# Acoustic Emission Testing (AT) for the detection of corrosion attack on ships (oil tankers)

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**Abstract.** The transportation of oil, which is the most important raw material for the energy production, includes most time crossing of the sea, mainly with oil tankers. This transportation can be very dangerous for the environment, how we learned it in the last decades. Some of the old oil tankers have had accidents with an enormous mass of oil spillage into the sea and fatal consequences for Flora and Fauna, in specific I will remember on the accidents of Prestige and Erika. Beside human errors the degradation of the structural integrity by corrosion attack was the most important reason.

For better controls of these tankers an Austrian, German and Polish consortium started 2002 an EC founded R&D project for "Detection and discrimination of corrosion attack on ships (crude oil tankers) with Acoustic Emission (AE)".

The intention of this project was to develop a discontinuous spot testing and permanent installed system. Both systems shall detect corrosion attack on oil tankers in-time and give the ships owners as well the port authority a fast and reliable tool to validate the momentous status of tankers.

During the last years the consortium has done extensive research works about the corrosion process and its effect on the emitted Acoustic Emission. It was possible to distinguish meaningful corrosion noise from disturb noise, coming from sea and structure itself. After development of intrinsically safe (Ex-proof) sensors, for both systems tests on ships were performed. Consequently the validation of the systems was done on Navy tanker "Baltyk" and a commercially used oil tanker "Icarus III". During these tests we could proof, that the permanent systems is able to check during the most service conditions and the spot testing has the capability to check and validate to corrosion status of the structure in harbour or on anchor place.

## Introduction:

Today the most important energy source and basis for the chemical industry is oil. The crude-oil has to be transported from the oil producing to processing (refinery, chemical plant) over great distances. Beside the oil pipelines the transport includes often the crossing of the sea. This part of the transportation-chain is often done by oil tankers.

Consequently transportation over the sea can become hazardous for the environment, how it was demonstrated often during the last decades. Even the normal shipping operation results in a specific amount of spillage. But the more important risks occur during the oil transportation by ships, if one of these tankers has an accident, how it happened frequently in the past (1).

All over the world many terrible accidents with enormous mass of oil spillage into the sea occurred and damaged marine-ecological systems and harmed the flora and especially the fauna for many years. Especially for Europe, where 90 % of the oil is arriving by sea and 3000 tankers transport oil and oil products to and from European ports, the risk of oil tanker accidents is particularly high, which can be proven by the most recent catastrophes (2).

Beside a lot of accidents, which were caused by human errors, like Amoco Cadiz or Exxon Valdez, many disastrous accidents in near history were caused by the degradation of ship structure. The most remarkable as shown in figure 1 have been

- Erika, which spilled 20.000 tonnes of oil and polluted 400 km of the Brittany coast (3) and destroyed not only the Flora and Fauna (e.g. famous oyster banks) but also the tourist traffic for years and
- Prestige, which spilled more than 35.000 tonnes, with a similar amount left inside the sunken tanker and till today polluted several hundreds kilometres of coast in Spain and France (4).


**Figure 1:** Accidents of Erika (top left, EPA photo AFP/Marine Nationale) and Prestige (top right, EPA photo EFE Pool/STF) and consequences for the environment (bottom left EPA Photo EFE/Lavandeira and right EPA Photo AFP/Valery Hache)

These accidents were caused by material degradation caused and/or influenced by undetected corrosion. Although the ship surveys were performed by the ship classification agencies in time periods, it is clear, that those surveys take a long time, because it is necessary to empty the tanks for the tests in order to get access to the randomly selected test points. Between such tests it is obvious, that ships will corrode under normal sea conditions. A specific amount of corrosion is acceptable and is taken into account by design. For the reason to hold this amount as small as possible the ship steel will be coated outside and this will be renewed in certain time periods. But the main problems are the bulk liquid storage tanks of tankers. Only the new tankers are coated also inside and constructed as double-hull tankers, where the ship hull and the tank wall are separated. The inspection intervals for coated tanks are five year and for old uncoated tanks these intervals may be reduced down to one year. Nevertheless these inspections and measurements will be performed on random points and take the oil tankers out of service for a long time period. Such a survey will result in testing of an enormous mass of points on a tank (screening), but will never become an absolute 100 % integral testing. The testing periods are sometimes too long for detection of the evolution of defects e.g. for pitting corrosion, which can break the wall in a short time periods.

## Project aims

All these facts together, mainly the disastrous accidents, led to the establishment of a consortium for a R&D project for the detection of all these types of corrosion and their validation for their impact to the ship safety by means of Acoustic Emission (AE). The basis for this project was the commercially available corrosion testing with AE of flat bottoms of the storage tanks in the oil industry (5). During this type of testing the corrosion of the bottom plates were detected with outside applied sensors. Based on the rapid development of the data treatment, the consortium was convinced, that this kind of testing could also be applied on ships with the limit caused from the rough environment (6).

The composition of this consortium, which applied for a funding of the European Commission (EC) is given in the following table 1.

**Table 1**: Composition of the consortium

| Company | Role | profession | country |
|---|---|---|---|
| TÜV Austria | Co-ordinator,<br>AE testing agency | Accredited testing-, inspection-, certification- and calibration organisation | A |
| Vallen | Equipment manufacturer | AE equipment manufacturer | D |
| Technical University of Gdansk | Ship expertise,<br>Testing organisation | University, department of off-shore and shipbuilding material | PL |
| Polski Rejestr Statkow | Ship classification expertise | Ship classification society | PL |
| Institute for Applied Research | AE testing agency | AE testing organisation | PL |
| Maritime Institute Gdansk | Corrosion expertise | Marine research, Corrosion expertise in marine environment | PL |

The application for the project was accepted by the EC and the project started on November 1st, 2002 under contract n° EVG1-CT-2002-00067.

The main goal of the project was to perform the necessary basic research, to develop two different types of AE testing equipment and to check the testing equipment together with the application rules on oil tankers for corrosion by means of AE.

*Permanent installation (on-line monitoring) system*

This high sophisticated system shall be capable to acquire the data during shipping of the oil tanker and can pick-out the ideal test time, depending on the environmental noise (e.g. rough sea, engines, propeller, passing of other ships). The results shall be provided to ship control and supervision soft-ware and give the ship crew an on-line information about the present status of the ship structure. This system would have the big advantage, that no stop before the discharge in the harbour or loading/de-loading platform becomes necessary. Unclear data, which have to be evaluated by a trained and experienced person, shall be transferred automatically to an evaluation centre on-shore.

*Discontinuous measurement (spot testing) system*

For tankers, where a permanent installation is not available or meaningful, the testing method shall be capable to detect and locate possible corrosion with few, invasive sensors on the anchorage or the harbour directly before discharge. These tests have to be performed within a couple of hours and shall also be evaluated in the same evaluation centre on-shore. The information of these tests shall be available to the shipping company, the classification society and to the port authority.

**Basic research**

The main task for the 1st part of this project was to the check the feasibility of the application of AE technique for corrosion testing of oil tankers. For this purpose the tests were done in two directions:

- lab-tests on steel samples for the detection of on-going corrosion processes and
- background (disturb-noise) measurements on real oil tankers

At the beginning the most common ship building materials where chosen. Samples from these ship building materials as well as pre-corroded samples from ships on repair yards were produced. These samples have had to undergo different kinds of corrosion processes, which were selected based on investigations by shipping and classification organisations regarding the causes of catastrophic disasters in the shipping industry. The probes were corroded immersed into a sour environment (3 % NaCl solution, pH = 4) like shown in figure 2. Furthermore the deterioration of the samples by an electrolytic corrosion process were monitored. The electrolytic corrosion process gave us the opportunity to control the velocity of the corrosion process and to compare it with the Monitored Acoustic Emission (AE). We took care to investigate primarily the most hazardous and also fastest corrosion types for the structure of the ships.

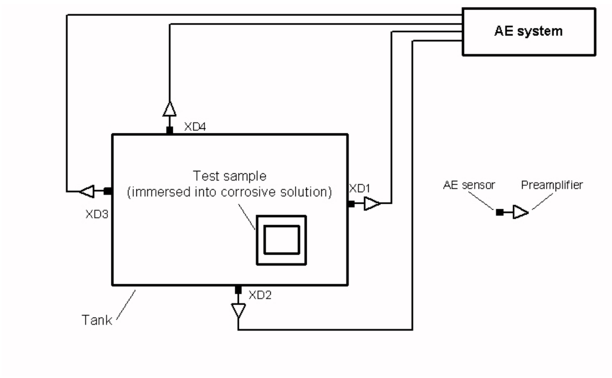

**Figure 2:** Sketch of lab test set-up (left) and plate of ship building steel immersed in corrosive liquid (right)

To acquire the background noise on ships we had to apply our sensors on ships within the harbour, at the anchorage, on open sea during operation and also during the sailing itself. For this reason we started first with measurements on the small Navy tanker "ORP Baltyk" to learn the different peculiarities of oil tankers. This measurement shall be done also to choose the best places for the application of sensors for the background measurement. Later on we took measurements on a big oil tanker "Icarus II" with a size of 35.000 DWT. At this tanker we applied the sensors in an empty ballast tank on the wall with direct contact to the cargo tanks filled with crude oil and the hull. We took care to get data from the centre tank as well as from one wing tank above and under the sea level, but also we acquired the noise from the hull in direct connection to the sea like shown in figure 3.

All tests, lab and background, were performed with an commercially available AE equipment, produced by our partner Vallen and used by the project co-ordinator TÜV Austria since many years (type: AMSY 5). Different sensors were employed to cover the frequency range, where the useful AE corrosion signals as well as the background noise have been expected. All the data were gathered and stored in a structured data base for the evaluation process, which should result in the separation of AE data, coming from the different types of corrosion, and background data, which cover the complete AE signatures from all possible occurring ship actions and the environment.


**Figure 3:** Sketch of mid ship section (left) of tanker ‘Icarus II’ (right)

The first results showed us, that the magnitude of the background was approximately three times higher than the corrosion signals, but we found out, and that was expected due to the source of origin, that the background noise has a frequency response only till to 50 kHz and the AE coming from corrosion have had also higher frequency contents. These differences gave us the opportunity to reduce the background noise to the same level like the corrosion signals by a band-pass filter. The corrosion signals were only slightly affected by the band-pass filtering and we could forward the data to further data treatment.

Based on the fact, that AE signals have no frequency dispersion as well as nearly no attenuation in liquids and lose energy only by the volumetric dispersion, we could expect the same frequency content near by the source as well as over remarkable distances. This led us to the application of a frequency domain pattern recognition system “Visual Class$^{TM}$” for the statistical classification of AE signals. With this software the frequency depended features of the AE signals will be compared in a multi-dimensional space and the classification can be performed based on training data for selected frequencies, which give the best separation for the present problem like shown in figure 4.

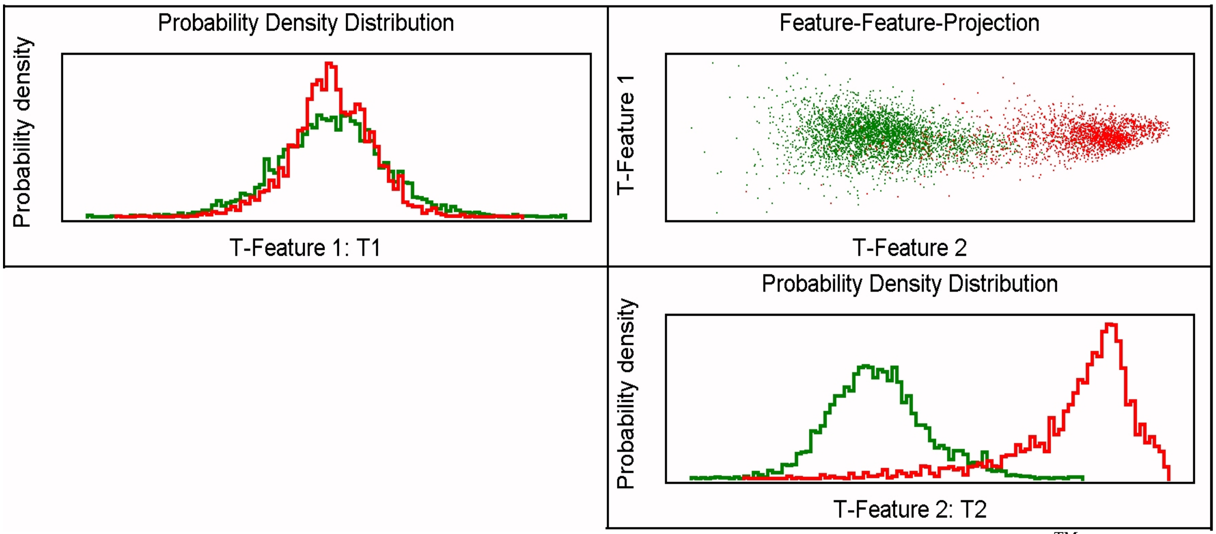


**Figure 4:** *Separation of corrosion and background AE signals in the feature space (Visual Class$^{TM}$)*

First trial tests showed the application of the “Classifier” obtained from training data and gave the “right” classification of the other test data with a score of more than 80% up to 90%, which is quite good for a statistical system.

## Trial tests on tankers

In the middle of the project we could demonstrate, that the method is feasible to detect and discriminate the AE signals born from corrosion process and background, which is coming from the structure.

To perform real tests with real corrosion probes on commercial tanker, we had to use an intrinsically Ex-safe sensor, because if we would open the tank the complete zone round the opening is Ex-Zone 0. Due to the fact that no sensor was commercially available at this stage of the project our partner Vallen started to develop such a sensor together with whole circuit till to the barrier to equipment. For this development the requirements for safety are in contradiction to the requirements on the safety of the sensors. Vallen was successful and the sensor was certified from the electrical department of TÜV Austria as ex-proof according the ATEX directive 94/9/EC. These sensors were adapted from their frequency dependence on the expected frequency for corrosion testing. In opposition to the AE testing for flat bottomed storage tanks, we have not to take care also for leakage testing and therefore the sensor have a higher centre frequency, than for flat bottomed storage tanks.

At this stage it was stage we decided to use the same basis sensor for the normal inside sensor for the permanent installation and also for the multi-element sensor, which was built–up from a sensor-holder and four single sensors as sensing elements.

With these new developed sensors we repeated part of the lab tests to establish a well defined classifier. After these pre-tests tests on different tanks of the Navy tank ORP Baltyk were performed. For the tests 4 sensors were built in one tank for a permanent installation and “artificial, natural corrosion sources” were situated in the tank. After filling up the tank the corrosion probes were detected during different shipping operations. For the localisation the available 3-D location algorithm of Vallen was used. A big advantage, in comparison to the flat bottomed storage tank testing was, that the AE waves reach the sensor directly in the liquid, without any wave transformation on the outside wall.

The second trial was to insert the MUSA (Multi sensor assembly = holder plus 4 sensors) from the top into the tank and submerge all sensors under the liquid. The sensor holder has to have a defined direction and position within the tank. When the AE signals from corrosion source were detected, the direction from where the sound is coming will be determined in spherical coordinates $\vartheta$ and $\varphi$, by a special software program. With this “sound beam” we could find out where it intersected the outside wall of the tank, which represents the location of the corrosion.

Together with the former defined filter criteria (frequency and logical) we were able to detect the sources properly.

The same spot testing measurement was done with the MUSA on the new “Icarus 3”, a double hull tanker, successful. During this measurement we found out, that the disturb noise for double hull tankers is lower, which increases anyway the sensitivity of the testing method.

## Results

During the project we could demonstrate, that AE is able to detect corrosion on ship structures within the tank and/or the ship hull. Based on different filter criteria, conventional band pass filtering and logical filtering with a frequency domain pattern recognition system, we are able to distinguish corrosion born AE signal from background noise.

We developed and have available a corrosion detection system, intrinsically safe EX-proof sensors as was as the necessary circuit and measurement system with the adjoining soft-ware. The system can be used twice, as:

- permanent monitoring system, which is able to monitor the tank after its installation into the tank. Based on the nearly absence of the wave attenuation within liquid, especially low viscous liquid, one tank can be supervised with 4 better 6 sensors. Because the results are available on time a logical evaluation system should be able to inform permanently the ship crew and the owner about the situation of the structure. Based on the experience with support of the results of the monitoring system the classification society is able to determine the next repetition tests, when the ship has to go on the dry-dock.
- spot testing system, before entering the harbour on the anchorage or before discharge in the harbour itself. For this reason the upper designed MUSA with 4 sensor elements can be inserted into the tank and submerged under the level of the storage product. The system is able to detect any corrosion process within the wall and stiffener. By measuring the arrival time at the different elements the soft-ware is able to define the direction from where the wave is coming. The intersection of this beam with the wall defines the region of corrosion. Such instrument would help the port authority for the assessment of the status of the incoming ship. Together with further intelligent filter criteria (e.g. location with at least two sensors (Δt-clustering)) the validity of the results can be increased.

The results of source location regarding a corrosion source immersed into a ship tank are shown in figure 5 for both systems.

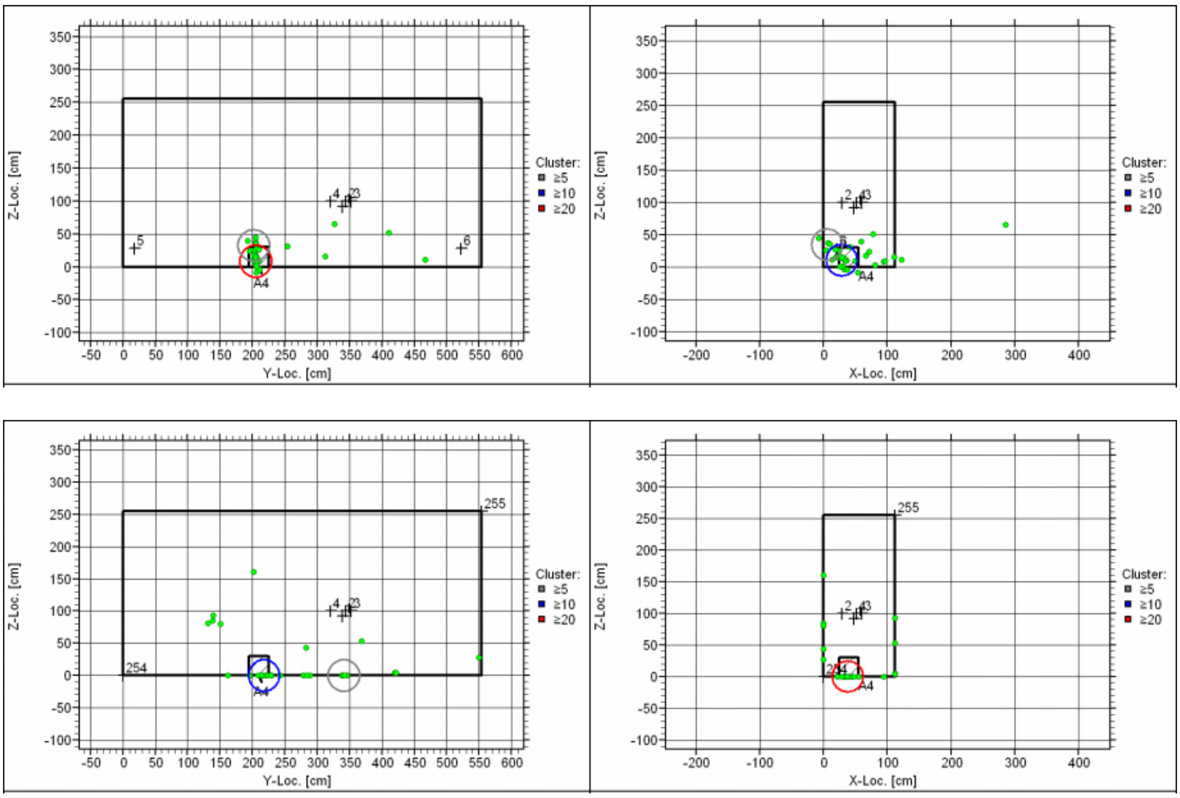


**Figure 5:** *Comparison of source location obtained by 3d location algorithm used for permanent installation (top) and by the MUSA location algorithm (bottom) used for spot testing.*

## Discussion

The results showed, that the R&D work for the testing of the tanks of oil tankers was done. Although the most work was done on single hull tankers, we are able to check from double hull tankers the tanks. If the outside ship structure is in contact with liquid e.g. as an additional ballast tank, the test method is also applicable for the hull structure.

The only problem, which isn't solved at the moment is the detection of corrosion within the deck plate. As long as the tank are not filled up to the maximum the deck plates are not in contact with liquid and the wave transfer is interrupted. If it is possible to fill up the tanks up to its maximum for testing purposes the test method can be used also for this region.

As like as every NDT method it is important to combine the results with the expertise of the inspection department of the classification societies for further follow up inspections. The permanent system can be included into other warning systems for the ship owner and the crew.

Nevertheless we know, that not only corrosion harms the ship integrity and therefore we will start to check the structure also for the appearance of cracks. Such a measurement would be important at minimum for the hot spots to create a common system for the ship safety, which would be important for the commercial point of view for ship owner themselves and also for the safety of the environment for the civil community.

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