Internal In-service Inspection of the floor and walls of Oil, Petroleum and Chemical Storage Tanks with a Mobile Robot

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ABSTRACT

The RobTank mobile robot can enter oil and chemical storage tanks through 300 mm or more diameter openings in the roof. It performs in-service inspection of the floor and walls while submerged in liquid thereby saving the cost of emptying, cleaning, and manually inspecting the tank. A navigation system keeps track of position and orientation within the tank. An array of ultrasonic wheel probes and two bulk-wave rotating probes look for corrosion thinning on the floor and walls up to half a metre ahead and under inaccessible floor areas. Obstacles such as drain sumps, heating coils, etc. are detected and avoided.

1 INTRODUCTION

This work is funded by the European GROWTH Programme under the project title "In-service inspection robot for structural integrity of tanks filled with hazardous liquids – ROBTANK INSPEC", Contract Number GIRD-CT2000-00230. Project partners are; UK: South Bank University, OIS Plc and Phoenix Inspection Ltd; Spain: Tecnatom; Portugal: MT, EID, Petrogal and ISQ-Instituto de Soldadura e Qualidade (project coordinator).

Inspection of the floor of oil and chemical storage tanks is essential to avoid leakages, which could lead to pollution and soil contamination. Current inspection practices require tanks to be emptied and cleaned before an inspection can commence [1-4]. This results in the tanks remaining out of service for quite long periods with direct economic and operational implications. The total time to empty, clean and inspect a storage tank can be between 1 to 9 months on the larger crude oil tanks. Despite safety procedures, the cleaning operators are exposed to hazardous chemicals and other hazardous conditions for long periods of time. Huge savings in cost and inspection times could be obtained by performing in-service inspection of tank floors and walls with robotic devices. Given the very large size of some storage tanks, to achieve this inspection it is necessary to develop mobile robots capable of:

- Entering tanks through manhole openings that can be as small as 300 mm diameter.
- Travelling on uneven tank surfaces and through sediment layers on the floor.
- Deploying a payload of Non Destructive Testing (NDT) sensors for the inspection of top and bottom corrosion on the tank floor.

- Changing surfaces from the floor to the wall to inspect lower parts of the tank that may be inaccessible from outside.
- Operating in explosive and hazardous liquids such as crude oil, petroleum products, ammonia, liquors, etc.
- Using onboard and external sensors for navigation and guidance of the vehicle in the tank.

2 INTERNAL INSPECTION OF TANK FLOORS AND WALLS: CURRENT PRACTICE

Current practice depends on whether the products in a tank are clean or dirty. The characteristics of storage tanks and corresponding inspection practice for the two broad category of product is discussed below.

2.1 Clean storage tanks containing blended oil products, chemicals.

The size of this type of tank varies from about 2 to 20 metres in diameter and height but usually have a fixed roof. In many cases visual inspection, coupled with a few cursory ultrasonic thickness measurements (USTT), is all that is required. In some cases a more detailed inspection can be a planned and a methodical USTT survey carried out. Spot readings are taken on the floor, patch and annular plates in a ‘domino’ pattern. The results are scrutinised to determine changes in thickness, any suspect areas and other critical items such as drain sumps are then manually USTT scanned. This approach allows the inspection authority or utility operator to vary the amount of NDT carried out based on the initial results and visual appearance. This method does have the drawback that isolated areas of under floor corrosion could remain undetected.

On the larger diameter tanks, magnetic flux leakage (MFL) is used for the initial inspection [5]. A portable carriage is pushed over the floor area. Sensitivity to defect detection is determined before tank inspection, usually to 40% thickness loss, and verified on a test plate. When the sensors detect an indication, the LED display is illuminated, an operator marks the floor position for further evaluation and carries on with the survey. For examination of the floor plate closer than 75 mm to the tank wall, a hand unit is available. The equipment is lightweight, battery operated and easily assembled. Suspect areas are further examined using either vacuum box or magnetic particle inspection methods.

2.2 Crude and fuel oil storage tanks

Crude oil tanks normally have large deposits of sludge (wax and sand) that can be up to 5 metres deep where the tank has not been opened for many years and has been used to store oil from many different production sources. These tanks have floating roofs, either double skin or pontoon type, with many manhole openings (for agitator entry). The diameter of these tanks is between 20 and 100 metres plus with construction from carbon steel. All will have annular floor plates with a minimum thickness of 12.5mm. Central floor plate thickness may vary between 6 to 12mm. The preparation periods for entry and internal inspection are lengthy with 6-9 months required for removal of the oil, gas, and sludge banks. Another 3-6 months are required for the process of washing the tank clean of all oil and venting it before men can enter the tank. The clean tank is first inspected visually followed by MFL techniques to find problem areas. UT is used as a final method to validate the problem areas. The inspections are carried out using floor scanners, either Magnetic Flux Leakage (MFL) or Low Frequency Eddy Current technology. These scanners can incorporate floor map displays for direct defect entry into the report package. Dependent on technique, annular floor plate thickness up to 35mm can be achieved with discrimination between topside and under floor corrosion. Examination of floor plate welds is a time consuming and difficult task due to residue of product and poor lighting condition. Attachments to the plate scanners for weld examination are under development. Fuel oil storage tanks can have heating coils fitted, these are usually 50mm diameter steam pipes, supported about 500mm above the floor. These coils severely hamper floor inspection with the floor attachment positions being possible defect locations.

Many of these large diameter tanks have additional wind loading support. Steel girders are welded around the tank perimeter between half and two-thirds its height to strengthen the tank. Unless adequate drainage is provided, they become water traps and subsequent corrosion sites. Access to these areas for inspection is provided either by erecting scaffolding or by motorized lifting platforms.

3 TANK FLOOR INSPECTION WITH ENTRY INTO THE TANK BY MOBILE ROBOTS

"Rob Tank Inspec" is a European project developing a robot for in-service inspection of storage tanks filled with hazardous liquids. The comprehensive inspection strategy adopted by project partners is to develop a modular inspection system that can inspect both clean and dirty tanks. The work reported here focuses mainly on development of a robotic system for clean tanks with a sediment layer on the floor that is not more than 50 mm thick. The applied inspection methods will allow the evaluation of tank floor and walls condition in order to prevent leakage situations or prioritise maintenance works within a set of several tanks.

The mobile robot and its payload of NDT sensors and instrumentation is designed to test the following Target areas:

- Under base corrosion: The fitting of shielding plates (to run off rain water) prevents access from the outside to under-wall corrosion areas. Current practice is to fit shielding plates to all tanks that are refurbished. The inspection robot deployed internally can provide access to this area of the annular plate.
- Sump drains: Another area of corrosion. The area requires scan inspection rather than spot inspection.
- Wind girders: Another area of corrosion. Can be inspected manually from the inside on floating roofs when roof falls below girder level. However, fixed roof tanks require inspection by a robot that may be operates both in liquid as well as air depending on whether the inspection is being performed in-service or on a tank that has been emptied for cleaning.
- Under heavier deposits of sludge: Experience has shown that likely areas of corrosion in crude oil tanks are to be found in areas where there is a heavy deposit of sludge.
- Under heating coils (steam coils): The area under heating coils in crude oil tanks is a particular area of corrosion.

3.1 First indication of problem areas prior to entry.

The first inspection will be done externally with Acoustic Emission (AE) methods [6]. AE methods may only give a rough indication of problem areas. There is an uncertainty associated with AE that leaves tank users in doubt whether the problem is really there and whether an early and expensive opening of the tank (before a planned outage) is really necessary. However, the combination of AE with local deployment of UT via the inspection robot will represent an advance on AE in giving a definite answer to a tank user. A detailed state-of-the-art of AE techniques, equipment and application to storage tanks has identified two suppliers of AE. The application of these commercial systems to tank floor inspection is expensive (due to a high number of probes, typically 32, with associated 32 electronic channels required). The AE technique requires high experience of data analysis that becomes meaningful only when evaluated with reference to previous inspections and a high knowledge of tank operating conditions and history. This means that initial AE assessment of the tank before being put in service (baseline inspection), previous AE inspection, information about operating conditions and general state of the tank are essential to make sense of new results.

Other alternative techniques to AE e.g. MFL, Pulsed Eddy Current (PEC) or Alternating Current Field Measurement (ACFM) have been investigated but found to be not suitable. However, Long Range Ultrasonics (LORUS) looks promising and a decision has been made to mount two rotating long range ultrasonic probes on the inspection robot to detect hidden corrosion in areas that can only be reached with angled probes and not with 0º probes.

3.2 Inspection of clean tanks with robot immersed fully in liquid

Clean tanks will be inspected while in service and without emptying them. In this case the inspection robot is required to provide quick access to floor areas that have been identified by external Acoustic Emission methods as possibly corroded and to confirm this with Ultrasonic Testing (UT). Also, internal inspection of corrosion on the walls in wind girder areas will be performed by the same robot. Hence, the robot is required to be capable of changing surfaces from the floor to the wall and vice versa. The project is developing a mobile robot for this task and the development is reported in this section.

Operating inside a storage tank intrinsic safety grading would the most stringent, zone 0 classification, but this applies to the vapour space between the liquid level and the roof space. There is no recognised electrical classification for operating within the product because at present there are no such devices. The objective is to attain operation safety - Category 2 of ATEX Directive.

3.2.1 Module 1: Surface changing Mobile Robot

A prototype surface changing robot has been developed that is able to enter through manhole openings of 300 mm diameter, travel on the floor, rotate through any angle within the full 360 degree maximum, and change surfaces from the floor to the wall and back to the floor.

The dimensions of the mobile robot are 200x200x500 mm. The robot will operate in a pH range that is towards the alkaline side 5 to 12, in liquid temperatures from 0 to 70ºC and pressure up to 3 bar. Its weight is about 20 kg with NDT sensors and it is designed to operation on rough floor surfaces through sludge deposits up to 50 mm deep and on tank walls. The maximum travel speed is up to 150 mm/sec. The flaw detector is able to measure internal and external corrosion with a thickness resolution of 1 mm on plate thickness ranges from 6 to 25 mm.

Two servomotors provide the drive for the wheels of the vehicle while one propeller mounted on top of the vehicle provides the thrust force for adhesion to the wall. The on-board servo systems are controlled from outside the tank via a serial communications link. Trajectory control of the vehicle is by teleoperation via a Windows based software interface.

To obtain a very compact and lightweight design, a new generation of DC motors and ClickServo motor control boards are used which the reduces the umbilical size to two twisted pairs for serial full duplex communications to a remote station at a distance of 100 metres.

The vehicle design incorporates a sealed, purged and pressurised central box where the servo motors, controller cards, NDT instrumentation (24 channel TD Scan Flaw Detector), and navigation sensors are carried on-board the mobile robot to guarantee explosion proof working conditions.

Currently two shaft encoders on the vehicle's drive motors provide feedback for control of the motors. The servo controller cards use the raw signals from the encoders directly for feedback error generation. The decoder counters can be interrogated via an RS 485 serial communications cable on the Operator's PC. Software running here can compute the speed and the position of the vehicle relative to a starting position and output it to any other module when required.

The vehicle is able to travel on the tank floor while submerged in liquid (tests have been performed in water), change surfaces from the floor to a wall and vice versa, and climb the walls of a tank change direction and travel at speeds higher than the specified (150mm/sec.). It uses thrust from a propeller to provide vehicle adhesion to a vertical surface and hence is able to climb on all types of surface.

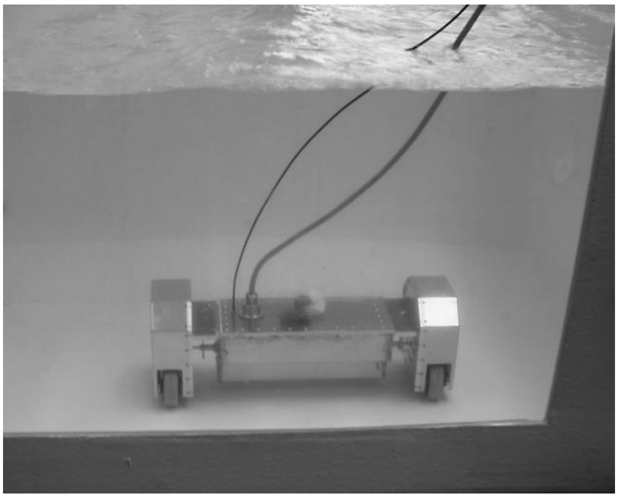

Figure 1: Robot immersed in a water tank while inspecting the tank floor

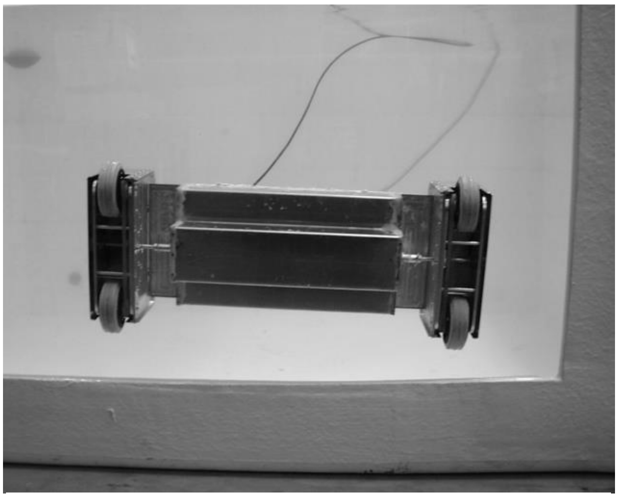

Figure 2: Robot climbing on a glass wall of the water tank after transition from floor to wall

3.2.2 Module 2: NDT Probes and Instrumentation

Research has determined a NDT sensor payload suitable for measuring internal and external corrosion with a thickness resolution of 1mm.

Two probe arrays, each 30cm long with 15 to 20mm pitch, are mounted to the front and rear of the inspection robot. The minimum detectable area is a 6mm diameter flat-bottomed hole at a range of 3 mm. A surface coverage of $3m^2$ per minute and surface speed of 10 m per minute are realisable with this arrangement. The inspection system is able to measure plate thickness between 6-25mm with minimum thickness of 3mm. Two sets of 0º (in the front and rear of the vehicle) high efficiency twin wheel probes have been developed to cope with large crude oil tank inspection difficulties and environment conditions. They are designed to European Standard EN10160 (July 1999) for the UT examination of steel planar plates. Tests on single and twin crystal probes for scanning the surface with a fluid gap or direct contact, ability to monitor wall thickness despite changes in probe orientation, size of probe, frequency of element and coverage, and the influence of sludge, sand and other tank constituents resulted in the development of a Wheel probe system consisting of a high efficiency ultrasonic inspection twin wheel probe that in the preliminary laboratory tests showed a promising behaviour working in crude oil tank environment simulations.

Two rotating bulk wave probes were developed and mounted on the two sides of the robot after research established that they will provide 100% coverage of large plate areas to give quantitative assessment. This speeds up the identification of potentially corroded areas in the plate with a look forward distance of 50 cm. Wheel probes that can penetrate debris and sludge on the tank floor provide quantitative data at the required rate. Tests show that the range of the ROBULK ultrasonic probe is approximately 1m in water, proper calibration is essential, the probe is tolerant of small coupling gaps and will work through thin sand layers albeit with reduced range. The probe can be motorized and encoded to produce a radar type B scan plot to detect the edges of tanks, welds, etc and can therefore be used for navigation. The sound wave dives under unattached obstacles and can therefore inspect under striker plates. Figure 3 shows the wealth of information that can be obtained with a rotating bulk wave probe operated in a small water tank fitted with a drain outlet, welded stud and a weld in the floor.

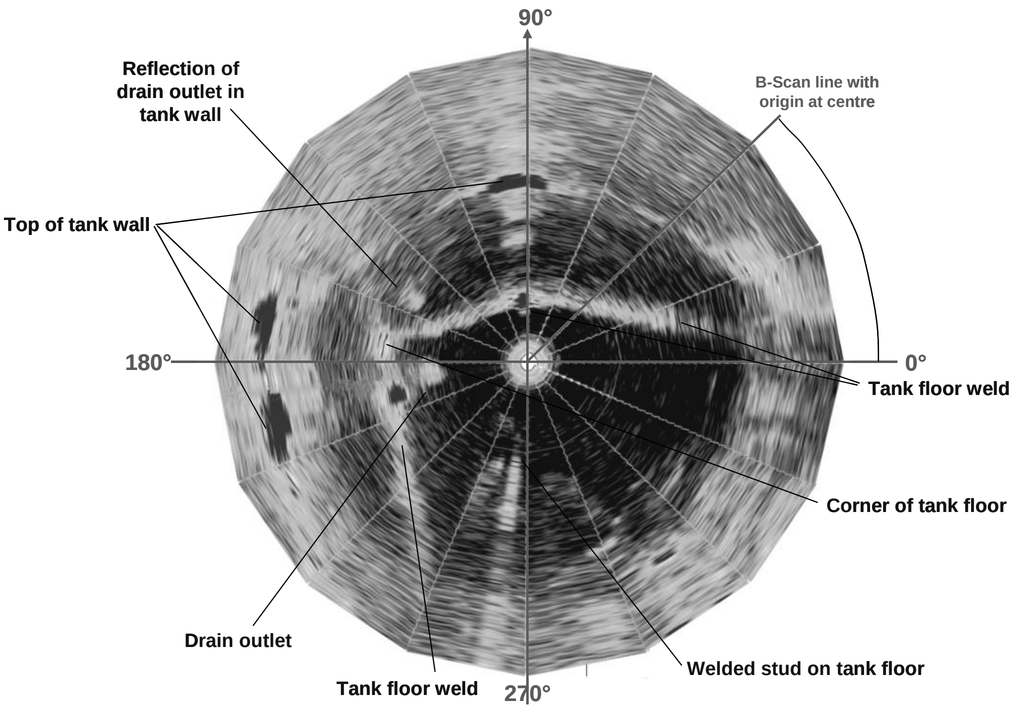

Figure 3: Linear B Scan transformed to a Rotary B Scan to clarify tank features

A commercially available TD-Scan 24 channel flaw detector with dimensions of 170x60x104 mm is mounted in the purged box on-board the robot. The TD-Pocket integrates a pulser/receiver, A/D converter, encoder inputs (the requirement is for one bi-directional input to describe forward/backward travel), and 2 unidirectional encoders to control the LORUS probes). Software for data acquisition, display and analysis in all standard NDT formats is provided. The TD Pocket uses TTL signals from one of the robots incremental encoders to position stamp the NDT data.

3.2.3 Module 3: Navigation Sensors and Electronic circuits

An Ultrasonic emitter Tower is mounted on top of the vehicle to simultaneously emit four ultra-sound signals to receivers mounted on the external wall of a tank. Each emitter is the hexamite “HE123 Underwater Ultrasonic Sensor”. A stack of three small electronics cards (overall dimensions of 100x100x60 mm) fire the ultrasonic emitters and process signals from the receivers. Four receivers on each face of the robot look out for reflections from obstacles in the tank. The system can locate the robot in the tank to within ± 0.5m.

An on-board Infrared Camera and electronics is fixed to the front of the vehicle (overall size is 70x70x185 mm) with a coaxial cable relaying images to an external monitor.

The final product will aim to meet all safety regulations for working in explosive atmospheres specified in API 653, API 575, Directive 94/9/EC (regulations CEN EN 1127-1:1997, CEN EN 50014:1997 and CENELEC EN 50284:1999) and Directive 1999/92/EC.

Surveys have identified three competitors; Maverick produced by Solex Robotics in USA, Tank Ray produced by Raytheon in the USA and OTIS produced by In Tank Services, [7-10]. On elucidating the performance of the two USA prototypes from conference reports it turns out that the range of tasks that they can be used in is severely restricted by the large physical dimensions of these robots. Also they cannot climb tank walls. The NDT is limited to plate thickness measurement which is not possible to do on the real problem areas such as corrosion under the tank walls, corrosion under striker plates and under overlapping plates. Hence, the Rob Tank robot will be an advance on these floor inspection robots.

3.2.4 Module 4: Umbilical and Deployment/Retrieval System

Manufacturers of equipment for off-shore environments recommend a copper cable which is more robust than optical fibre and has the required bandwidth for data acquisition. The design of a system to deploy the umbilical is progressing. The cable will be supported by buoys on the product surface. The system will seal the entry position avoiding no escape of product vapours and will provide movement on demand from the vehicle. The cable will be supported on a single pulley and pass through a cleaning chamber to remove product residue. A winch mechanism will be based on the ground and a method for deployment, cleaning and retrieval of the robot is under design.

The cleaning chamber removes product residue and also cleans the cable before it enters a tank to avoid contamination especially in the case of the chemical tanks. It is envisaged that the tether will be incorporated into the outer sheath of the umbilical cable and connected to the robot vehicle in 2 positions. Deployment and recovery would therefore be of a single coil, removing the problem of possible entanglement.

4 FIELD TRIALS

Three Petrogal tanks have been selected for field trials. A fire fighting training tank will be used to assess the ability of the robot system to work within oil products environment and depending on availability two industrial water tanks will be used to perform NDT inspection of tank floor and walls, navigation and obstacle avoidance tests. The tanks have been emptied, cleaned and a complete assessment and comparison of different inspection techniques carried out. The performance of the Rob Tank robot will be compared with these results.

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