AE-Monitoring for Surface Transport Product (Ships, Trucks and Railway Cars)

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ABSTRACT

Beside human errors the different technical degradation processes like corrosion and fatigue cracks are the most common reasons for structural failures of all surface transport products like ships, road tankers and railway tank cars. To avoid the failure of these structures, maintenance and inspection have to be carried out on a time span basis. These activities can become time consuming and consequently expensive. Beside this disadvantage a lot of examples exist, where weakened structures (ships, trucks and railway cars) have failed during operation with the result of oil spillage and/or even fatal accidents.

It is necessary to detect and identify evolving defects on time to enable appropriate repair works, which is only possible by permanent monitoring of the structure, which can be used as an important tool in the complete health monitoring of the structure. A real time monitoring to detect cracks as well as corrosion would be possible with Acoustic Emission (AE). The use of this technique for a health monitoring has the disadvantage, that it is also sensitive to process noise and environmental influences. This has to be overcome by the application of logical filtering and data treatment.

For the solution of this problem an EC-funded project (SCP7-GA-2008-218637 “Cost effective fatigue and corrosion monitoring by means of Acoustic Emission on transport products”) was launched to develop an overall, innovative strategy for the maintenance and inspection. The project partners, leading companies on their specific field (Acoustic Emission Testing (AT), Non Destructive Testing (NDT), Inspection, Ship Classification, Research, Maintenance and Shipyard) developed together a monitoring concept including a new adapted intrinsically safe AE-equipment for different surface transport products.

The application of the key technology (AT) was adapted for the specific needs and was embedded in clear application rules for proceeding calculations and definition of hot-spots, continuous monitoring, follow-up inspection as far as possible while in-service and preventive inspection and maintenance for ships, trucks and railway cars.

The results of the pre-tests in different laboratories of the partners and validation tests during shipping operations on-board of ships, trucks on road and railway cars in operation show the applicability of the technology. Finally the special developed intrinsically safe AE- equipment will be presented.

INTRODUCTION

In parallel to time-driven maintenance and inspection, predictive maintenance and inspection is useful to overcome the drawbacks of the first one, which is time consuming and expensive and furthermore has the risk to miss the initiation and development of degradations. Especially if such degradations develop into severe defects during service and become in the worst case the reason for a breakdown of the structure. This can lead to environment pollution and even fatal consequences.

With Acoustic Emission Testing (AT) and, if necessary follow-up Non Destructive Testing (NDT), predictive maintenance and inspection can be applied continuous or periodic for monitoring the structure of transport products (ships, railway cars and trucks). This complete system will be developed during the project [1].

At the beginning pre-tests were carried out in laboratory to investigate the applicability of AT using specific measuring setups for detection of degradations and their evolution caused by corrosion or cracking under conditions, which can occur on all transport products [2]. Due to high sensitivity AT is able to detect minor structural defects, but at the same time it is also sensitive to environmental- and process noise. This background noise can usually be separated from the desired data (data related to specific defects) by means of several filtering processes (simple frequency or logical filters e.g. pattern recognition features). Therefore the background caused during typical service conditions at transport products was recorded with AT for further data treatment. Measuring data and analysis have shown the applicability of AT on ships, trucks and railway cars for detection of material in-homogeneities and discrimination of desired data and background.

In the next steps, development of measuring setup and measuring equipment have been started to adapt AT for trial-tests on real structures. In contrary to other NDT methods, e.g. VT, PT, MT, UT, RT, which inspect only small defined areas, AT is an integral technique, i.e. the whole structure or its hotspots can be inspected using only a limited number of AE sensors mounted at the structure. On the other hand AT is a qualitative and not a quantitative testing method. Consequently follow-up NDT using conventional methods have to be applied for further analysis of the defects detected and roughly qualitative classified by AT.

Clearly all the regulations, defined in ADR, RID, ATEX and/or classification rules, which are valid for the transportation of hazardous goods, e.g. crude oil, fuel, compressed gas, need to be respected. Therefore an important part of the project is the adaptation and development of the measuring equipment used for AT according the requirements demanded by the regulations, i.e. for oil transportation ships and trucks the AE sensors and their cabling have to be intrinsically safe.

While first tests were carried out at different structures, in parallel finite element (FE) calculations of stress distribution at tank trucks and railway tank cars were undertaken to obtain in addition theoretical results besides the knowledge gained from experience.

PROJECT CONSORTIUM

The project consortium [3] is composed of 11 companies coming from 8 EU-member states (Table 1). Different experts in maintenance, inspection, testing, classification, mechanics, design and calculation regarding TP are represented by the project partners.

Table 1. Partners of the Project Consortium.

Project Partner (project short name)	**Expertise**	**Country**
TUV AUSTRIA SERVICES GMBH (TUV)	Testing and Inspection Institute, Project-Coordinator	Austria
Vallen-Systeme GmbH (Vallen)	AE-equipment producer	Germany
ABS - Europe Ltd. (ABS)	Ship classifier	United Kingdom
Bundesanstalt für Materialforschung und -prüfung (BAM)	Institute for Materials Research and Testing	Germany
Aristotle University of Thessaloniki (AUTH)	Mechanic and calculation experts, especially trucks	Greece
Gdańsk University of Technology (GUT)	Maritime and ship experts	Poland
Instituto de Soldadura e Qualidade (ISQ)	Testing and Inspection Institute	Portugal
Laboratory of Applied Research (LAR), Krákow University of Technology	Testing and Inspection, especially AT	Poland
Nuclear N.D.T Research & Services S.R.L. (NNDT)	NDT testing company	Romania
Reneko AS (Reneko)	Maintenance and repair company	Estonia
Naval Shipyard Gdynia (NSG), Stocznia Marynarki Wojennej S.A.	Ship repair yard	Poland

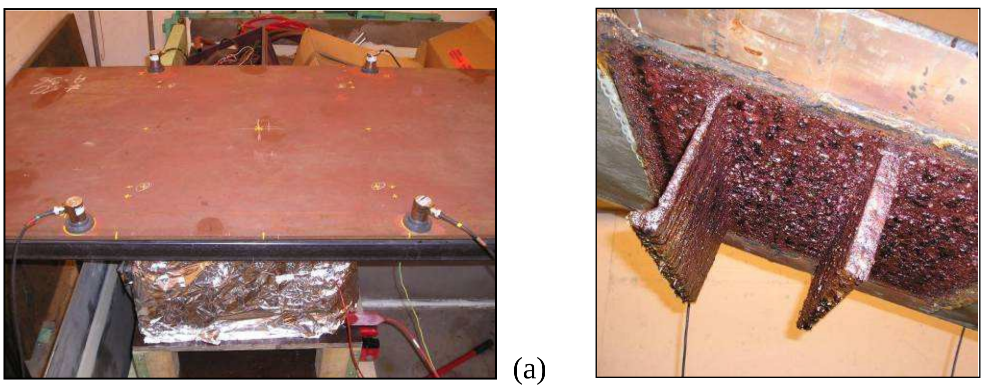
PRE-TEST IN LABORATORY

The new technology will be based mainly on Acoustic Emission (AE). It is common knowledge, that AT has been used to detect different degradation processes, corrosion and fatigue cracks. During this stage the AE signal coming from defects and background, under conditions similar with real conditions were checked. In addition, several measurements were carried out using different types of AE sensors, in order to determine which is the best type of AE sensors (receive characteristic) for recording the desired data.

Corrosion (generation and detection)

Results from a previous EC-funded project “Corrosion detection of ships” (EVG1-CT-2002-00067) proved that AE sensors are able to detect signal coming from active corrosion in ship hulls. During these measurements the AE technology uses acoustic waves travelling through water from the source (corrosion) to the AE sensors. Moreover, one task of the current project was to check the possibility to detect and monitor active corrosion appearing on the bottom side of deck-plates at ships with AT by mounting AE sensors on the top side.

Therefore, AE sensors mounted on the top side of steel test plates similar to deck-plates on ships were used for monitoring corrosion on the bottom side of the test plate (Fig. 1). For these measurements a stainless steel basin was pressed to the bottom side of the steel plate and by means of heating up an acid mixture inside the stainless steel basin a vapour was created similar to the atmosphere existing in the space below the deck-plates of crude oil cargo tankers.



(a) (b)

Figure 1. (a) Generation of corrosion and detection with AT; (b) corroded bottom side of steel test plate.

The results of the test measurements proved, that the corrosion generated on the bottom side of the steel plates could be detected by AT with AE sensors mounted on the top side of the plates. Also the wave attenuation was measured.

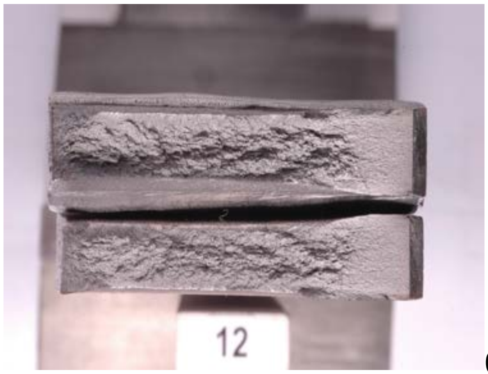
Fatigue Cracks (generation and detection)

The tests for monitoring of fatigue crack were performed at three project partners (BAM, LAR and GUT) for different transport products. The works have to be divided into three parts for ships, railway cars and trucks, respectively, because of different test conditions regarding crack mode, loading, cycling and loading frequency, depending on different structures and service conditions. Specific test specimens were mounted in test machines for applying cyclic loading (Fig. 2) until break. In parallel the acoustic data was registered.

Background Measurements and Data Discrimination

Data related to background noise generated during service conditions for the different transport products are needed as reference data for creating filter procedures, for their frequency content and especially for their pattern. Therefore trucks and railway cars were equipped with AE sensors and AE monitoring was performed during different service-like conditions, e.g. during movement. For ships, as a first step the results of the former EC funded project were used. The results are as expected: the data discrimination needs because of high background (transportation) noise logical filtering. The results confirmed our intention to use a frequency domain pattern recognition technique, provided by partner Vallen (Visual class®).


(a)



(b)

Figure 2. (a) Butt welded sample in testing machine; (b) Fractography of the fracture after breakthrough.

A filter procedure based on frequency domain pattern recognition was created and it was possible to show that data discrimination is possible. But for a more reliable filter procedure more specific data from different types of transport products related to background data as well as data of fatigue cracks and corrosion under real shipping conditions are needed. It's obvious that various defect mechanisms and behaviour occurs at different types of ships, railway cars and trucks. More measurements were carried out on real structures to acquire additional data (classification and control) for analysis.

ADAPTATION AND DEVELOPMENT OF MEASURING EQUIPMENT

The AE monitoring equipment has to be checked and adapted for their applicability for monitoring at different structures. For the application at different types of ships, railway cars and trucks also the instruments have to be different. AE sensors were mounted on ship e.g. on the deck plates or within water ballast tank. At railway cars and trucks AE sensors can be fixed at the outer side of the tank. The power supply of the acquisition system, the AE sensors and the cabling have to be installed safely and protected against damage. But, especially for those products carrying hazardous and explosive goods, the measuring equipment has to fulfil specific requirements defined in ABS rules (ships), ADR (trucks), RID (railway cars) and/or ATEX. In any way the AE sensors and cabling have to be ex-proof and intrinsically safe (Fig. 3).


(a)

(b)

Figure 3. (a) Prototype of intrinsically safe sensor; (b) new developed acquisition system (3 different sizes).

On board of tank ships exist safe rooms (no ex zone), where a usual acquisition system can be positioned. At tank trucks the acquisition system can be installed inside the driver's cabin, but has to be implemented according the requirements of ADR and ATEX. On railway tank cars for the acquisition unit a special housing to protect the system has to be mounted additionally, clearly both housing and acquisition system have to fulfil RID and ATEX requirements.

New version of acquisition systems, in different sizes, and intrinsically safe sensors have to be developed. Intrinsically safety of cabling is ensured by a signal isolator developed in the current project. This signal isolator between the acquisition system and the cabling to the AE sensors represents the barrier between hazardous und not hazardous areas.

HOT SPOTS CONCERNING FATIGUE CRACKS AND COROSSION

At the different transport products the hot spots, where cracks and corrosion occur predominantly, are known from experience. These hot spots are of high interest for monitoring, because the defects typically occur frequently and at first in these regions.

For comparison of hot spots, regarding fatigue cracks and stress, the stress distribution at different types for tank trucks and railway tank cars were determined with finite element (FE) calculations based on the demands described in ADR and RID (Fig. 4).

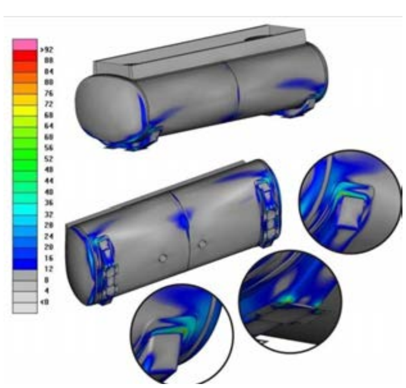
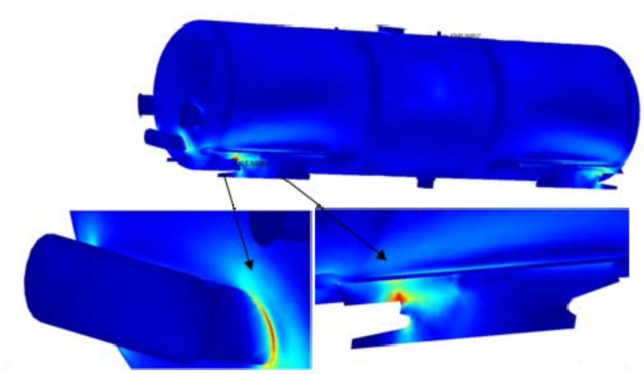

(a)

(b)

Figure 4. Example of results from FE calculations of stress: (a) at a tank truck; (b) at a railway tank car.

Hot spots related to corrosion can be found mainly near to the hot spots of stress, coating defects also occur mostly in these regions. Corrosion appears in the tank in the areas, which are more subjected to moisture. The positions of the specific regions depend on the structure of the tanks and the cargo-product.

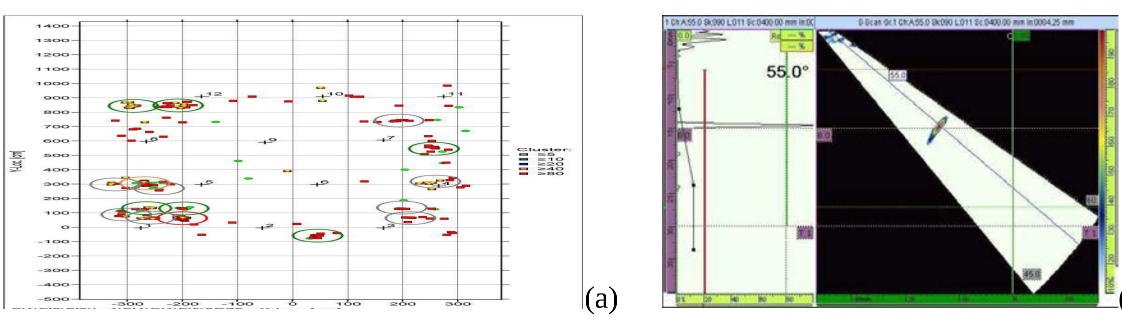
MONITORING TEST AT REAL STRUCTURES

Monitoring tests have been carried out at different trucks, railway cars and ships. Different procedures including requirements on the AE equipment and test performance were performed before the tests. Trucks and railway tank cars were monitored during movement on road (different conditions, street surface and velocity) and railway-line. Depending on the type of tank different maximum pressure tests were applied to the tank, while the structure was simultaneously monitored with AT.

We were able to apply the AE sensors on trucks and railway cars on the outside part of the tank shell (Fig. 6). The AE sensors on ships were mounted inside the ballast tank or deck surface and measurements were performed with empty as well as with full ballast tanks during different shipping conditions, e.g. during cruising, anchoring.

Figure 6. Example of monitoring measurement at a tank truck equipped with AE sensors.

Indications detected with AT in the structure during pressurization of the tank were reported (Fig. 7 a) and marked on the structure for further analysis by means of follow-up NDT using, e.g. VT, PT, MT, UT, RT.



(a) (b)

Figure 7. (a) Indications from AT during pressurization of the tank; (b) one result from follow-up NDT (phase array).

SUMMARY

At the beginning of the project we could demonstrate that AT is able to detect active corrosion and fatigue cracks. Based on this result it was obvious, that AT can be used for permanent monitoring of different transport products. The indications detected from AT could be validated during follow up with conventional NDT. Due to high background noise, additional data analysis (logical filter processes) became necessary for the discrimination of the data coming from real defects and that coming from the background.

More tests, monitoring at real structures with AT and follow-up NDT, were performed. For creating a useful data base a large number of data coming from monitoring tests on real structures under service or similar to service conditions is needed.

Additional monitoring tests at ships and trucks have been scheduled or already started. Measured data will be stored, analysed and included into the data base. Based on a larger data base, containing data related to cracking, corrosion as well as background noise, the data discrimination processes in combination with frequency domain pattern recognition features will be improved.

ACKNOLEDGEMENTS

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