DETECTION OF CORROSION ATTACK ON OIL TANKERS BY MEANS OF ACOUSTIC EMISSION (AE)

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Abstract

The oil transportation over the sea with oil tankers can become, because of oil spillage in case of an accident, very dangerous for the environment, with fatal consequences for Flora and Fauna, e.g. the accidents of Prestige and Erika. The accidents were often caused by the degradation of the structural integrity (corrosion). An EC-funded R&D project had the intention to develop discontinuous and permanent installed AE testing systems for the detection of corrosion attack on oil tankers in-time.

After extensive research works about the corrosion process and its effect on the emitted Acoustic Emission, the technology was able to distinguish meaningful corrosion noise from disturb noise. After development of intrinsically safe (Ex-proof) sensors, both systems were tested for their validation on real ships (Navy and commercially used oil tankers). These tests 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.

1. Introduction

For the chemical and petro-chemical industry the most important energy source and basis for further products is crude oil. This crude has to be transported from its origin (oil fields) to further processing (refinery, chemical plant) over great distances. Beside on-shore transportation this transportation-chain includes often sea crossings, which is mainly done by oil tankers.

How it was often demonstrated during the last decades the sea transportation can become hazardous for the environment. Even the normal shipping operation results in a specific amount of spillage, but much more important risks occur during the ship transportation, if one of the used tankers has an accident, how it happened frequently during the last years.

In the past many terrible marine accidents with enormous mass of oil spillage into the sea wasted the ecological system and harmed the flora and fauna of the sea and coast for many years (1). Especially for the European coast, where 90 % of the oil is arriving by sea and approximately 3000 tankers transport oil and oil products to and from the European ports, the risk of oil tankers is rather high, it was demonstrated by the most recent catastrophes (2).

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

- § Erika, which spilled in 1999 more than 20.000 tones of oil and polluted 400 km of the coast of Brittany (F) and destroyed only the Flora and Fauna (e.g. famous oyster banks) but also the tourist traffic for years (3) and
- § Prestige, which spilled in 2002 more than 35.000 tones heavy fuel oil with a similar amount of left inside and polluted till today hundred kilometres of coast in Spain and France (4)

These accidents were caused by material degradation created and/or influenced by undetected corrosion.

Although the normal ship survey will be performed by the ship classification societies in defined time periods, it is obvious that those ship surveys based on randomly selected test points are time consuming and expensive. In the mean time the ship corrode under normal sea condition, which is acceptable to a specific amount and is taken into account during the design. The outside corrosion is mainly solved, the new tankers are also coated inside and constructed as double-hull tankers, where ship hull is separated from the tank wall. But all the tests for ship survey based on a random and statistical basis and therefore the out-coming result will never be 1oo %. Likewise the testing periods are sometimes too long for the detection of the evolution of defects e.g. for pitting corrosion, which can break through the wall in a short time period.

Figure 1*: Sinking of oil tankers 'Erika' (top) and 'Prestige' (bottom).*

2. Targets of the project

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: structure of the consortium

Company	Role	Profession
TÜV Austria (A)	Co-ordinator, AE testing agency	Accredited testing-, inspection-, certification- and calibration organisation
Vallen Syst. (D)	Equipment developer	AE equipment manufacturer
Gdansk University of Techn. (PL)	Ship expertise, testing organisation	University, department of off-shore and ship-building material
Polski Rejestr Statkow (PL)	Ship classification expertise	Ship classification society
Institute for Applied Research (PL)	AE testing agency	AE testing organisation
Maritime Institute Gdansk (PL)	Corrosion expertise	Maritime research, Corrosion expertise in maritime environment

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 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.

3. 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

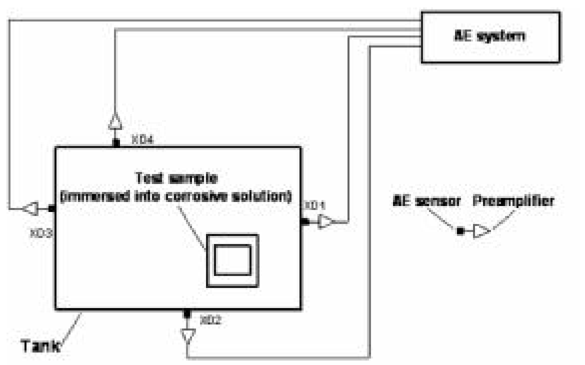

Figure 2*: Sketch of lab test set-up (top) and photo of test basin for corrosion measurements on ship building steel samples (bottom).*

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 samples were 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 was 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.

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 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.

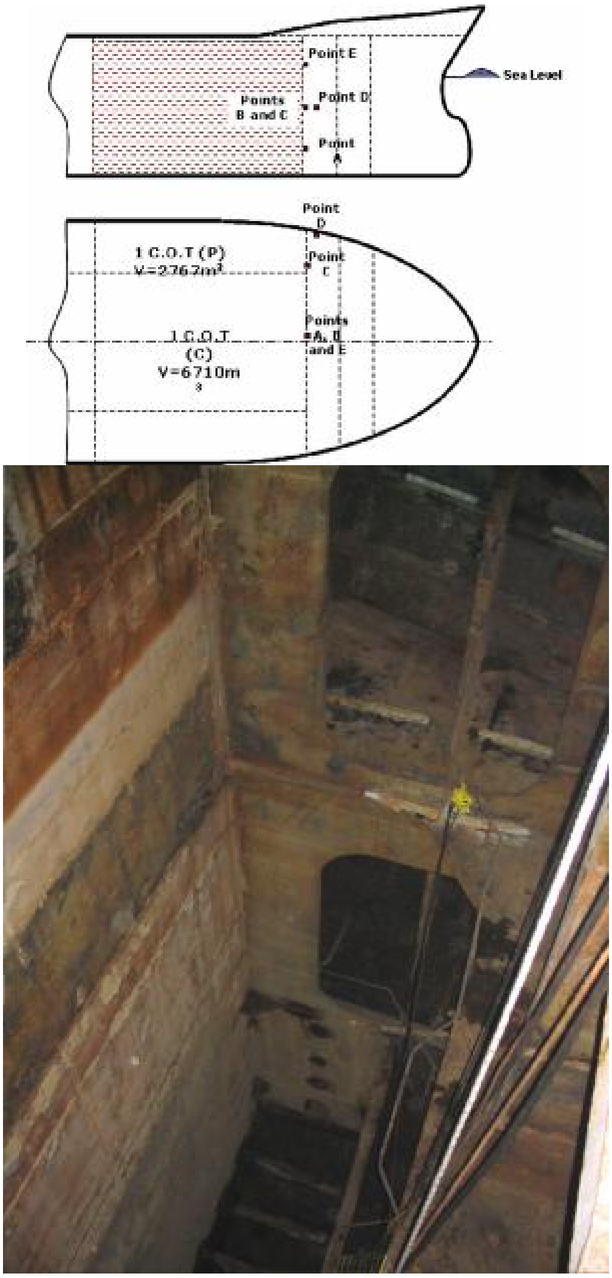

Figure 3*: Sketch of background noise measurements on M/T Icarus II (top) and photo of situation inside the ballast water tank near to the bow (bottom).*

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 loose energy only by the volumetric dispersion, we could expect the same frequency content nearby the source as well as over remarkable distances. This led us to the application of a frequency domain pattern recognition system "Visual Class™" for the statistical classification of AE signals. With this software the frequency dependend 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.

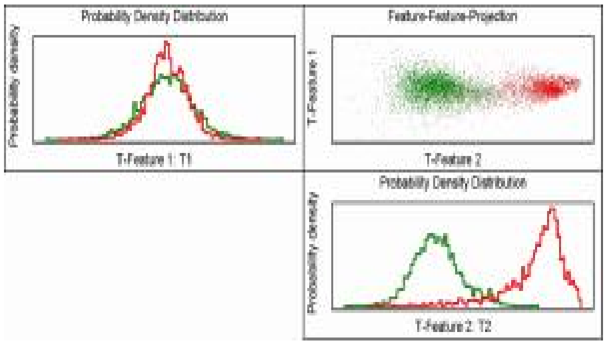

Figure 4*: Separation of corrosion (red) and background noise (green) with the help of frequency domain based pattern recognition. The two features T1 and T2 have best separation power.*

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.

4. Tests on tankers, equipment validation

At the end of basic research we could demonstrate, that the method is feasible to detect and discriminate the AE signals, which were produced from corrosion and from disturb noise from the environment and the structure itself.

To perform real tests with real corrosion samples on commercial tanker, we had to use an intrinsically Ex-safe sensor, because if we would open the tank the complete zone around 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 the whole circuit till to the barrier before the measuring 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 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.

The necessary repetition of a part of the lab tests to establish a well defined classifier for the new type of sensor, gave us the opportunity to develop also real corrosion samples.

These samples were developed at 2 partners TÜV and MIG in parallel to establish "artificial samples", which can cover the complete field of different corrosion processes and start them, whenever it becomes necessary, in covered samples without any contact to the real tank. These corrosion samples gave us later on the possibility to validate our detection system with noise coming from real corrosion processes.

After the pre-tests in the lab and the development of the corrosion samples and their validation in the lab, 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 samples 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 ϑ and φ, 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.

We found out, that according the receive characteristic of the sensors most time only 3 sensors of the MUSA got the AE, which leads to the development of an new "3D" the "Cuboid 3 D" location system. This location system assumes that the source is on or nearby the wall of the tank. With this additional restriction we could overcome the difficulties coming from the receive characteristic of the different sensors within the MUSA.

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

The same spot testing (application of MUSA together with 4 sensors) was performed on the new Icarus III, a new double hull tanker, during shipping and on the anchor place successfully. As a further benefit during this test we could prove, that the disturb noise within the tanks for a double hull tanker is much lower. This is obvious, but based on this fact the sensitivity of the method will be increased for such tankers.

5. 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 well 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 described 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 (nearby the wall). By measuring the arrival time at the different elements the new soft-ware is able to define the direction from where the wave is coming. The resulting the region in the wall will be defined by the new Cuboid 3 D location software. Such instrument (MUSA) would help the port authority for the assessment of the status of the incoming ship. Together with all further intelligent filters and perhaps the insertion of 2 MUSA the validity of the results can be increased.

6. Discussion

The results show, 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 last remaining and pressing problem, which is not solved at the moment is the detection of corrosion within the deck plate. As long as the tanks 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, especially fatigue 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.

7. References

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