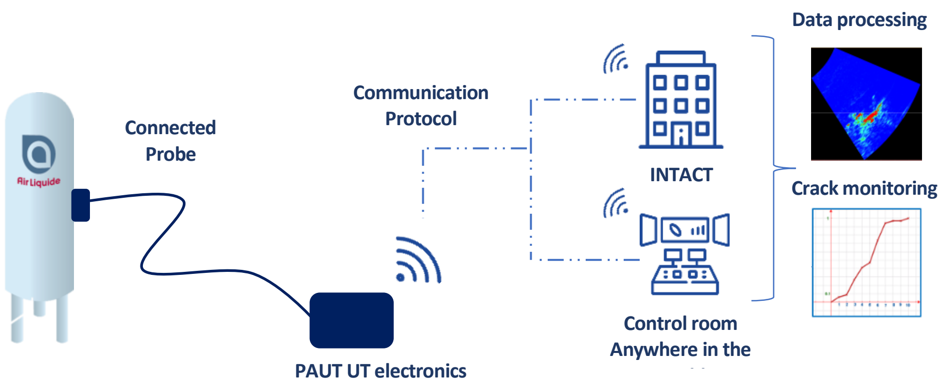

Figure 2. Communication protocol of the connected probe.

PROOF OF CONCEPT

Context

At the Air Liquide facility in Europe, a fatigue crack was detected in one of the PSA adsorbers. This crack was specifically found in the weld connecting the internal grid bed support to the inner surface of the bottom head (see to Figure 3).

Air Liquide had already scheduled repairs for the site; however, in the interim, they wanted to ensure that they could delay the shutdown and repair activities without compromising the safety of personnel and the site.

Implementation

During this period, an opportunity arose to test a connected probe with the aim of validating its capability to remotely measure the depth of the defect. The connected probe prototype was securely attached to the external head of the equipment, and precisely positioned at the location where the crack was detected on the internal side (see Figure 4).

Figure 3. Fatigue crack at the support/head weld location.

Figure 4: Connected probe, fixed to the bottom head (left), into the skirt volume (right).

The connected probe was connected to the PAUT electronic board using a wire, which was situated at a distance of 30 meters outside the ATEX area. This PAUT electronic board encompasses an electronic card, UT software, an internet connection for data transmission, and enables the control of the connected probe as well as the execution of specific queries (see Figure 5).

Figure 5: UT and electronic system to pilot the connected probe at Air Liquide site.

Results

The monitoring of the crack depth using the connected probe was conducted from Ekoscan premises in France. The objective was to demonstrate the effectiveness of the method, and the results are presented graphically (see Figure 6 and Figure 7).

Figure 6 shows the remaining ligament (the difference between wall thickness and crack depth) is shown in millimeters over time. The x-axis represents a total duration of 600 seconds, which corresponds to a complete pressure cycle of the PSA. A query, consisting of a sectorial scan to measure the crack depth, is performed every 10 seconds, resulting in the plotting of a dot. All the dots are connected to form the blue line.

The inner pressure of the PSA is represented by the green dotted line. It can be observed that the measurements are relatively consistent when the pressure remains stable within a range of +/- 0.2 mm. However, a notable difference is seen in the remaining ligament when the PSA is pressurized compared to when it is at low pressure. Specifically, the remaining ligament measures approximately 38.4 mm during pressurization and 39.1 mm during low pressure. This difference indicates a slight opening of the fatigue crack depending on the inner pressure of the PSA.

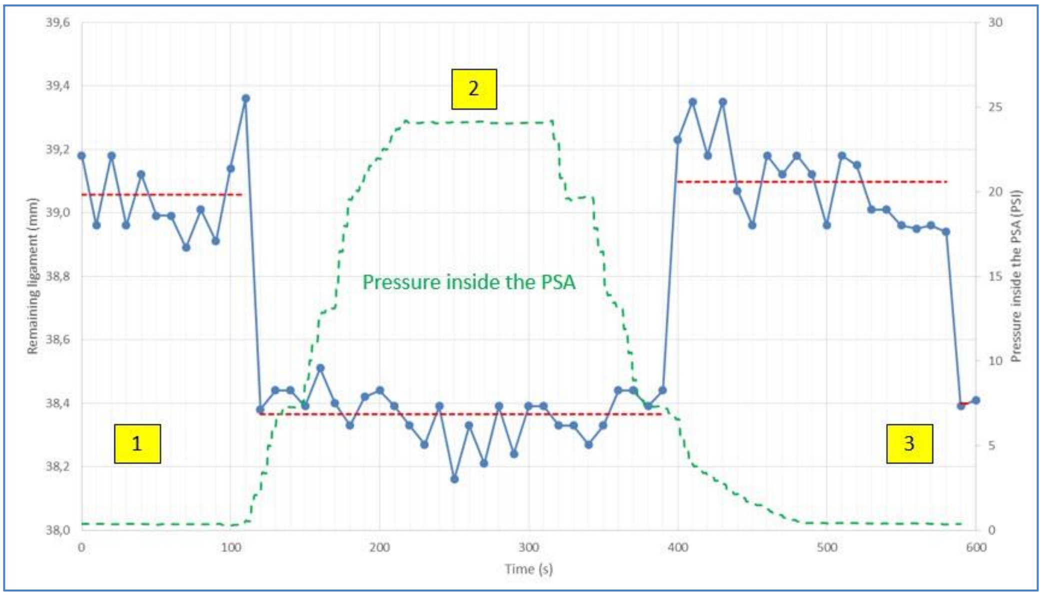

Figure 6: UT and electronic system to pilot the connected probe at Air Liquide site.

As shown in Figure 7, in the scans, area 1 and area 3, where the inner pressure of the PSA is below 1 bar, exhibit striking similarities. The multicolored zones in the scans correspond to ultrasonic signals originating from the internal surface and resulting from the rebounds of second-order UT signals. In the middle of the scans for area 1 and area 3, characterized by no pressure within the PSA, small stains can be observed forming a vertical line. These stains represent crack diffraction signals.

On the other hand, area 2, corresponding to when the PSA is under pressure (22 bar), displays only one task. However, this task is located higher compared to area 1 and area 3. These observations suggest that when the crack is under pressure, it tends to be more open, and the diffraction is only visible at the crack tip where the single task appears.

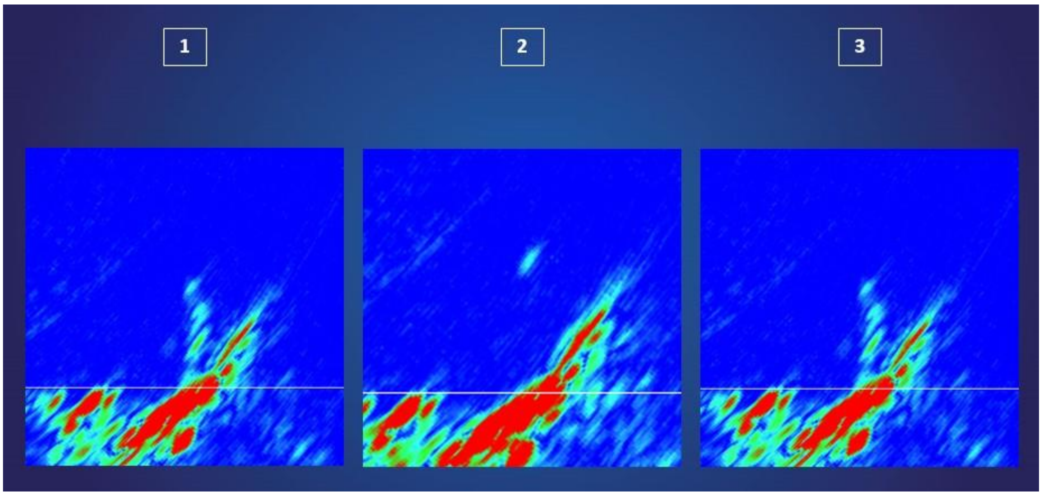

Figure 7: UT sectorial scans at area 1, 2 and 3 of Figure 6

The successful piloting of the connected probe was achieved first from the control room and subsequently from the INTACT facilities located in Saint-Rémy, France.

During the testing, it was demonstrated that the connected probe, when viewed on the PC board screen without physical contact with the probe itself, enables the detection of existing cracks at depths ranging from 3 to 10 mm. Moreover, the remote scan can be easily adjusted to focus on the crack front.

CONCLUSION

In conclusion, this study focused on the development and testing of a connected probe for in-service monitoring of fatigue hydrogen induced cracks at pressure equipment, specifically targeting the PSA used in gas production plants. The aim was to improve inspection efficiency, reduce costs, and enhance safety.

Traditionally, inspections of PSAs required site shutdowns, extensive scaffolding, and manual inspections, leading to significant logistical challenges and costs. To address these issues, Air Liquide R&D and INTACT collaborated to develop advanced technologies and methodologies.

Once a crack has been identified to optimize inspection frequency and enable continuous monitoring, the connected probe was introduced. This probe, positioned externally on the PSA and remotely controlled, utilized ultrasonic technology to monitor the evolution of internal hydrogen-induced fatigue cracks. It allowed for real-time monitoring and data extraction, enabling timely decision-making and reducing the need for frequent physical inspections.

The POC testing conducted at Air Liquide's facility demonstrated the successful application of the connected probe. The crack detection and monitoring were achieved remotely from INTACT, validating the probe's ability to measure crack depth and monitor crack progression. The results, presented graphically, showed consistent measurements, and revealed the influence of PSA inner pressure on crack behavior.

The connected probe technology proved effective in detecting cracks at various depths, ranging from 3 to 10 mm, without requiring direct contact with the probe. The remote scanning capability and adaptability to focus on crack fronts further enhanced its usability and reliability.

Overall, the development and testing of the connected probe offered a promising solution for in-service monitoring of pressure equipment, such as PSAs, ensuring continuous monitoring, enhancing safety, and optimizing inspection intervals. The successful results obtained from this study pave the way for its future implementation at other sites with the same need for real-time crack monitoring, or other applications such as HTHA (High-Temperature Hydrogen Attack) and corrosion.