DETECTION OF CORROSION ATTACK ON SHIPS, ESPECIALLY OIL TANKERS, WITH ACOUSTIC EMISSION (AE)

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Abstract: The transportation of oil is done mainly by ship tankers. In the last decades a lot of maritime disasters with these crude oil tankers occurred (e.g. Erika, Prestige). Every accident led to extreme pollution with horrible consequences not only for the environment but also for the life of the inhabitants of the affected coasts. Although most of these accidents were produced from human errors, the material degradation of the ship hull, caused by corrosion, played an important role.

Because the Acoustic Emission technique is already used to detect and discriminate the stage of corrosion a consortium started to investigate the potential of this technique for oil tankers.

The aim of this project is to develop an on-line monitoring during transportation by permanent installation and discontinuous measurement during stops in harbours by spot testing.

Since the start of the project a lot of lab tests as well as background measurements were done on different types of oil tankers up to a size of 35.000 DWT. The gathered data were evaluated with a frequency domain pattern recognition system and it was possible to distinguish the acoustic signals from corrosion against the acoustic background noise on the ship.

Together with the on-coming developments of specific AE-equipment and the improvement of the data base this project will lead to an important breakthrough for the safety of shipping hazardous products like crude oil.

Introduction: Beside all other energy sources (e.g. coal, nuclear power) oil is one of the most important basic materials for the production of energy and also the modern civilisation. Most of the oil has to be transported from its origin to the places for processing (refinery) and consequently to the consumer over great distances, which includes at most times crossing of the sea and this is mainly done by oil tankers.

How we have learned in the last decades this transportation can become hazardous for the environment. Even during the normal shipping a specific amount of spillage occurs. But the real risks of oil transportation by ships occur, if one of these oil tankers has an accident, how it happened frequently in the past. In the last decades 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. As examples the most disastrous accidents in the last decades were

- Torrey Canyon; the oil leaked from the ship (31 million gallons) and spread along the sea between England and France, killing most of the marine life it touched along the whole of the south coast of Britain and the Normandy shores of France, and blighting the region for many years thereafter.
- Amoco Cadiz; she ran aground off the coast of Brittany, France on March 16, 1978, spilling 68.7 million gallons of oil. It currently is n° 6 on the list of the largest oil spills of all time.
- Exxon Valdez: On March 24, 1989, the Exxon Valdez grounded on Bligh Reef, and spilled nearly 11 million gallons of oil into the biologically rich waters of Prince William Sound.
- Braer: The 85.000 tonnes of oil spilt by the Braer ranks eleventh largest in the table of oil spills in the world (in terms of the amount of oil spilled), just over twice as much as was spilled by the Exxon Valdez, and constitutes the largest ever pollution incident in Scotland.
- Erika, which spilled 20.000 tonnes of oil and polluted 400 km of the French coast and finally

- Prestige, which spilled more than 35.000 tonnes, with a similar amount left inside the sunken tanker and till today several hundreds kilometres of coast in Spain and France were polluted.

Figure 1: Picture of the sinking tanker 'Erika' (EPA photo AFP/Marine Nationale).

Although some of these accidents were caused by human errors, another big part is related to material degradation caused and/or influenced by undetected corrosion. Ship surveys are performed by the ship classification agencies in time periods, based on type and age of the hull. It is clear, that such 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. For uncoated tanks the inspection intervals can be reduced down to one year compared to inspection intervals of five years for coated tanks. These inspections and measurements are random point tests and take the oil tankers out of service for a long time period. Nevertheless this testing method will be a testing of an enormous mass of points on a tank (screening), it will never become an absolute 100 % testing and the testing periods are sometimes too long for e.g. pitting corrosion, which can break the wall in a shorter period of time.

Figure 2: From 'Erika' disaster affected bird (EPA photo AFP/Marcel Mochet).

All these facts 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. 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, AE testing agency	Accredited testing-, inspection-, certification- and calibration organisation	A
Vallen	Equipment manufacturer	AE equipment manufacturer	D
Technical University of Gdansk	Ship expertise, 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.

Figure 3: Picture of the broken tanker 'Prestige' (EPA photo EFE Pool/STF).

The main goal of the project is to develop two types of AE testing equipment and procedures to check the 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). This system would have the big advantage, that no stop before the discharge in the harbour or loading/de-loading platform becomes necessary. The treated data shall be transferred automatically via radio 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.

Results: The main task for the 1st part of this project, which was concluded on April 30th, 2004 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.

First 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. Especially we have corroded the test samples immersed into a sour environment (3 % NaCl solution, pH = 4) and we have also monitored the deterioration of the samples by an electrolytic corrosion process. The latter gave us the opportunity to control the velocity of the corrosion process. We took care to investigate 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 and where the best places for the application of sensors might be. 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 with direct contact to the cargo tanks filled with crude oil. 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.

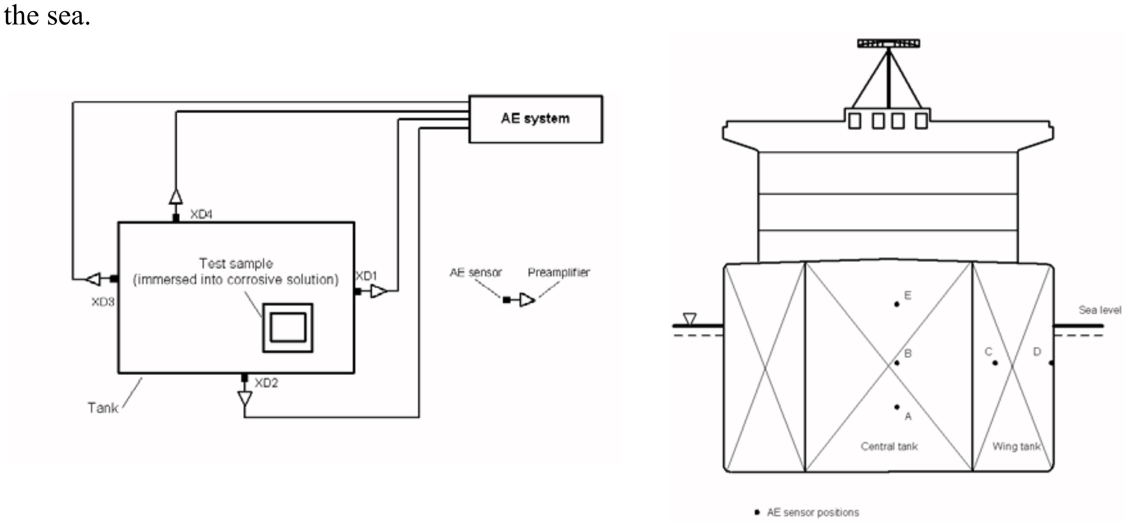

Figure 4: Sketch of the lab– and background measurements.

All these tests were performed with the 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.

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, which 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 nearly not affected by the band-pass filtering and we could forward the data to further data treatment.

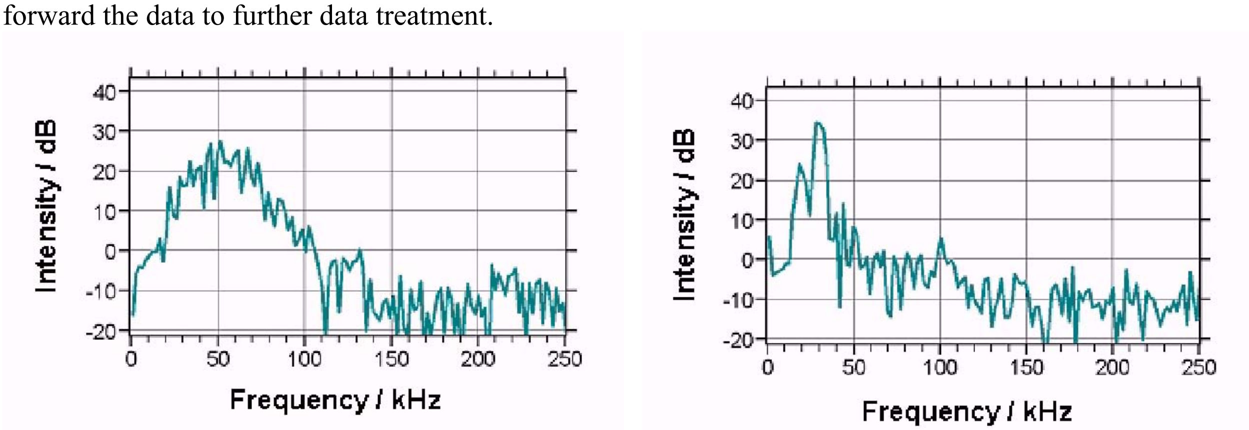

Figure 5: Frequency distribution of corrosion and background AE signal.

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 can 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.

Even for AE signals, which were acquired outside of the respective lab- and oil tank (signal transfer through the wall), we were able to distinguish AE signals coming from corrosion processes against the background. The application of the "Classifier" obtained from training data 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. Together with further intelligent filter criteria and location with at least two sensors (Δt-clustering) the results were very promising for the further data treatment and the separation of AE signals. For invasive sensors, which acquire the AE signal without any transfer function directly from the liquid, the separation score shall be higher in any case.

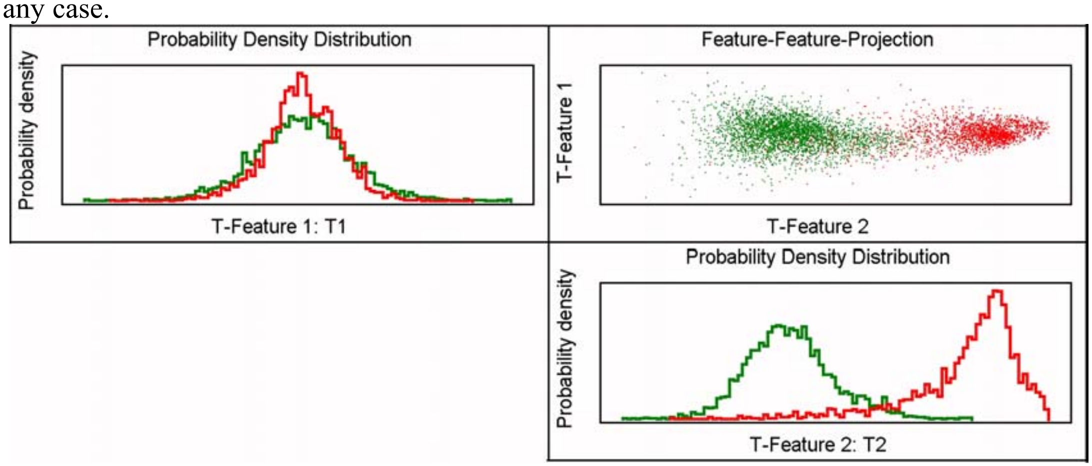

Figure 6: Separation of corrosion and background AE signals in the feature space (Visual Class^{TM}).

Discussion: The results showed, that the basic for the testing of the tanks of oil tankers, which are especially for single hull tankers an integral part of the structure, was done. One important point for the further developments, still under construction, is the intrinsically safety of the sensors including the whole circuit till to the barrier to the AE equipment.

In the following two years the consortium will develop the two proposed systems (permanent installation and spot testing) with invasive submerged sensors within the oil tankers, which will be combined from sensor arrays and/or multi-element sensors. These sensors in combination with the adjoining software will be able to decide whether corrosion is present in the structure or not. If AE signals from corrosion will be detected, the direction from where the sound is coming will be determined in spherical coordinates ϑ and φ. If two or more sensors will be submerged within one tank the origin of the AE corrosion signal can be found at the intersections of the sound beams, which can be validated by the presence of the tanker wall at these intersections.

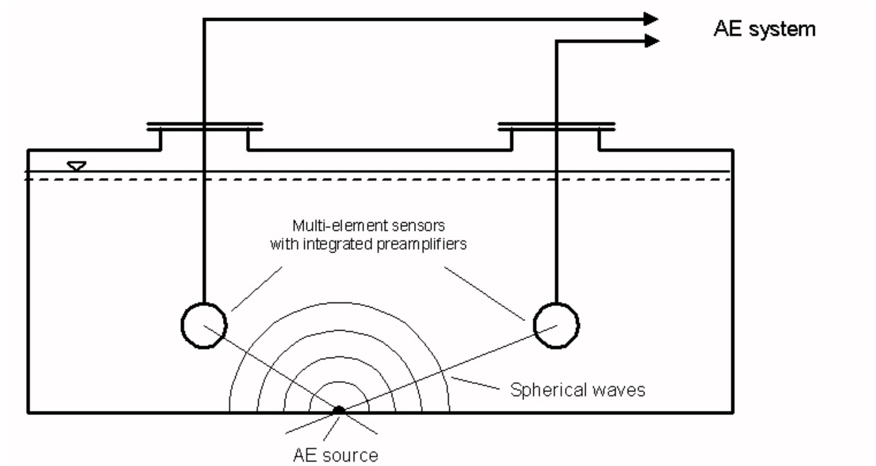

Figure 7: Sketch of corrosion location within a ship tank by means of two multi-element sensors.

The design of the permanent measuring system and its installation can only be performed together with classification societies and dockyards. For the system check and application the contact with the port authority is an absolute must. Therefore the consortium has the intention to establish an User Group, where all potential users including the shipping industry will be combined. This User Group shall give the potential user the opportunity to guide the further developments in a way, so that the applicability becomes as easy as possible in order to achieve a safer oil transportation over the sea.

The current status of the project is presented on the internet-website: www.ship.tuev.at.

Conclusions: The targets of the EC funded project "Detection and discrimination of corrosion attack on ships (crude oil tankers) with Acoustic Emission (AE)" are the development of a permanent corrosion detection system and a spot testing system for oil tankers as well as the establishment of the adjoining specifications for their application.

Till to the present stage the necessary measurements in lab (corrosion samples) and on real ships (background measurements) were done. The developments for the necessary invasive, intrinsically safe sensor and further adaptations of the equipment were started.

The acquired data (AE parameters and transient time signals) were evaluated and we found, that background signals can be separated from corrosion signals by the help of different filter steps (e.g. band-pass filtering) in combination with the application of the frequency domain pattern recognition system "Visual Class^{TM}". Together with all other works, determination of the equipment specification and study about the integrity of the ship hull structure etc., the feasibility of corrosion testing of oil tankers with AE was proven. A big step was already done, but a lot of work has still to be done in the future till this important tool for an increase in the safety for the oil transportation over the sea will be finished.

References: Project Description for EC-project N° EVG1-CT-2002-00067 "Detection and Discrimination of Corrosion Attack on Ships (Crude Oil Tankers) with Acoustic Emission (AE)"

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