Structural health monitoring using acoustic emission on metallic components in industrial plants

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Abstract:

The Structural health monitoring (SHM) is a method to safeguard the integrity of metallic components or component assemblies during service. This process involves a continuous or periodic measurement, the extraction or selection of degradation-relevant data and the statistical analysis to determine the actual state of the system condition. Acoustic emission (AE) monitoring detects and locates potential defects in plant components like piping and pressure vessels. An essential advantage of acoustic emission is that it allows assessing the components regarding evolving defects, leaks or even active corrosion during operation. Therefore, acoustic emission qualifies excellently as a tool for structural health monitoring.

The sensors of the monitoring system have to be mounted at preselected positions of the metallic structure and a tailored data analysis programme evaluates the incoming signals to provide a reliable statement regarding the structural health. Individually designed alarm and warning criteria enable corrective actions to prevent that the observed degradation evolves to failure.

In order to meet the requirements of customers from the oil and gas industry or the energy generation industry, TÜV AUSTRIA developed a monitoring technique for hot and cold surfaces including a methodology for collecting, transferring, storing and evaluating the measuring data.

This paper contains case studies where structural health monitoring with acoustic emission is used to provide an alternative to the regular requalification procedure of the monitored metallic pressure equipment.

1. Introduction

The performance of a conventional water pressure test indicates total failure in the form of visible deformation or leakage. A conventional acoustic emission testing (AT) is used as a periodic inspection method for the condition assessment of metallic pressure equipment. Accompanying pneumatic or hydraulic pressure tests are generally performed up to 1.1 times of the design pressure of metallic pressure equipment, while the acoustic emission testing provides a statement regarding the structural integrity of the item under test and can also detect early failure mechanisms. A relevant issue of AT is that the pressurization is performed with the operating medium. In contrast to hydrostatic testing no hazardous waste will be produced. Furthermore residual humidity may induce or facilitate failure mechanism. Therefore plant operators avoid complex cleaning and drying procedures which would be required after completion of the test. Acoustic emission testing is appealing for industry and enables the plant operators to optimize the plant availability with low operating costs for the recommissioning of the pressure equipment after the inspection test.
Structural health monitoring by means of acoustic emission is the next milestone in AT history. The pressure equipment operational parameters, such as working pressure, temperature or cycles should be recorded during the performance of the pressure test with AE. The monitoring period for SHM can either be discontinuous (e.g. 3 days 4 times per year) or continuously.

In general information regarding the current conditions of the metallic components in industrial plants is of vital importance for every plant operator. Therefore, one main task of the maintenance department is to take proper actions for ensuring secure operation. As an illustration, there are a lot of different methods on the non-destructive testing sector, to estimate the duration of a service period for pressure equipment, which are provided by TÜV AUSTRIA. Hence, there is increased attention on structural health monitoring using acoustic emission. Precise information regarding the actual conditions of the metallic components would enable the maintenance department to point out the components which should be repaired or when they should be replaced. That would give an economic advantage by preventing a shutdown of entire industrial plants and enable an appropriate repair.

2. Acoustic Emission Monitoring Concept

The main function of structure health monitoring is to merge the AE-data with the operating parameter (pressure, temperature, volumetric flow rate...) in the measuring system (see figure 1). Subsequently these monitoring data will be stored and can be analysed with dedicated software (e.g. Vallen Systeme “Automation Manager”). The automation manager has an online access to the measurement data. For example, if certain criteria are exceeded, an alarm message is sent if necessary per email and a test report is created over a predefined inspection period.

Figure 1: Acoustic emission monitoring concept

Two kinds of sensors will be applied in these use cases. Standard sensors VS150-RIC from Vallen Systeme with a temperature range up to 60 °C are mounted on the metallic surface of the pressure equipment. For a temperature, up to 180 °C, VS150-BD-V01 sensors are
mounted directly on the tested surface. For temperature ranges above 180 °C, a specifically designed waveguide device is applied between the test surface and the acoustic emission sensor. The VS150-BD-V01 sensor is certified for hazardous areas and is connected to the AMSY-6 measuring system with a 20-meter hazardous-certified coax cable and an AEP3-BD-V01 preamplifier.

The sensitivity of each measuring chain is checked with the Hsu-Nielsen source before the test. The AE system is an AMSY-6, which can acquire AE data and waveform data simultaneously for each channel. It has an internal pulsing unit, which sends on request an electric pulse to a sensor. That electric pulse is transformed into an acoustical pulse by the sensor. The other sensors may detect the sent pulse after propagation in the metallic structure. The AE system measures the time period from the emitting to the receiving sensor and that together with the distance between emitter and receiver gives the speed of sound. This pulsing function, defined as “Auto Pulsing”, will also be used to check the functionality and sensitivity of the measuring chain before, during and after the 24h-AE-measurements.

The software for data acquisition, visualisation and frequency analysis is also provided by Vallen Systeme. With VisualAE™ evaluation data files can be created concerning to the metallic pressure equipment, the respective relevant operational parameters (pressure, temperature, strain, volumetric flow rate...), cluster evaluation factor (CEF) [1] and external data (weather data).

“Automation Manager”, the software used for structural health monitoring with acoustic emission is also provided by Vallen Systeme. For a better comparison 24h measurements will be saved with previously configured data acquisition and visualisation files. With the “Auto Pulsing” function mentioned before the measuring chain is checked at certain intervals. If a previously defined deviation of AE parameters occurs, an alarm should be sent as a result [2]. Similarly, previously set limits of the acoustic emission results can trigger alarms. Consequently, digital inspection reports will be created. The structure health monitoring could be performed discontinuous or continuous.

3. Examples of monitored metallic Components

- Urea plant (passivation air cylinder, figure 2)
The entirety of the structure of the passivation air cylinder can be monitored by an application of acoustic emission testing. As an example, for a simple standard sensor arrangement, 3 sensors must be applied linear on the 660-mm diameter cylinder in figure 2. The used sensor is the VS150-RIC, which has a resonant frequency of 150 kHz. The sensitivity of each measuring chain is checked with the Hsu-Nielsen source before the test. The “Auto Pulsing” function of the Vallen Systeme was executed before and after a 24h-AE-measurement and periodically in a 6 hours cycle. This functional check of the AE measuring chain was appended to each 24h-AE-measurement inspection report (see figure 3). The AE system is an AMSY-6, which can acquire AE data and waveform data simultaneously for each channel and is able to intercommunicate with the “Automation Manager” software.
While the pressure equipment was in operation the 24h-AE measurement was recorded with the operation pressure as external parameter. For the passivation air cylinder SHM used acoustic emission was done discontinuous 3 days 4 times per year.

- Urea plant (Nitrogen cylinders, figure 4)

The same sensor arrangement as the passivation air cylinder was applied for this both nitrogen cylinders. Those metallic pressure equipment are exposed to environmental impacts. Thus, the external parameters were enhanced with the data of the weather station for a profound analysis. The monitoring time was also the same: discontinuous 3 days 4 times per year.

- Preheater for fuel gas in gas-fired power station (figure 5)

- Main steam distributor (figure 6)

The main steam distributor should give an example of the application of an acoustic emission monitoring system during operation at temperatures up to 170 °C. A sensor arrangement with 5 sensors must be applied linear on the 450-mm diameter cylinder in figure 6. Whereas 3 sensors were mounted directly with magnet holder and 2 further sensors were mounted between those 3 sensors with a waveguide technique. For this example, external parameters are temperature, pressure and volumetric flow rate. The electrical signal of these 3 parameters was fed directly into the acoustic emission system.
4. Results

The verification of the structural integrity while the metallic component is in operation was implemented by the evaluation of a 24h-AE-measurement and provides further information: Existence of active AE-sources caused by the act of defect-mechanism in the structure, grading of the intensity of the AE-sources during the applied pressurisation and localisation of the AE-sources in space of the whole structure.

Moreover, in respect of safety-relevant measures the early recognition potential of AET in contrast to alternative test methods is from vital importance, especially to the common hydraulic pressure test (water pressure test). This also includes an early detection at approximately 30 % of the load of the component failure for ductile materials. Also, possible defect-mechanisms can be observed in a microscopic range.

Figure 7a) shows the cluster evaluation factor (CEF) and the pressure versus time of measuring. This graph gives conclusions about the load profile; it shows minimum- & maximum- working-pressure, and pressure intervals during operation of the metallic component. The cluster evaluation factor is applied for on-line evaluation of located events. The CEF calculation is based on prototype data acquired on structures with known defects. The evaluation range of CEF start from 0 (no located events = 0 severity) up to 4 (very high severity).

At the example of the passivation air cylinder the traceable, active AE-sources are located among the sensors xd4 and xd5 at the range between 380 and 400 cm (see figure 7b).
Exactly on this position the mounting ring is fitted. Therefore, this area was verified on the cylinder with an ultrasonic test. This inspection method exhibits no noticeable indications. Hence, the result suggests that the activity of the acoustic emission was caused by mechanical friction between the mounting ring and the passivation air cylinder.

The important advantage of the monitoring inspection report is the history of those 12 x 24h-AE-measurements which could be compared easy. An equally important reason to realise SHM is the adequately long monitoring period of about 290 h compared to one hour of a conventional acoustic emission test. The project target was the extension of the service period till to next inspection (one year).

5. Conclusion

Structure health monitoring using acoustic emission on metallic components will become an increasingly role on non-destructive testing sector. The system effectiveness of new industrial plants is growing and the knowing of the actual conditions of the metallic components in industrial plants is of vital importance for every plant operator.

Conventional acoustic emission tests will be more popular because they are performed with the process medium, but this method must take a requalification. The test performance must realise during a planned shut-down and usually on pressure equipment in ambient conditions. Often the prevailing test requirements do not represent the operating conditions or only in a limited way. Also, the material is sometimes not sufficiently loaded as in operation, for example material properties modify with temperature.

In case if points which mention above should be relevant, acoustic emission monitoring could be the solution. However, the degradation of the material happens normally during operation Nevertheless not during testing. Consequently, structure health monitoring using AET is recording during operation and as a result it is a measurement of the degradation process. Considering this analytic data, the “Automation Manager” makes it possible to send a warning if defect-mechanism occurs as early as possible. Moreover, for a measurement during operation, no further time must be spent for testing in a shut-down. Additionally, in
case of severe degradation, the scheduled operation time can be observed with acoustic emission monitoring to safeguard the time till to replacement of the metallic component.

This enables further improvements of customer specific implementation of SHM using acoustic emission, which shall foster a broad acceptance of acoustic emission by equipment users/operators.

References:
