CORROSION TESTING OF SHIP BUILDING MATERIALS WITH ACOUSTIC EMISSION (AE)

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KEYWORDS

Ship disasters – oil spillage – corrosion testing – frequency based pattern recognition technique – corrosion classification – continuous monitoring – spot testing

ABSTRACT

One of the most important raw material for the energy production is oil. This crude oil must be transported from their origin to the process and consumer over great distances, which includes at most times crossing of the sea, which for Europe is done 90 % by oil tankers.

How we have learned in the last decades this transportation became hazardous for the environment. Some of the old oil tankers, mainly single hull tankers, have had accidents with an enormous mass of oil spillage into the sea and fatal consequences for the marine-ecological system and harmed the Flora and especially the Fauna for many years. In specific I will remember on the accidents of Erika (December 1999) and Prestige (November 2002) with tremendous pollution of the environment. Although some of the accidents were caused by human errors, a further reason was the degradation of the structural integrity by corrosion attack.

Because the conventional controls of these tankers were expensive and time consuming and time span between these controls of the tankers were based only on the time between the controls and do not refer to the condition of the tankers.

Based on these facts a consortium, consisting from TÜV Austria (A), Vallen Systeme (G), Technical University of Gdansk, Polish Registration Society, Institute for Applied Research and Maritime Institute of Gdansk (all Poland) were created and started in 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 permanent installed and spot testing system. The aim of both systems was to detect the corrosion attack on oil tankers in-time and give the ships owners as well the port authority a fast and reliable testing system to validate the status of the checked tanker.

Within this paper the first investigations (corrosion tests within the lab) on ship building materials and background measurements on ship within the harbour and the open sea will be demonstrated. The classification of the Acoustic Emission, based on a frequency domain pattern recognition, shall be demonstrated. Based on the recent information the testing and grading of the structure will be possible within few hours on the tankers quasi in-service, which will increase the acceptance of the method by the ship owner.

A short out-lock in the further investigation within this project shall conclude the paper.

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.

	
Erika *(EPA photo AFP/Marine Nationale).*	*Erika* *(EPA Photo AFP/Valery Hache)*

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.

	
Prestige (EPA photo EFE Pool/STF)	*Prestige (EPA Photo EFE/Lavandeira)*

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.

CONSORTIUM OF THE EC FUNDED PROJECT

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 done in spring 2002 and accepted by the EC. The project started on November 1st, 2002 under contract n° EVG1-CT-2002-00067 "Detection of corrosion attack on ships, especially oil tankers, with Acoustic Emission".

The main goals of the project are 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 span, 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.

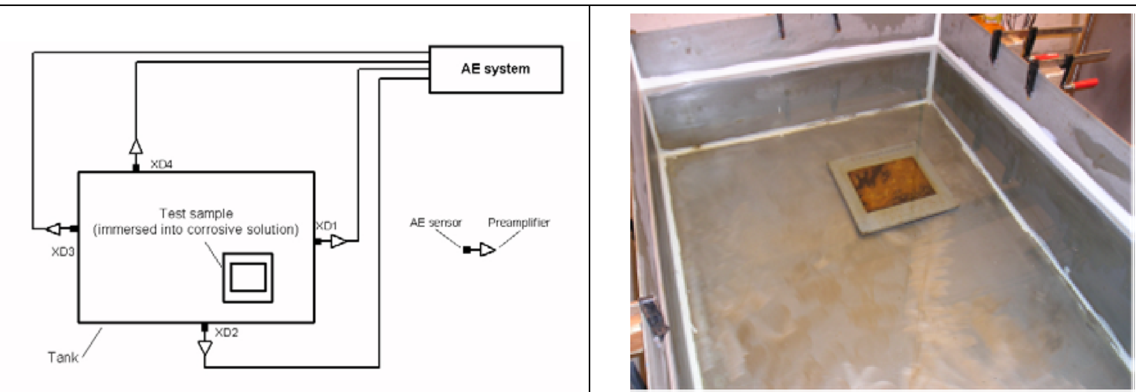
- Discontinuous measurement (spot testing) system

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. This testing could become very meaningful for old tankers, where for further service period it is too expensive to install a permanent testing system.

PERFORMED TESTS

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. This feasibility study includes to prove, that the corrosion process of ship building steels produce AE, and it becomes possible to distinguish the corrosion born signal from the background noise. 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 naturally pre-corroded samples taken 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 monitored also the deterioration of the samples by an electrolytic corrosion process. The variation of the current gave us the opportunity to control the velocity of the corrosion process. Beside the plain corrosion we took care to investigate the most hazardous and also fastest corrosion types for the structure of the ships (e.g. pitting corrosion with an Ω-type profile).

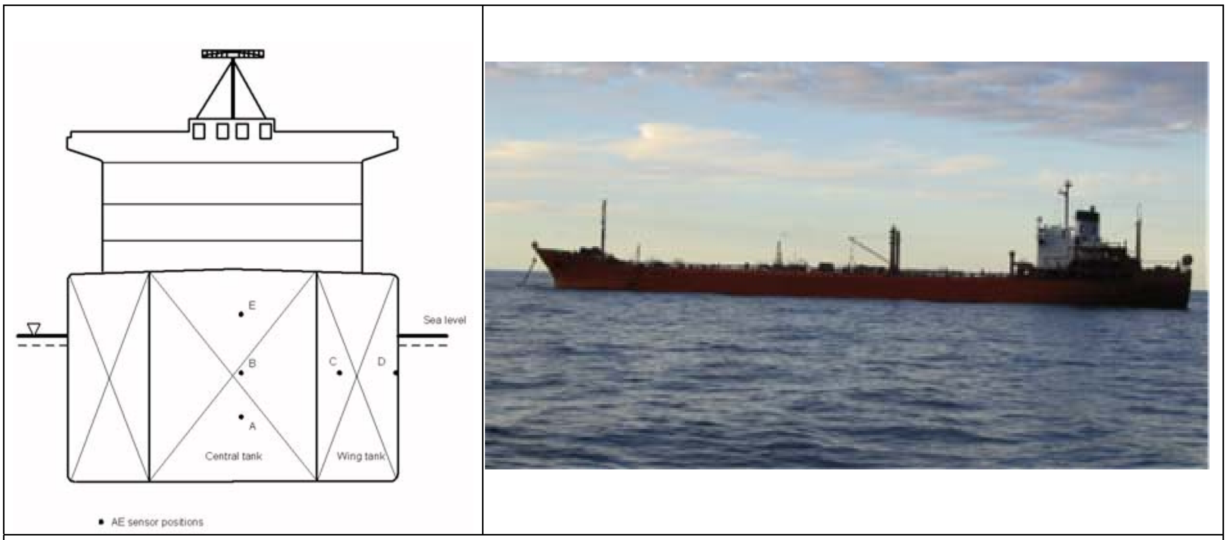


Sketch and photo of lab measurements

To acquire the background noise on ships we had to apply our sensors on ships within the harbour, at the anchorage-place, in 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. The gained results give us important basements for 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 at different positions above and under the sea level, but also we acquired the noise from the hull in direct connection to the sea.

All these tests (lab - and background measurements) 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 (VS 30-V, VS 75-V and V 150 RIC) were employed to cover the frequency range, where the useful AE corrosion signals as well as the background noise based on our former experiences have been expected.

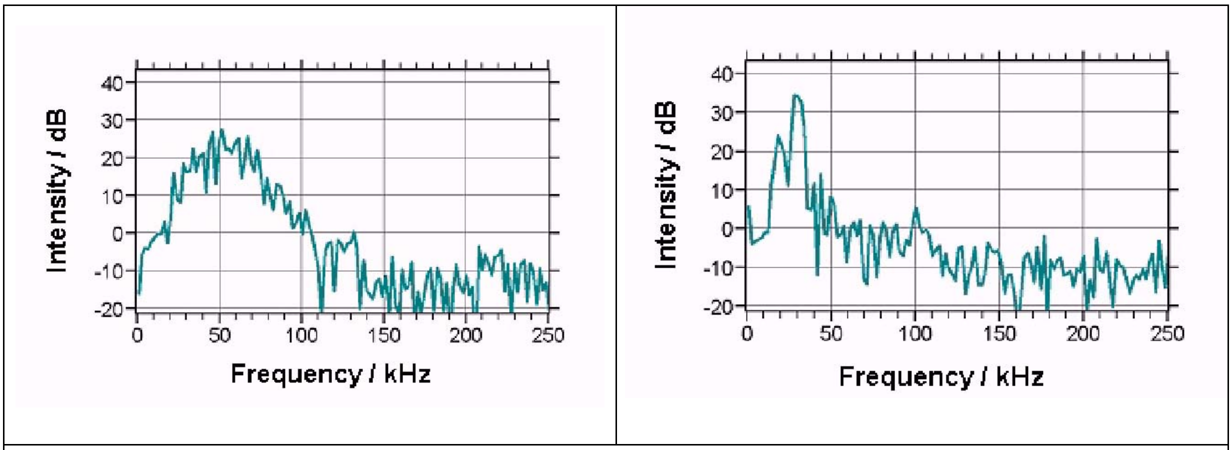
All the data were gathered and stored in a structured data base for the evaluation process, which should result in the separation of AE data, coming from the different types of corrosion, and background data, which cover the complete AE signatures from all possible occurring ship actions and the environment.



Sketch of background measurements on Ikarus II (photo)

RESULTS

The first results showed us, that the magnitude of the background, especially on the sea, 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 AE signals produced from background noise has a frequency content of mainly under 50 kHz. The frequency content of the corrosion signals goes up to 60 to 70 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.

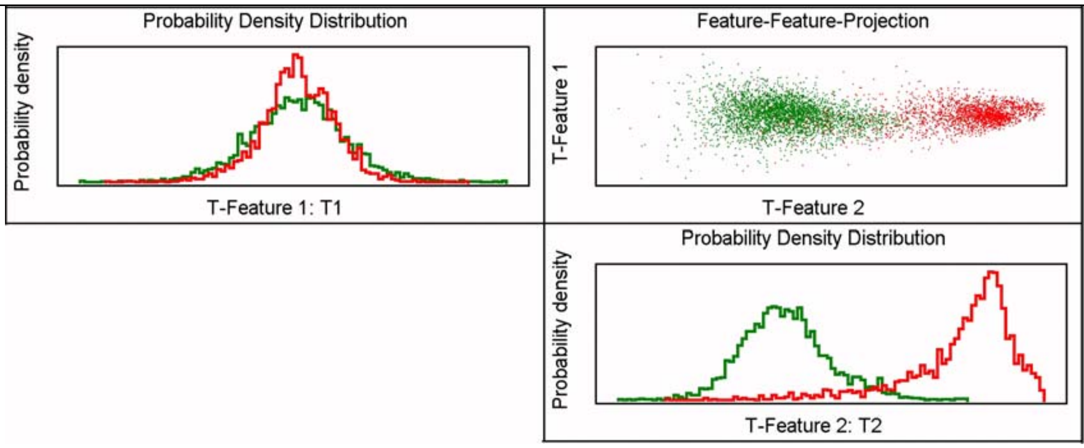


Frequency distribution of corrosion and background AE signal

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 in the signal 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 (twice times signal transfer through the surface of the wall), we were able to distinguish AE signals coming from corrosion processes against the background. The application of the "Classifier" produced 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 + intersection with the wall) 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.

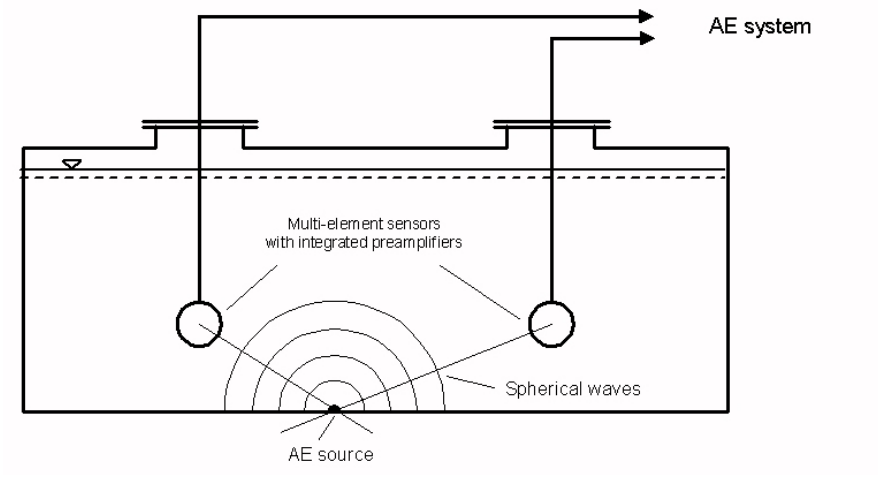


Separation of corrosion and background AE signals in the feature space (Visual Class^{TM})

DISCUSSION

The results showed, that the basement for the AE testing of the tanks of oil tankers, which are for single hull tankers an integral part of the structure, was done. One important point for the further developments, still in the certification procedure, 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 multi-element sensors in combination with the adjoining software shall be able to decide whether corrosion is present in the structure or not. This corrosion process shall be weighted in a second step. 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 tank wall or its stiffeners at these intersections.



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 many potential users including the shipping industry will be called together. 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. Furthermore the members of the User group have the opportunity to accompany the validation procedures of the testing system.
The current status of the project is presented on the internet-website: www.ship.tuev.at.

CONCLUSION

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.

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