NOVEL AE MONITORING OF HYDROGEN INDUCED DAMAGED VESSEL AND REAL TIME ALARMS. A CASE STUDY

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Abstract

Hydrogen induced cracking (HIC) damage is a common damage mechanism, expected typically in vessels in severe wet H₂S service. It can occur at relatively low temperatures, as the atomic hydrogen is concentrated at the impurities within the steel. The occurring damage is mostly cumulative and it can be manifested in various types such as blistering, step-wise cracking or stress-oriented cracking. As such, the qualitative and quantitative evaluation of structural integrity of any vessel possibly suffering from wet hydrogen damage is of great concern from a safety, environmental and financial point of view. In the present paper, results of the application of real-time AE monitoring of a HIC damaged area of a thick-walled amine absorber in severe wet H₂S service are presented. The damaged area was found during a routine UT inspection. UT and AE trials were performed in order to fine-tune and maximize the effectiveness of the application. This resulted in a unique correlation database from which monitoring criteria were developed, that greatly maximized the AE location performance and minimized the false alarms due to the noisy environment. Major benefits of the AE monitoring application include an overall increase of health and safety, as well as minimum down-time for the refinery until a full vessel replacement becomes possible.

1. Introduction

Acoustic Emission [1][2] has been successfully applied for the integrity assessment of static structures such as pressure vessels and storage tanks during both in-service and hydrostatic tests for a wide range of manufacturing materials. Extensive testing of such equipment has led to the development of AE testing procedures, evaluation criteria and international standards [3][4]. In addition to that, industry applied procedures, such as MONPAC & IPAC [9][10] for pressure vessels, extended the codes’ pass-fail assessment to quantitative evaluation of fault severity and criticality, providing the industry with a tool for 100% evaluation of the vessel, capable of giving early warning of developing defects, increasing, thus, the operational safety.

In areas with high stress concentration and where local strength may lead to crack propagation, as in the case of step wise cracking HIC or SOHIC (Figure 1), local monitoring
can be performed. Many variables, like temperature, contaminations, microstructure etc., may affect and thus differentiate the final damage.

Although surface breaking cracks are visible, their detection may be performed with various other NDT techniques like UT (TOFD-PA), EC, PT or RT. Many of these methods may also provide information about the crack size, position and orientation.

In cases where the primary interest is the crack growth and its criticality in relation with the variation of operating conditions, continuous AE may be used by utilizing the stochastic stimulation of the structure (varying pressure, temperature variations etc.) [6]. In this paper, a novel adaptation of the method and application of real-time alarm criteria over a noisy environment is presented. This was possible due to the unique AE & UT findings correlation database. The continuous monitoring was able to provide an early indication of possible damage accumulation in severely damaged areas.

![Figure 1 – (a) Stepwise Indication - HIC (b) Through Thickness Indication in HAZ – SO-HIC [6]](image)

2. Case Study: HIC Monitoring of Amine Absorber

During a routine internal inspection, a large number of surface breaking blisters was found on the internal surface of the 91mm-thick column (Figure 2) with an operational temperature of 60°C. These indications appeared just above the operational water level, on the internal surface of the 2nd course of the column. Subsequent base metal and weld ultrasonic (UT) inspection with phased arrays (PA), as indicated by [6] were performed in sampled areas of the column. UT inspection showed unexpected scattered indications in both areas (HAZ & base metal).

The indications that were discovered were ranging from planar to step-wise (Figure 3a). Some larger clustered axial-oriented indications were also discovered that appeared as through-thickness damage (Figure 3b). The presence of these indicated that the damage was already in an advanced state.

To this respect, the planning for continuous monitoring was established due to the criticality of the column regarding its structural integrity condition as well as its impact on the general safety during subsequent operation, until its replacement.
3. Setup

Eight areas (1–8) with larger clusters of identified damage were selected for monitoring as being the most critical. Area 6, was selected as a reference since it was damage-free (Figure 4a).
In total, twenty-two (22) R15i AE sensors, with a 150 kHz resonant frequency and integral preamplifier, were mounted around the 2nd course in triangular formation (Figure 4b), where the first and last four sensors were used as guards, in order to exclude operational or other activity not correlated with the damaged areas. These were mounted after the column was brought back to service.

The sensors were mounted with high-temperature couplant and magnetic holders (Figure 5a). The connection to the more centralized junction boxes (Figure 5a) was performed via coaxial cables that were shielded inside elastic tubing (Figure 5b).

From each of the junction boxes the coaxial cables were routed to a nearby shielded isobox where the physical connection with the system (Figure 5c) was established. All routing to the system was performed via larger diameter elastic tubing to shield the cables against the elements.

4. Attenuation Measurements & Location Verification

AE signal attenuation measurements (Figure 6a) were performed along the axial direction, circumferential direction and 45° angle from the circumferential direction. As is often observed in thick vessels, the signal attenuation was relatively low (65 dBAE at 500cm from an AE probe). In this respect, it was expected that the predefined tight array of Acoustic Emission probes would greatly increase the event detection capability of the resulting setup.
5. System Functionality and Sensitivity Verification

For any monitoring scheme, safeguards and system checks must be enforced in order to maintain a high confidence level for the functionality of the system. For these reasons, daily routines were performed in order to ensure that the system was functioning properly and the sensitivity of the probes was not degraded due to the operation of the column or exposure to the elements.

This was achieved by using the Auto Sensor Test (AST) feature of the MISTRAS μSamos Express-8 boards in predefined and/or random intervals and the results were cross-referenced with the reference AST results acquired when the probes were initially mounted. The AST feature data comparison shows the difference of AE features between two data
sets. The comparison of the newer AST measurements (when performed) with the reference AST measurements was automatically performed by the system each time new AST data was available. Graphs from AST trials showing typical AE features for each probe are shown in Figure 8a. In addition, for system performance, the Average Signal Level (ASL - Figure 8b) of each channel was continuously monitored in order to have clear indications about any abrupt operational changes or external noise that could contaminate the acquired data.

![Figure 8](image)

In the rare case that a sensor’s response was degraded from its average behavior and sensitivity, local crew was performing the necessary adjustments.

6. Data Evaluation and Reporting AE Results Grading

Daily evaluation and reporting of acquired data was decided due to the criticality of the situation and the massive amount of acquired data. AE and UT phased array trials were performed in order to develop a unique correlation database. Upon the completion of trials and by using the resulting database the real-time alarm criteria were greatly improved and fine-tuned in order to be used in real-time alarms. The number of false alarms during continuous monitoring was greatly reduced, thus maximizing the effectiveness of the monitoring. A confidential list of Events Cluster Activity, Amplitude and Energy Criteria and time compensation/normalization was agreed with the client, upon the completion of initial trials. The typical daily report contained the cluster activity grading of the monitored areas assigned into 4 categories (Table 1a).

![Table 1](image)

In addition, a summary weekly report was generated at the end of each week (Table 1b).
7. Monitoring and Real Time Alarms

24/7 remote access to the \(\mu\)Samos Express-8 AE Monitoring Workstation was available through a high speed internet connection. Daily reports of operational parameters of the column and weather conditions were correlated in order to filter the data. AEWIN software was used for automated located data clustering during acquisition (Figure 9). The alarm generation according to the aforementioned categories and criteria was subsequently triggered.

![Figure 9](image)

(a) Example of automated clustering (b) Real-time automated clustering

An interesting observation is that there is significant located AE event clustering, in the areas of interest.

8. Discussion & Conclusions

In general, this novel AE monitoring method of verified HIC damaged areas, offers the unique opportunity for asset owners to be informed rapidly and continuously, with minimum interference, about the condition of the structural integrity of critical assets that need to operate at their design limits.

Results of the test can be given almost immediately, upon the alarm triggering, with full evaluation within hours after, thus providing a great assistance to the general operations regarding the asset.

More specifically, safety and operational risks are minimized and operational efficiency is increased, therefore minimum downtime is guaranteed.

Location optimization using high-density AE probe arrays shows a highly promising contribution to the early detection of damage areas even in case that were not identified.
previously. This was shown in (Figure 9b) where the area between probes 6, 7 and 11 was not initially selected for monitoring. However from the initiation of AE monitoring the resulted large AE event cluster that was located, change the criticality of this area. and additional UT-PA follow up that was performed revealed many smaller critical indications.

Finally, all the above advantages can be further exploited by installing permanent AE monitoring systems with remote access functionality, in order to assess the structural integrity of assets during in-service operation and/or prolonged time periods. Typical systems of this magnitude are already successfully monitoring critical assets, thus greatly promoting the minimization of safety risks and the increase of operational efficiency.

References


[12] EN 15495:2007, “Non Destructive testing - Acoustic emission - Examination of metallic pressure equipment during proof testing - Zone location of AE sources”.


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[20] Noesis V9, Pattern Recognition Software, Mistras Group Hellas ABEE.