Automated IBEX crawler for PAUT inspection for in-service ferromagnetic assets

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Abstract: In order to guarantee the safety of the gas production plants, AIR LIQUIDE perform NDT inspections regularly following closely the maintenance plan. A high critical asset is the PSA Pressure Swing Adsorber, dedicated to the hydrogen purification. These adsorbers need to be inspected for Hydrogen Enhanced Fatigue cracks. Conventional inspection would require stopping operations, build scaffolding for the totality of the height that can be up to 15m tall and 6m diameter, perform the inspection manually by 2 operators, grind the inspected area to remove the paint and repaint after the inspection. To follow the maintenance plan, these inspections are done with high frequency, involving elevated cost to carry on the logistics around the inspection. This necessity motivated the partnership AIR LIQUIDE R&D + INTACT to develop an automated crawler for PAUT inspection for in-service ferromagnetic assets.

The objective was to perform PAUT inspection in any ferromagnetic asset welds with an autonomous robot. The robot, called IBEX Crawler is deployed at the lowest part of the vessel, and controlled at the ground level by an operator. It is able to change movement for the inspection of longitudinal and circular welds. It includes an encoding system to know the exact location of the indications. The crawler brings on board an electronic 128 board controlled by fiber optic, laser tracking and machine vision camera. The inspection results are analyzed with 3D reconstruction and managed by mechanical integrity assessments proprietary.

Today INTACT IBEX crawlers travel worldwide between Air Liquide’s sites to assure the integrity of their assets.

Keywords: PAUT (Phased Array Ultrasonic Testing), PSA (Pressure Swing Adsorber), SMR (Steam Methane Reformer)
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**Context**

**SMR units for hydrogen production**

**Units of 4, 6, 10, 12 PSA adsorbers**

**Damage mechanism**

Hydrogen Enhanced Fatigue (HEF)

**Adsorption / desorption**

= Fatigue pressure cycle

**Design**

- ID: up to 4m
- Height: up to 15m
- Shell thickness: 20 – 60mm
- Material: SA-516-Gr70

**Operation**

- Temperature: Ambient
- Pressure: 0 – 40 bar (200-800 seconds per cycle)
**Pain points & traditional NDT inspection**

<table>
<thead>
<tr>
<th>Pain points</th>
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<tbody>
<tr>
<td>Hydrogen Enhanced Fatigue (HEF) cracking is challenging to detect at early stage</td>
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<tr>
<td>Need of routinely inspection of all welds (Longitudinal, circular and nozzles)</td>
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<tr>
<td>An accurate sizing is needed in order to follow the crack evolution</td>
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<tr>
<td>Danger to undetect or unaddressed a crack, as when reaching a certain size the evolution will accelerate drastically (inspection reliability)</td>
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<td>Equipment with big dimensions, up to 3m diameter and 15m height</td>
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<table>
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<tr>
<th>Traditional inspection</th>
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<tr>
<td>Need for safety equipment to work at height</td>
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<tr>
<td>Manual scanner</td>
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<tr>
<td>TOFD</td>
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<tr>
<td>Stop operations</td>
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<tr>
<td>Scaffolding</td>
</tr>
<tr>
<td>Repaint after inspection</td>
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<td>Paint removal by grinding</td>
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Collaborative development: Advanced inspection automation

Robotic
IBEX crawler

Acoustic
Software
Acoustic method development

- **TOFD** (historical method)
- Standard PAUT (Sectorial Scan)
- "Custom" PAUT for PSA (Sectorial Scan)
- Advanced PAUT for PSA (PWI/TFM)

**Benefits:**
- Better detection on sizing
- Access to the shape of the defect
- Improved accuracy & characterization of the crack
Acoustic method development (advantages)

A view → CORRECTIVE MAINTENANCE
- TOFD detects defects between 4 and 9 years after PAUT which may lead to more complex maintenance operation, additional shutdowns

→ PREDICTIVE MAINTENANCE
- PAUT detects defects early which allows PSA adsorbers integrity management, predictive maintenance and to anticipate maintenance operations
Mobile robot remotely controlled, allowing the PAUT inspection of welds (Longitudinal and Circumferential) for in-service ferromagnetic assets. Detection and sizing of Hydrogen Enhanced Fatigue indications (HEF).

**Features**

- On-board electronic 128 elements PAUT board
- PAUT transducers up to 2x64 elements
- Fiber optics for communication with transducer
- Machine vision camera
- Laser OD weld profile reconstruction
- Non marking magnetic wheels (no paint damage)
- Motorized probe lifter
- PWI/TFM imaging
- PSA dedicated software for data acquisition and analysis
- Automated reporting
PSA PAUT Inspection automation (Advantages)
PSA software development

Dedicated PSA inspection tool
POC at industrial site in France (Air Liquide)

- PSA adsorbers welds fully inspected remotely
- IBEX crawler capable of turning from longitudinal welds to circumferential welds
- Data acquisition and analysis done successfully
- Knowledge of the PSA integrity at an earlier stage
- Estimation on residual lifetime for each of the indications
- Integrated maintenance report specifying the intervals of future inspections

Critical zones identification

Calculation of interval between inspection by Fracture Mechanics

Design of efficient inspection plan

• FFS If indication is found
• Continuous monitoring if short interval
• Shutdown if critical defect

Industrial site advantages

✓ No need for preparatory work before inspection
✓ No paint removal
✓ No scaffolding
✓ No repaint
✓ No shutdown
✓ No risk at height
✓ 100% volumic inspection
✓ Live reporting
✓ High repeatability
✓ Decreased inspection time
✓ Direct link to FFS / remaining life calculation

Cost saving
Time saving
Safety
Higher performance

Results
• Air Liquide need for more precise and periodic inspection of PSA adsorbers for cracking (HEF) was addressed by the development of a robot capable of performing a remote inspection of welds.

• The collaborative project between INTACT and AIR LIQUIDE, involved various fields such as acoustics, robotics, electronics, mechanics and software.

• The result is the IBEX crawler. After going through several stages of development, the IBEX crawler is now fully functional and operational. To date more 70 Air Liquide sites have been inspected with the IBEX crawler.
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