IMPLEMENTATION OF ACOUSTIC EMISSION METHOD TO THE CONVENTIONAL NDT STRUCTURE IN OIL REFINERY

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Abstract

The article is the addition to the article [1] and describes some results of AE laboratory at an oil refinery during the past 17 years. Some problems of AE application for testing industrial pressure vessels and possible solutions of these problems are presented. On the pressure vessel tests, it is shown that AE testing is the essential factor for increasing of the efficiency of complex NDT of dangerous industrial hardware.

Introduction

NDT is the main means of achieving reliable operation of industrial pressure vessels and piping. This information is necessary for industry and environmental safety provision of potentially dangerous processes. Usage of new NDT methods, such as AE method, gives a chance to improve traditional NDT structure of industrial objects in essence. Such improvements could include:
- Considerable growth of testing volume without increasing testing time;
- Testing of previously inaccessible parts of constructions;
- Increased effectiveness of traditional NDT methods;
- Possibility to obtain new diagnostic information, for example, about flaws growth.

In order to realize this, change is possible only in case of successfully passing complicated stages of adaptation to industrial conditions. The first stage considers potential advantages of a new method against other methods in practical inspection, and establishes the scope of correct applications of this method. Factory management should get conclusive proof that the new method is really useful for equipment testing.

Kirishi refinery is the largest one in Russia. It processes 22 billion tons of crude oil per year. More than 70% of production is exported. There are several thousands of pressure vessels at the refinery and they are the main objects for AE testing at the plant.

Fig. 1. Results of pressure vessels AE testing at Kirishi oil refinery.
Usage of AE method in Kirishi refinery has not become widespread for piping, though its periodical testing was successful. Possibly piping is thought to be simpler objects compared to vessels. So, their validation used less complicated methods than AE. Moreover, from the point of view of factory management, if there are doubts in quality of some parts of piping, it is more rational to change them at once, rather than assigning their resource by complicated testing methods.

Thus, the complicated testing methods such as AE have the best perspective in solving really difficult tasks, or tasks that can not be solved by other NDT methods.

Problems of AE Applications at the Refinery

1. The feature of AE testing is an opportunity of integral assessment of condition of an industrial object. Meanwhile collected information contains reactions of a large number of control channels to physical processes of different nature; for example, the formation of cracks, fretting or friction of construction elements, noise of turbulent flows, etc. The extraction of the informative characteristics of crack formation from the “interfering” processes is complicated task.

2. AE test procedure is connected with the detection of dynamical processes. The analysis of such processes is more complicated, than one of static processes, which are the base of the most traditional NDT methods. Therefore the serious problem in AE testing of industrial objects is the correctness of usage criteria for assessing the hazard level of defects. These criteria, basically, are derived for the small specimens for laboratory testing, but we believe that AE testing of pressure vessels requires another type of testing including material testing in fracture mechanics. Every industrial object (unlike laboratory specimen) is a complicated system with individual features of AE generation during its loading. Many factors influence on AE features, part of which is impossible to predict \textit{a priori}. Therefore, direct use of formal criteria and automatic algorithms does not yield adequate assessment of defect hazard. Automatic algorithms are advantageous in speed of decision-making, but often unsuitable for solving non-standard tasks.

In the situation described above, the competency of experts is essential. But this practical experience is difficult to be formalized. It accumulates as a result of analyzing a large volume of experimental test data of industrial objects. Unfortunately, in such experience prevails subjective component. The objective component of our practice is the usage of high-quality hardware and software for data collection and analysis. During 16 years we utilized several AE systems, each of which was one of the best in the world at that time. Our experience has been formed as a result of about 500 pressure-vessel tests. Synthesis of objective and subjective components has given the results that may be assessed as successful: in our plant AE method becomes established and included in the system of basic NDT methods, though it was taken as exotic at the beginning [2-4]. Even so the role of subjective experience is still significant.

3. As a rule, in today’s Russia, the development of high technology and expensive NDT methods is possible only with direct financial support of large industrial companies. In spite of advantages of AE method, its implementation is possible only where management has progressive thinking for enhancing the safety and is willing to provide financial support until the benefits overcome the cost. For this reason the implementation of AE method does not depends on its advantages but depends more on the attainment level of factory management.

4. The problem of “false-negative rejection”. According to testing results of alternative NDT methods only a small part of active AE sources (15-20%) are considered as indicators of significant defects. As a rule we cannot predict the hierarchy of the relative hazard of defects on the
result of AE testing. All active sources in AE test method are considered to indicate potentially
dangerous defects, until the opposite would be proved. For the testing of dangerous objects this
strategy is more preferable, than “non-rejection”. Such approach may be compared with inadmis-
sibility of any cracks in pressure vessels, which is declared to be Russian norms [5]. Probably
such approach could be compared to the complication and ambiguity of the hazard assessment of
cracks that is offered today by fracture mechanics. All the more, it is hard to expect that similar
tasks would be solved explicitly by AE method.

5. The previous problem is only the consequence of other problems: the verification of the
results of AE testing is not just useful, but necessary. Unfortunately, in our applications, we can-
not use AE method as in-depth method. AE results must be confirmed with other NDT methods.
On the other hand, AE method is used to assess results obtained with other NDT methods. If any
local defects are first detected with a conventional NDT method during vessel inspection, it is a
reason for further AE testing. As a result of AE testing, first, AE is used for logging the kinetics
of defect's development for danger assessment. Second, AE determines the location of other de-
fects, if they exist in the structure, but undetected due to their locations being out of inspection
zone of traditional methods.

Efficiency of AE Method for Integral Testing

Complex testing allows us to compensate disadvantages of different methods and to combine
their advantages. Furthermore, combination of test methods increases the probability of detection
(POD). Periodic AE testing by loading a vessel by pressure is an example of complex testing due to
AE is combined with such classical method, as is hydraulic test. This is a good illustration of the
advantages of complex testing. It is obvious that hydraulic test of a vessel, combined with AE test,
gives much more information than ordinary hydraulic test.

It is well known that a testing procedure during consecutive applications of several NDT
methods is optimal, if methods with maximal speed of getting information are used first. Probab-
ly, AE method has no match with this qualitative characteristic. AE method may be used as the
basis in complex testing due to its performance and other unique properties, such as the capability
to integral testing of large constructions and the detection of defects with potential for growth.
It also may be thought as investment to achieve savings in testing of large objects. For example,
if AE testing is applied, it is not necessary to test 100% of welds of large pressure vessels by
conventional methods. Disadvantages of conventional methods (low productivity, large costs of
material and time for metal preparation, etc.) do not allow making the complete testing of large
objects within a reasonable period of time. In complex testing, AE method is first applied for lo-
calizing zones with potential defects, and then other NDT methods with lower productivity are
used in those local zones to find geometry of probable and confirmed defects. In such way real-
ized the conception of economically efficient 100% test of large objects.

This approach is shown in the following example. Test object - spherical vessel for LPG
storage with inner diameter 10.5 m, wall thickness 16 mm, volume 600 m³. There are 16
longitudinal steel sheets welded with each other and terminated by the hemi-spherical top and
bottom caps. Analysis of AE test data showed local zones of the shell (with pointed coordinates
and size), which need additional testing by conventional methods (VT, UT, PT, RT). Also
indicated are the possible type of defects and the degree of their possible hazard (according to the
features of detected signals). On Figs. 2 and 3 are shown the results of additional testing.
Fig. 2. Drawing of upper part of the sphere tank (10.5-m diameter) with weld marks. Defect zones (1 to 3) are also indicated.

Fig. 3. Drawing of lower part of the sphere tank (10.5-m diameter) with weld marks. Defect zones (4 to 6) are also indicated.
Zones 1 to 3 with defects localized by AE and then verified with conventional NDT methods are shown in Fig. 2:

- **Zone 1** – a cross crack of 5-mm depth at the weld of upper cap; verified with VT and PT.
- **Zones 2 and 3** – zones with relatively high AE zonal activity. Sources were not localized by location algorithms. This could be explained that these are small defects, which increased their AE activity while load was applied. Probable type of source is the irregularities of metal or small defects, which are located close to sensors. There were small defects below the UT limits, but detected with AE.

In two zones, determined with planar location, and in one zone determined by zonal location, there were no defects verifiable with UT and PT.

To carry out additional inspection for finding the type of active AE sources, it was needed to use the aerial lift, to build scaffoldings and partially dismount service passes (in the upper part of the vessel). After the additional inspection, that constructions were used during repair job of detected defects. It is necessary to notice that the probability to find these defect zones by traditional NDT methods was very low; zones with defects (base metal, welds, located in the upper part of the vessel) are seldom getting in the scope of ordinary testing.

In Fig. 3 are shown zones with defects localized by AE and then verified with conventional NDT methods:

- **Zone 4** – a part of weld (900-mm long) in the middle part of the tank: UT was applied and it detected defects of non-allowed dimensions; the defective weld was repaired (shell segment was localized as a zone of high AE activity around channel #8).
- **Zone 5** – area of parent metal on the inner part of the surface with crater type defects, which had the mechanical nature (maybe they appeared during the tank assembly); the depth is 2-4 mm., area to 250 mm², defects verified with UT and PT;
- **Zone 6** – weld defect in the middle part of the tank, verified with UT, repaired. Zone registered with planar location on the sphere.

In two more zones localized on one of vertical welds, the defects were verified with UT, and weld was repaired. There were also detected two zones of AE activity, but defects were not verified with UT or PT.

Concerning the precision of localization of defect by AE, in real engineering practice, the scraped square for the conventional NDT methods of UT and PT is usually 300 x 300 mm. The test takes place at this square. Let us consider, for example, Zone 5 (Fig. 3), determined by AE. Zone is formed with three closely located clusters. The largest cluster (100-cm diameter) contained 12 events, detected by a minimum of three sensors. The cluster was initiated by integral action of crater defects. They are located, mainly, in the form of three compact groups, localized on squares with dimensions from 10 to 30 cm² (in Fig. 3 the dimensions of location cluster are enlarged for visualization; in real tests, cluster dimensions were smaller). For three compact groups of defects, at a given cluster size of 30-cm diameter, the coordinates of cluster center calculated by the spherical location algorithm differ from the coordinates of cluster centers of real defect groups, measured at the object in the following table.

According to Russian standards [6], the precision of multi-channel location shall be better than greater of two wall thicknesses or 5% of distance between two sensors. According to the first criterion we obtain: \( \Delta_1 = 2h = 32 \text{ mm} \). On the second criterion (the distance between two sensors varied from 2700 to 3400 mm) \( \Delta_2 = 135-170 \text{ mm} \). So the precision of location is within the limits prescribed in the standards. The minimal size of inspection for NDT used in refinery
### Location clusters

<table>
<thead>
<tr>
<th>Location clusters</th>
<th>Coordinates of AE sources measured directly on object (the centers of defects groups, Degrees)</th>
<th>Spherical location results (coordinates of the location clusters centers, Degrees)</th>
<th>Absolute difference in coordinates value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Longitude</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>Cluster №1</td>
<td>131.0</td>
<td>-58.0</td>
<td>130.6</td>
</tr>
<tr>
<td>Cluster №2</td>
<td>138.5</td>
<td>-58.0</td>
<td>137.0</td>
</tr>
<tr>
<td>Cluster №3</td>
<td>146.5</td>
<td>-57.0</td>
<td>145.5</td>
</tr>
</tbody>
</table>

Practice is 300-mm square. Therefore, such precision is satisfactory for engineering applications. In some cases, the size of preparation zone for additional NDT may be increased to 400 or 500-mm square when location uncertainty is suspected.

It can also be used for the planar scheme for locating specific segments of a vessel, because the sphere diameter is large and the square segment is small relative to the whole surface. It is useful for detailed analysis of spherical location and is shown on Fig. 4 for Zone 3.

**Fig. 4.** Results of planar location of AE source activity on the shell segment of LPG storage tank, which was identified as defect group of crater type defect on the inner surface of the vessel.

On the example vessel, it is necessary to test about 490 m of welds. For inspection with PT or UT (under a code clause of 100% welds inspection), we must prepare the metal surface area of
more than 147 m² (covering 150 mm on both sides of the weld). Yet, such methods do not inspect the parent metal of the shell outside the welds. Here lies the effectiveness of AE method for inspection as every part of structure is examined automatically.

By AE testing the whole volume of metal is evaluated with a network of 48 sensors (mesh of the network is determined with test conditions and test purposes). Scrapped area for 48 sensors is about: 0.01 x 48 = 0.48 m². Furthermore, for checking AE test results by PT and UT methods, it is necessary also to scrape the surface in the zones, localized with AE method. So in the example considered, the scraped area for NDT was 1.35 m². Total scraped area was 1.83 m². Comparison with previous evaluation shows a high efficiency of AE testing applied as an integral method for diagnostics of large pressure vessels.

So, AE testing is a good tool for NDT resource optimization in condition monitoring, when it is necessary to provide a high level of diagnostics of dangerous industrial objects within limited time available for inspection.

Usage of AE Information Power

One of the advantages of AE method is the ability to collect much information, which contributes to its successful usage. It is especially important in cases where the lack of preliminary information about test object could cause non-optimal usage of testing procedures or possible inaccuracies in measuring flaw locations. Unfortunately, such events sometimes take place during testing of large industrial objects.

Usually, modern AE equipment collects large quantity of information during a test, which may be redundant for our conventional practice of vessel testing. For example, we seldom use waveform analysis. To gain desired results we are often satisfied with other data analysis procedures. However, this redundancy appears as insurance from possible testing imperfections and is a powerful compensatory factor when some parts of information is lost (due to non-optimal sensor arrangement, or their insufficient quantity, or existence of background noise).

These circumstances can be illustrated on example of vertical column testing with following parameters: outer diameter – 3200 mm, wall thickness – 36 mm, volume – 426 m², height – 53.6 m, insulation layer – 150-200 mm thickness. The column was assembled on site from 3 segments, manufactured at factory. Segments were assembled with two mounting welds, which were made during the column installation. Lower field weld is located at 28.6 m height, upper – at 47.6 m. Lifetime of column - 29 years.

The primary intent of AE testing was the quality control of these welds. AE testing was carried out twice with an interval of 5 years. Before the first testing it was assumed that there were no serious problems in field welds. Therefore we used a less number of sensors then really needed for this column. To place several sensors we needed help of steeplejacks (industrial mountaineers). Their dangerous work could cause inaccuracies in some length measurements. However, these shortcomings in testing arrangement were compensated by information power of AE method. The quantity of information was quite enough to detect serious flaws in field welds with confidence and to localize most of these flaws. The results of AE testing became the reason for 100% test of field welds by other NDT methods and consequent repair of several parts of field welds. The second AE testing, carried out 5 years later, had several differences from the first one, which are shown in table below.
As it could be seen in this table, the outlines of two testing differ considerably. Main advantage of the second testing was using more sensors. Therefore information of flaw coordinates was more accurate. Probably the second testing was more informative then first one.

It should be taken in account that key task of AE laboratory in an oil refinery could be formulated simply:
1. To detect problem part of construction;
2. To localize with sufficient accuracy the most dangerous flaws existing at the time of testing.

On the base of such statements the results of two testing practically coincide. However, the results of these two testing have differences. These differences gave us data going beyond the scope of key task. For example, we obtained data about flaw growth dynamic in this area. Also, we got data about the quality of repair done and about the suitability of further repair. For this it is convenient to use instruments of AE data analysis, which permit us to visualize the structure of problem areas in whole construction (or in big segments of construction).

Two drawings, taken from results of data analysis, show planar locations of AE sources in the lower field weld area. The drawing is matched with drawing of shell reamer, where positions of manholes, welds and repaired areas are shown.

In Figs. 5 and 6 are marked several zones with the following conditions:
- Zone 1.1, 1.2, 1.3 – large clusters of non-metallic inclusions and small discontinuities on different depths in base metal.
- Zone 2.1, 2.2, 2.3 (same positions as zone 1.1, 1.2, 1.3 – 5-year later) discontinuities with areas from 4 to 140 cm² formed. The largest bulge was placed in zone 2-1.
- Zones from 2.4 to 2.8 join to repaired parts of weld. AE activity appeared in these zones after weld repair. UT instrument detected high concentration of small discontinuities there. By analogy with variations in zones 1.1 – 1.3, it could be supposed with great probability that in zones 2.4 – 2.8 are forming discontinuities as a result of small flaws fusion.
- Zone 2.9 – crack in the weld made at a machinery plant (7 mm in depth, 30 mm in length).
Fig. 5. Results of planar locations of AE sources in lower mounting weld area in first testing.

Fig. 6. Results of planar locations of AE sources in lower mounting weld area in second testing.
Analysis of the distribution of active zones on these two drawings and the results of additional NDT in these zones led to several important conclusions:

1. The quality of field welds was considerably worse than that made on a machinery plant. Therefore just the use of field welding limit the safe lifetime of the vessel.

2. As a result of long operation time, the degradation processes of material of welds and of base metal near welds were actively developed over the last 5 years. The second AE testing showed that with time these processes spread to plant-made welds too.

Repair of the weld does not always eliminate the problems. During repair the strain conditions of the metal in repair zone can get worse. It intensifies the degradation process in metal due to hydrogen embrittlement, which is the main damaging factor for this vessel. In fact, it can raise the risk of vessel failure. Therefore, the continuation of repair of local flaw zones is not recommended.

In general, similar results were received during testing of the upper field weld. On the basis of complex results the refinery management made decision to change the column. Whole chain of testing and repairs during the 5 year period is as follows:

(AE-1) → (NDT-1, 100%) → (Repair-1) → (+ 2 year) → (NDT-2, Local) → (Repair-2) → (+ 3 year) → (NDT-3, Local) → (Repair-3) → (AE-2) → (NDT-4, Local) → (Decision of column change).

So, in our practice we are using only a small part of information collected by AE system. For this reason its volume is redundant, but even during solving simple tasks of industrial testing, this AE redundancy can be useful. It can be used:

1. As additional insurance from testing arrangement faults;
2. As a reserve for solving more high-level tasks than we are solving routinely.

Conclusions

1. Phases for implementation, for demonstrating the capabilities and for proving the efficiency of AE method are successfully finished at Kirishi oil refinery.
2. It is now at a stage of determining the optimal utilization schemes of AE method in complex testing, which combines the capabilities of several NDT methods.
3. We have started the implementation of continuous AE-monitoring technology. The results of trial performance will be used for the assessment of implementing AE-monitoring systems at the new production lines. New equipment will operate in more difficult conditions than one of the existing production lines. Therefore, it is necessary to develop new technologies for their safe exploitation.

References


[5] PS 03-576-03. Pressure vessels design regulations and their safe operation, § 4.7 (ПБ 03-576-03. Правила устройства и безопасной эксплуатации сосудов, работающих под давлением, п.4.7).

[6] PS 03-593-03. Regulations of AE testing of vessels, apparatus, boilers and operation pipelines, § 4.5 (ПБ 03-593-03. Правила организации и проведения акустико-эмиссионного контроля сосудов, аппаратов, котлов и технологических трубопроводов, п.4.5).