Acoustic Emission: a Modern and Common NDT Method to Estimate Industrial Facilities

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Abstract. Particularly with regard to the effort of the industry to reduce the shut down time of industrial facilities, the desire for a practicable and economic NDT method for periodic inspection becomes more and more interest. In the last few years, the acoustic emission (AE) method achieved to fulfil this requirement. In addition to the enormous development on hard- and software-components for AE systems in the last years, the increase of practical experiences and knowledge leads to a wide range of applications for this test method in Europe and worldwide. On the other hand, the implementation of AE in the European standardisation assured a high quality of certified test personnel. Parallel to this, the evolution of product and process standards raised the acceptance of AE for industrial application. In many European countries, for example in Austria, the AE is settled in the national law for the periodic inspection of several types of storage and pressure vessels as well as piping systems.

Amongst other, AE is able to detect and locate material defects, corrosion and leakages with a high sensitivity and accuracy and enfolded usually the overall shape of the tested structure. Due to this property, AE is particularly suitable as a test method for large structures. In the practice, the verification of suspect places detected by AE, will be done with other NDT methods (visual inspection, ultrasonic, radiographic a.s.o.). Together with the interpretation of the AE results, an accurate conclusion about the actual condition of the structure will be possible.

The presentation describes the current situation of AE from the Austrian point of view and explains the interaction between different NDT methods based on the results of some practical applications.

Introduction

In the past years acoustic emission testing (AT) has proven to be a powerful maintenance tool. Already many different testing techniques are available for a broad variety of components and test purposes. Metallic components of plants to be tested after a certain period of service are operated in large quantities at sites related to chemistry, petro-chemistry, gas or pulp and paper. The most common applications are:

- AT on pressure vessels for cracks and corrosion,
- AT on pipelines for leakage,
- AT on flat bottomed storage tanks for leakage and corrosion.

All applications have in common, that the test conditions should be similar to normal service conditions. Therefore pressure vessels are tested preferably by pressurisation with the same medium as used for operation till to a load exceeding at least the maximum service pressure. Pipeline testing with the leakage detection pig even requires a pipeline being in service so that the device is driven by the product from the pig launch to the receiving trap. And for corrosion testing on flat bottomed storage tanks it is essential to have the same storage product for the test as used during normal service. These examples show clearly one major advantage of AT: it can be performed at a minimum of service interference.The next major advantage of AT is given by the fact that there is no need to have a sensor placed right at the defect position. In the course of the defect indicating process elastic waves are emitted into and propagate through the surrounding material. Therefore information regarding the defect is transmitted from the origin till to sensors mounted at fixed, predefined positions with distances to each other in an array element of several meters. Thus only few sensors are necessary to cover large areas completely and ensure a 100 % testing of the component or defined parts thereof.

Wave propagation takes place with the speed of sound, which is characteristic for the material and wave type (and the wave mode in case of lamb waves). Consequently AE is detected by sensors located at different positions in general at different points in time. The differences in arrival time are exploited with the help of suited software algorithms for source location. It aims on obtaining a limited area of the test object where the elastic wave was emitted into the surrounding material due to the defect indicating process. This location ability gives another major advantage of AT and this is the link to other NDT methods. A suspicious area can be reported to the client and opens the way for performing follow-up tests economically in order to verify the defect indication and then to characterise the defect more precisely.

The next step concerns to judge the severity of the indication, especially during a pneumatic test on pressure equipment. In such a case one further major advantage of AT is exploited: it is able to give early warnings. Thus, pressurisation can be stopped before the situation becomes critical. Early warnings are also essential for testing of flat bottomed storage tanks. Since AE is able to indicate a corrosion process taking place on the metallic bottom sheets, the tank may be taken out of service for repair before the tank bottom becomes leaky at the affected area. Figure 1 summarises the advantages offered by industrial applications of AT.

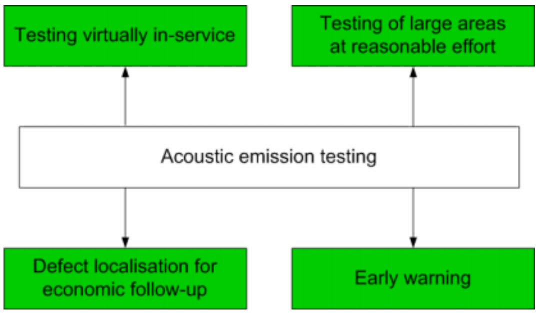

Figure 1: Main advantages of acoustic emission testing for industrial applications.

The philosophy of applying AT is not to replace other methods like ultrasonic testing (UT) or radiographic testing (RT) at already solved testing problems where testing techniques are well established and state-of-the-art. It is much more beneficial to use the results from different methods complementary. Again, AT is able to indicate degraded components of plants and then to report affected areas. But for follow-up activities in order to quantify a defect e.g. in terms of exact size or remaining wall thickness other NDT methods are required.

Acoustic emission testing in Austria

Starting with tests on nuclear power plant components in 1977 by TÜV Austria, industrial clients became aware of this powerful NDT method. Although the measuring systems have been quite simple in those days compared to today’s state-of-the-art like the Vallen

AMSY5, the obtained results were quite impressive. As an example, unreported repairs of pumps could be detected and roughly located. In the following years AT was carried out by TÜV Austria on two large gas storage spheres before they were set into service the first time. Due to the results obtained by AT during the hydrostatic pressure test different defects were found [1]. The hydrostatic test itself just gives the result 'passed' or 'not passed' without any other further information regarding the condition of the tested component. Therefore these defects would have stayed undetected without AT. After this successful start the testing technique was then steadily improved so that the repetition tests could be performed by pressurisation with natural gas, the storage medium. Sphere and location result are shown in figure 2.

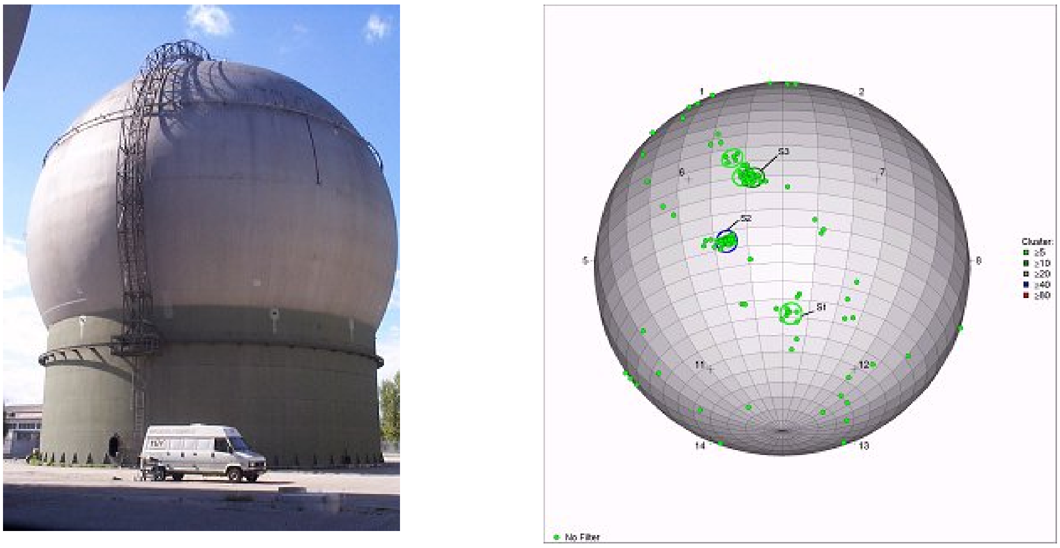

Figure 2: AT on storage spheres. Repetition test of natural gas storage sphere (left) and found indications of defects by AT (right)

The successful start also triggered the development of other testing techniques like leakage testing on flat bottomed storage tanks [2], repetition testing on LPG storage tanks [3, 4] or repetition testing on drying cylinders (steam drums) in paper mills [5, 6]. Till today, with many other applications available, the way of tackling new testing problems is still the same: homework first in terms of trial test series in a controlled but representative lab situation and then step by step adaptation to the situation given in the field. Following this procedure for every new application carefully there have been no major set-backs in the market introduction of new testing techniques. Due to the positive experience AT made its way. For some types of pressure vessels it turned even from an exceptional applied testing method to the standard application, e.g. for LPG storage tanks or drying cylinders. This process was supported also by the progress made in European standardisation, where among others the following standards have been developed:

- EN 473 (AT personnel),
- EN 13477 part 1 and 2 (AT equipment characterisation) and
- EN 14584 (AT on metallic pressure equipment).

It is worth noting that the new national regulation addressing periodic inspection of pressure equipment, the 'Druckgeräteüberwachungs-Verordnung', gives a solid basis for further activities in this field. Providing a proven testing technique is available this regulation enables vessel operators to choose AT for repetition testing as they find it useful and beneficial for their plant operation. Till today a total of more than 20.000 tests were performed by TÜV Austria since 1977 (other competing AT service providers have gained their own share of the market) show the broad acceptance of AT in Austria.

Examples of practical experience

Beside already stated testing techniques the field of application comprises testing on small and medium sized pressure vessels as well as large components like storage vessels or chemical reactors. The testing of flat bottomed storage tanks has been extended to leakage and corrosion testing [7, 8]. There are still many problems in plant operation, where AE is able to support. Research works are carried in order to develop new applications of AT. Currently an EC funded project for corrosion testing on crude oil tankers and product tankers is co-ordinated by TÜV Austria, Institute for Technical Physics [9]. But also the already existing testing techniques are steadily kept state-of-the-art to obtain the maximum available information from the measurement and thus to maximise the benefit for the client. The following examples are an outline of the broad range of testing techniques successfully applied at industrial plants in Austria and other European countries.

Drying cylinders (steam drums) in paper mills

The drying cylinders of paper mills made from cast iron are tested with AT by pressurisation with compressed air. Performing a hydrostatic test on a built-in drying cylinder would lead to damage of the bearings and deformation of the cylinder. With AT there is no need to disassemble the drying section (typically consisting of about 40 cylinders) of the paper mill and the balance of the drying cylinders is not affected. There have been found casting defects, crack like defects as well as erosion. These defects are shown in figure 3.

Figure 3: AT on drying cylinders (steam drums) in paper mills. Application of sensors on cylindrical shell (top left) and defects found at follow-up inside inspections: casting defect (top right), crack like defect (bottom left) and erosion (bottom right).

Leakage testing of pipelines

The testing tool is fed into the operated pipeline at the pig launch and driven by the liquid product till to the receiving trap at the end of the pipeline. The tool carries an AE sensor in order to acquire leakage sound along the pipeline. After it has been recovered from the receiver, the stored data is transferred to the analysis unit. The testing tool is frequently employed in Austria at the OMV Schwechat for testing the pipelines connecting the refinery on the right side of the river Danube with the storage facility on the other side. Artificial (for qualification purposes) as well as natural leakages have been detected. On one job in China at an off-shore installation there were detected two leaks during one pig run (360 km in total). The uncertainty of localisation was less than 1‰ which enabled the client to find and to repair the defects within a short period of time. Figure 4 shows the off-shore installation and the evaluation of the pig run indicating two leaks.

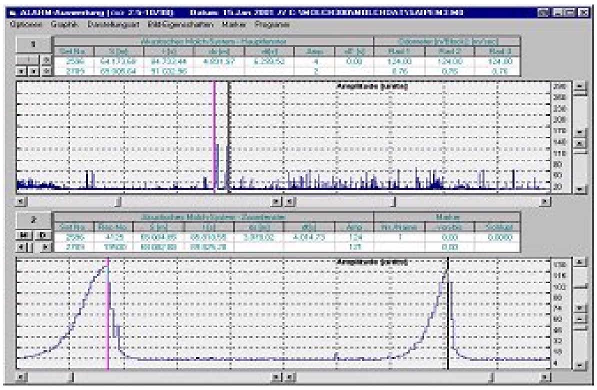

Figure 4: Leak detection with the ALARM tool employed at a 360 km off-shore pipeline (left) and evaluation of the pig run (right). One can easily see two peaks in the plot at the bottom indicating two different leaks.

Flat bottomed storage tanks

The tank containing the liquid storage product may be tested for leakage and corrosion simultaneously. Corrosion is detected on the inside and for single floor tanks also on the outside of the bottom. Degradation of the tank floor is caused by a corrosive environment and is ruled either by the storage product itself or by the contamination with other corrosive media, e.g. water. After the tank is built, tested to proof its strength and then set into service, it can be expected that the tank floor becomes leaky only if it has been affected by corrosion over many years. Thus corrosion testing prevents leakage and this is the general attempt for the testing technique. Severe corrosion shall be indicated in time so that repair can be scheduled as other storage capacity is available. The testing is completed within two days in case of a large tank (diameters up to 100 m and more). A smaller tank may be tested even within a shorter period of time. Interference with normal service is therefore minimised. There have been found heavy corroded tank floors affected by general corrosion as well as localised forms of corrosion. At one crude oil exploitation field a tank for storage of salt water was tested and resulted in indications of severe corrosion. This was reported to the client, who did not expect to find a problem. The inside coating of the tank was in good condition at the last inside inspection, therefore the test result was questioned. It was finally decided to opening the tank in order to verify the indicated corrosion source. The inside inspection revealed that the indicated corrosion source was a sacrificial anode as shown at the top of figure 5. The tank operator just had forgotten to mention, although he had been asked for cathodic protection installation in advance to the test.

Another example of tank floor testing concerns a tank, which failed to pass the concluding hydrostatic test for tightness after renewing the severely damaged floor. The repair was performed under high pressure in order to get the tank back into operation within a short period of time. However, the welds have been leak tested by means of vacuum box testing carried out in the course of the construction. All weld defects found were repaired and therefore no problem was expected for the concluding hydrostatic test. The tank has been loaded with water and after a certain filling height first indications of leakage were seen at the annular ring. The tank has been erected inside a metallic retention tank in order to avoid product spillage into the surrounding environment in case of failure. Water flowed into the small space between the two metallic floors and leaked at one section below the annular ring of the tank into the retention area. The estimated diameter of the defect with respect to the leak rate and hydrostatic pressure had been in the range of some millimetres. Compared to a tank size of some thousands of square meters one can easily imagine that finding the defect by visual inside inspection would have been rather difficult. AT was able to reduce the follow-up NDT for finding the defect to a minimum and thus it made considerable contribution to keep the deadline for tank re-entry into operation. It turned out that at one overlap of three sheets the fillet weld had left a short gap open (length of 30 mm) as shown at the bottom of figure 5. This defect was not detected by vacuum box testing since there was no indication by bubbles due to the high leak rate.

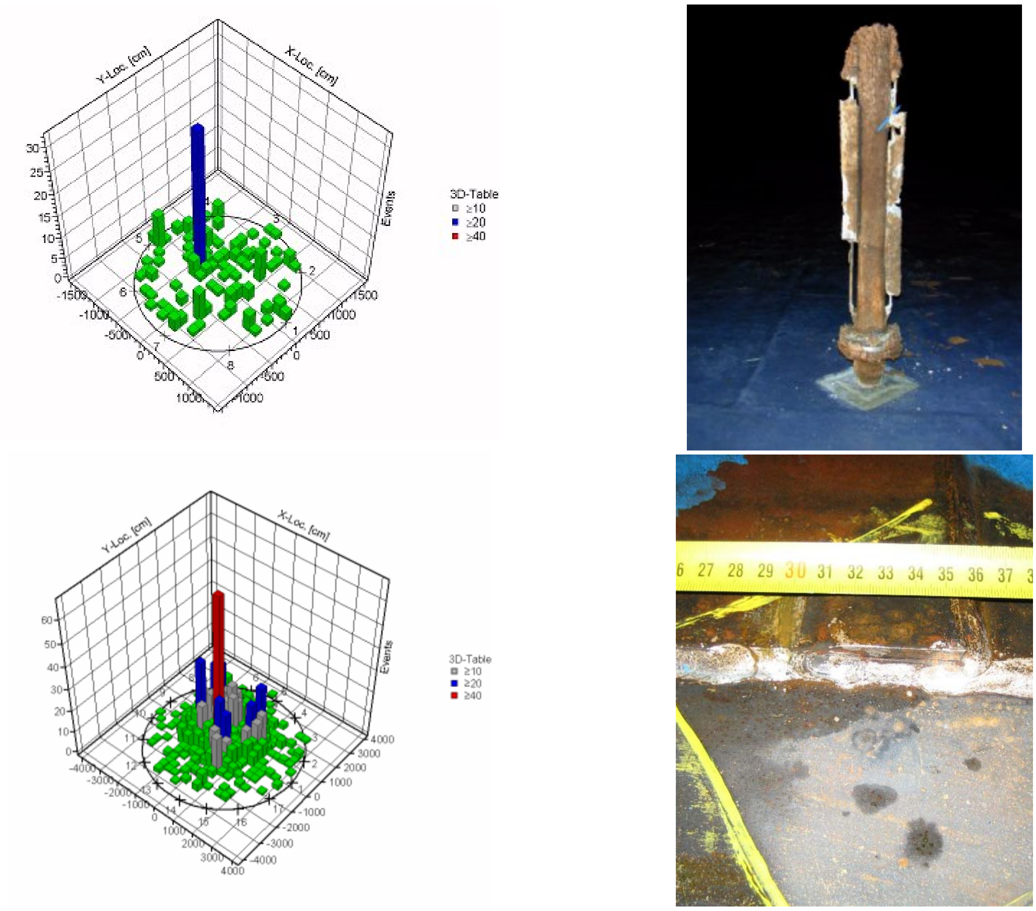

Figure 5: AT on flat bottomed storage tanks for corrosion and leakage. Evaluation of a test on a salt water tank (top left) and found sacrificial anode (top right). Evaluation of a test on a crude oil tank filled with water for strength test (bottom left) and found improper welding at an overlap (bottom right).

Pressure vessel testing

The advantages of applying AT compared to the traditional procedure of hydrostatic test plus visual inside inspection are numerous. Just to name the most important: reduction of downtime, omitting of residual humidity and no risk of product contamination with water. It is a fact that AT provides much more useful information concerning the condition of the pressure vessel under test than a simple ‘passed’ or ‘not passed’ obtained usually by a hydrostatic test. Repetition testing after a 10 years service period was performed with AT on a thermally insulated pressure vessel (storage of liquefied hydrocarbons), cylindrically shaped with vertically oriented axis and a capacity of 300 m^3. A total of 17 sensors VS150-RIC, Vallen-Systeme with integrated preamplifier of 34 dB were applied to monitor 100 % of the shell under load during the pressurisation with nitrogen. During the test indications for severe damage had been obtained. The preliminary result of the measurement gave rise to strong concerns regarding vessel condition. The clusters built from located events of substantial intensity appeared to be aligned in circumferential direction at different vertical levels as indicated by dash lines in the location plot of figure 6, left side. Attention was focused on the linear aligned indications near to the upper head close to or even at the circular weld seam. Right side of figure 6 shows a section of this area after the thermal insulation has been partly removed. One can see easily the corrosion product just below the circular weld seam.

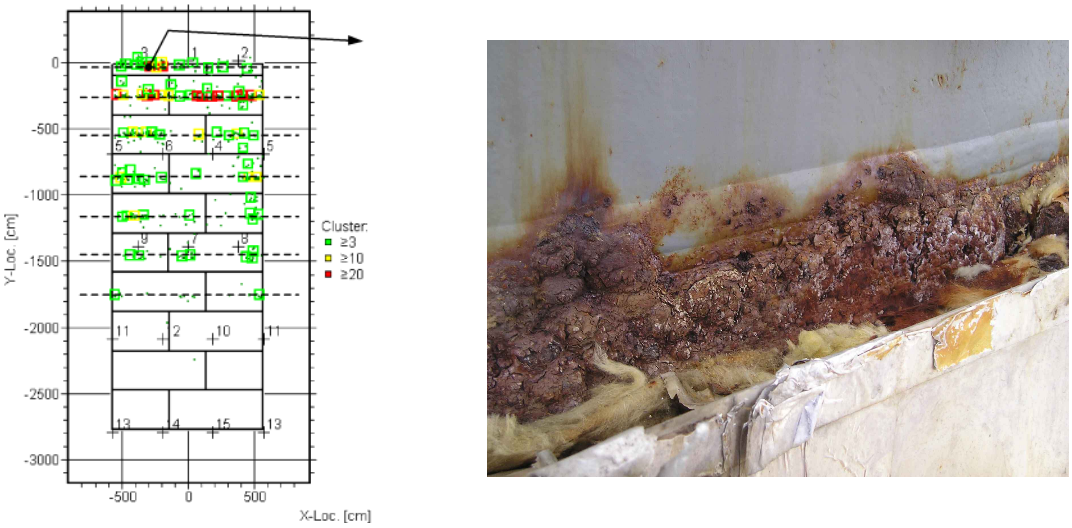

Figure 6: Preliminary location result just after the test and visually detected finding at one suspicious area, sketch on the left – unwrapped cylindrical shell with linear aligned clusters of located events at different vertical levels indicated by dash lines, photo on the right – taken after removal of thermal insulation at position indicated in the left sketch by an arrowed line with dot at its origin.

Due to undetected damage of the insulation covering at the upper head, water seeped into the insulation and was retained at the first ring element (holding the thermal insulation in proper position) just below the circular weld seam at the upper head. There it caused circumferential aligned corrosion damage with loss of wall thickness up to 8 mm (more than 50 % of the nominal wall thickness of 14 mm). Top left side of figure 7 shows a section of the affected area indicated by AT (see sketch of figure 6) after removal of the thermal insulation and a close-up taken after grit blasting. When the first ring element was damaged itself, water was able then to pass downward more easily to the next position. The vessel shell was corroded in the same way as above and this led to a loss of wall thickness of up to 7 mm at this position. Top right side of figure 7 shows a section of the affected area indicated by AT too (see sketch of figure 6) plus a close-up taken after grit blasting. Step by step the humidity was able to spread out to lower parts of the vessel and was trapped at the ring positions. Underneath the thermal insulation the evolving corrosion damage has been hidden for years until it was indicated by AT. It is assumed by experts concerned with the problem, that the vessel would have passed the traditional procedure for repetition testing. According to these considerations, the hydrostatic test would not have led to failure because of safety margins in material strength as well as design. And by means of a visual inside inspection there has been no chance to find these defects on the outside of the shell. Thus, AT prevented catastrophic failure during the next service period of the vessel and contributed significantly to safe and economic plant operation.

Repair was performed by welding reinforcing segments onto the shell at the top three positions of circumferential aligned corrosion damage like given in figure 7, bottom. After completion of repair works the entire shell was grit blasted, a protective coating was applied, a state-of-the-art thermal insulation was mounted and finally the vessel was set into operation again.

Figure 7: Follow-up NDT to the AT indications and performed repair, top left side photo - corrosion damage with depth up to 8 mm near to circular weld seam of the upper head, top right side photo – next corrosion damage near to structural ring element of thermal insulation with depth up to 7 mm, photo at bottom – repair of corrosion damage with reinforcing segments.

Summary

Testing virtually in-service, a low number of sensors to be mounted compared to the size of the test object, location ability and early warning ability are the main characteristics of AT. More than 20.000 tests with AT have been performed by TÜV Austria on different kinds of components since 1977 in Austria and Europe. Storage spheres, flat bottomed storage tanks, drying cylinders in paper mills, pipelines, LPG-tanks and other pressure equipment are some examples of regularly tested industrial structures. By means of AT detailed information regarding the actual condition is obtained. Thus, AT results are used for predictive maintenance, where repair is done in time before failure occurs.

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