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Materials and Coatings Damage Resulting from Environmental Degradation Aboard Naval Ships

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ABSTRACT

Maintenance and preservation of seawater and fuel, ballast tanks and voids resulting from the environmental degradation of coatings present a unique and costly problem for the United States Naval Fleet. Present methods of inspection require human entry into the tanks only after a series of measurements have been taken to ensure safety. With the advent of remotely operated vehicles and cameras having a high level of accuracy and functionality, it has now become economically feasible to employ these instruments for the inspection of tanks and voids of the United States Naval Fleet. This paper presents two unique remotely operated inspections systems, which allow for unmanned inspection of tanks and voids along with quantitative results of the damaged coating areas.

Keywords: Coatings, environmental degradation, unmanned inspection, tanks, voids, damage control, galvanic corrosion, corrosion detection algorithm, remotely operated paint inspector, insertable stalk imaging system, corrosion detection

1. INTRODUCTION

Shipboard tanks and voids makeup a significant percentage of below deck space and are necessary components for normal operation for primarily seawater ballast control, damage control, compensated fuel, and fuels storage. The size and quantity of these tanks vary considerably for each class of ship, with the typical number of tanks per ship in excess of 300 for carriers, 46-77 tanks for cruisers or destroyers, and 90-153 tanks for amphibious assault ships[1,2]. Operationally, each tank may need different degrees of service depending on mission requirements, thus creating widely variable maintenance concerns.

Due to the nature of these tanks and the medium that these carry, combined with dissimilar metals in the tanks, there is a strong possibility for galvanic corrosion to occur. These tanks utilise both a surface coatings system and a sacrificial zinc cathodic protection system to minimise coating degradation and to negate the effects of galvanic corrosion, which could damage the structural steel in the tanks. As a result of the severe environment encountered

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by these tanks and voids, up to 50 per cent of tank maintenance is due to hidden damage or unplanned work Error! Bookmark not defined. Thereby, the US Navy maintenance for seawater ballast tank and other tank preservation costs continue to increase, and is also concurrent with a corresponding increase in the time interval between overhaul cycles.

The tank configuration and geometry are often unique for each tank, and maintenance is complicated by complex structural members, T-beams and baffles. The working conditions inside the tanks are often difficult and provide less than ideal coatings quality assurance scenarios. At present, tank inspection requires the tank to be manually opened, gas freed, staged (if necessary) and cleaned in preparation for the coatings inspector. The objective of the coatings inspector is to evaluate the overall and localised conditions of the tank, concentrating on overall tank integrity, coating condition, and sacrificial zinc protection system. As might be expected, coatings inspections vary widely in determination and quality. The current criteria for differentiating tank condition, and required action states, that all tanks with more than 3 per cent damage require complete refurbishment (blasted and recoated). The error factor in typical human inspectors is ± 5 per cent, therefore significant funds may be expended due to rehabilitating tanks that are actually within the 3 per cent criteria, but are reported to have 3 per cent to 8 per cent coating damage. On the other hand, a conservative damage assessment of a tank with a large amount of damage could require costly structural repairs.

The maintenance of tanks involves more than just repainting the surfaces, because tank inspection and assessment alone requires the need for manual opening, gas freeing, staging (if necessary) and entry of trained personnel. Presently, 4000 tanks of the US Naval Fleet are inspected annually, at a conservative cost of $32 million/year, with the average cost of an individual tank inspection at approx. $8-15 thousand. Error! Bookmark not defined. For this, tank inspections are performed at least once every dry-dock cycle, or nominally at least every 5 to 7 years, depending on the service or ship class. Once tanks are identified for refurbishment, costs escalate to over $250 million/year to perform tank maintenance for the US Naval Fleet. This represents only a small percentage of the 20,000 Navy tanks in service. Of these costs, which provide for staging, surface preparation, and coatings application, dollars should be spent on those tanks in the worst condition. The installation of a new tank coating system costs on an average $300K/tank, and for cases in which there is structural damage, another $300K on an average is expended[3].

2. REMOTE TANK INSPECTION SYSTEMS FOR TANKS & VOIDS

As a result of NAVSEA initiatives in Engineering for Reduced Maintenance (ERM1) and Capitol Improvement for Labour (CIL) tanks and voids, development of a smart remote inspection system has taken place concurrently by way of a remotely operated vehicle called the remotely operated paint inspector (ROPI) and an insertable stalk inspection system (ISIS). Both these systems incorporate an optical camera, a lighting package, a image analysis software, and a tank-ranking software. These systems provide quantitative measurements and visual data, similar to that which a tank coatings inspector would collect, but with increased objectivity, trending capability, and significant cost savings over manned tank entry. These systems, when used either stand alone or as part of a corrosion-sensor monitoring system, provide an objective visual analysis of tanks condition and a quantitative evaluation of coating integrity.

2.1 Insertable Stalk Inspection System

The hardware components of the ISIS have been developed by the Everest Inc, New Jersey. This system, shown in Fig. 1, incorporates a CCD camera, a 70W lighting, a hatch-mountable pole (stalk) for camera insertion, and a video recording device.

Logistically, the ISIS was developed from the standpoint of an inspection team that may remotely inspect a bank of tanks from a single location with one or two hatch-mounting points per tank. This was intended to maximise optical coverage of singul

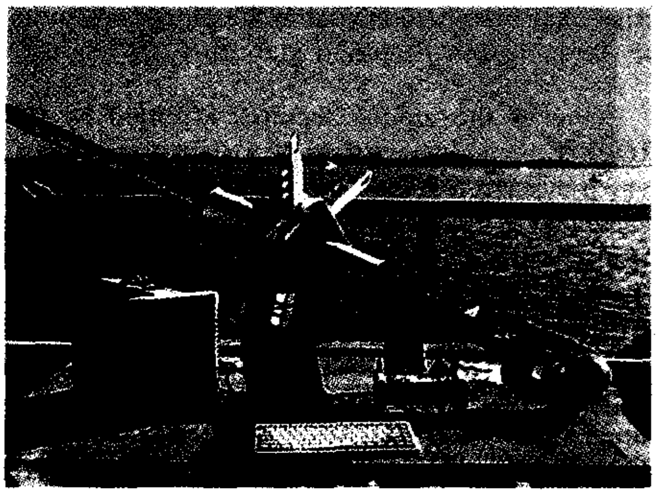

Figure 1. Complete insertable stalk inspection system

tanks and the number of tanks that may be viewed from a single location so that manned entry and time to move from tank-to-tank may be minimised. The hardware was also designed for increased modularity and compactness so that movement to other locations is unimpeded. This system consists of a titanium hatch mount, 30.48 cm (1′) titanium stalk segments, which may be quickly connected together in any length configuration, and a camera-mount armature, all of which are easily collapsible and stowed in a lightweight backpack. This method of transport makes access to tank hatches easier, particularly due to the fact that many hatches are in confined quarters.

One of the important attributes of the ISIS is that it may be utilised to evaluate tank status in both deballasted (Fig. 2), and ballasted tank states. As a consequence, there is no need for costly in-port deballasting and flushing of tanks. In addition, tank surfaces that are either mission-critical or require extra analysis, may be evaluated at an enlarged view, via the zoom feature. Where tanks are ballasted, the ROPI may be inserted for additional evaluation.

During any given tank inspection, the ISIS is inserted up to 2.74 m into the tank through a personnel entry hatch and is mounted on to the hatch. The operator then records high-resolution images (stills) and video of all tank surfaces for subsequent analysis with the corrosion detection

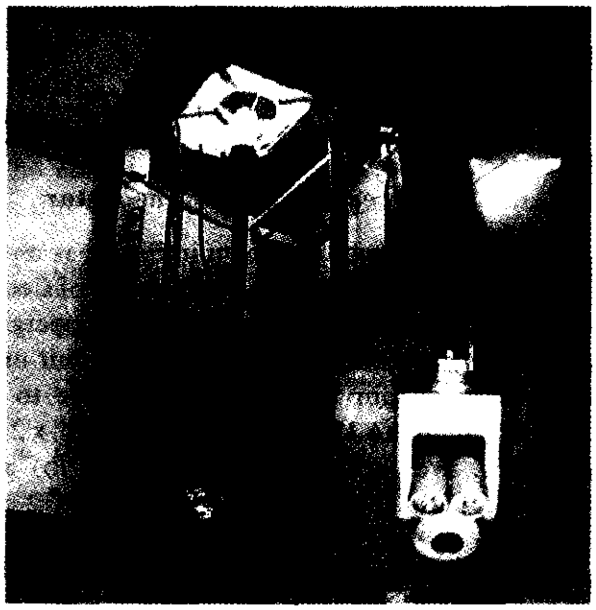

Figure 2. Insertable stalk inspection system being tested in the full-scale ballast tank mock-up.

algorithm. The system is configured so that digital video is recorded for archiving and reference for maintenance personnel. More importantly, the still images are utilised for analysis by the corrosion detection algorithm. It has been approximated that the line-of-sight approach to tank inspection utilised by the ISIS may provide between 80-90 per cent coverage (for a two-position inspection) of all tank surfaces, depending on the size and number of obstructions. Of particular concern is the overhead areas which are the classical locations for severe damage, specifically on the backside of the flange on overhead structural T-beams, which are difficult to insure proper surface preparation and coating application. These locations cannot be viewed directly in many cases, thus creating an error source for the ISIS. To date, this issue has been addressed by making the assumption that failure at these sites is first initiated by attack at the edges of the T-beams, where the coatings are the thinnest. Given the latter, it may be assumed that if severe attack is noted visually on T-beam edges, then the posterior flange faces are also damaged.

The ISIS is presently in use by the Naval Research Laboratory, USA, in the US Fleet and has been deployed on several ships, including the

USS CLEVELAND LPD-07, USS SAIPAN (LHA2), USS WASP (LHD1), USS COMSTOCK (LSD45), USS PORTLAND LSD-39, and USS KINKAID (DD965).

2.2 Remotely Operated Paint Inspector

The ROPI system, as shown in Fig. 3, is under cooperative development with Inuktun Inc, of Cedar, Canada, and is essentially a mini remotely operated vehicle. Any remotely operated vehicle unit used as a tank inspection system must be able to be deployable through a 33.02 cm x 53.34 cm (13″ x 21″) tank hatch. Weighing only 3.629 kg (8 lb) and being only 35.56 cm x 22.86 cm x 20.32 cm (14″ x 9″ x 8″), the ROPI is ideal for use in tanks that are ballasted and have numerous obstructions, such as baffles and plumbing, which would prevent useful implementation of the ISIS. The anodised marine-grade aluminum ROPI is outfitted with an auto-hover system that allows for smooth vertical evaluation of tank surfaces and a forward speed of 1-2 knot. The auto-hover feature allows for a (5.08-7.62 cm) resolution jog in the vertical direction for each toggle of the depth control once the system has been placed in auto-hover mode. A total 340 W of lighting, including two standard 20 W lights and two 150 W auxiliary lights with intensity control, are included onboard for adequate lighting in a variety of conditions. As in the ISIS, a zoom-operable CCD camera is also housed onboard. This Sony camera, equipped with autofocus, displays crisp imagery which is vital to the proper operation of the corrosion detection algorithm.

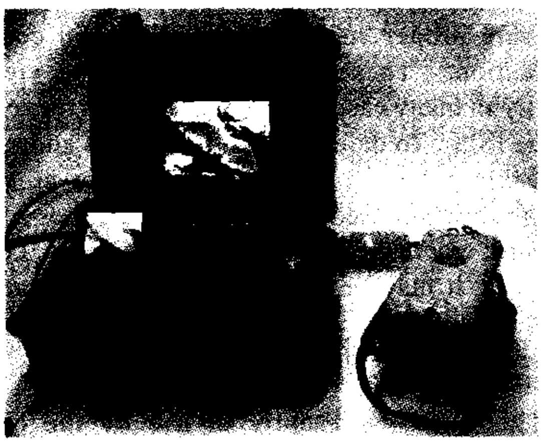

Figure 3. Remotely operated paint inspector

One of the unique features afforded by the ROPI is the inclusion of dual-reference electrodes, which measure the tank condition from a corrosion standpoint. These corrosion sensors provide a number of advantages over both the Navy-patented corrosion sensor and the ISIS, in that (both) a global view of the tank condition and a highly localised measurement may be obtained in mission-critical spaces. The data obtained from the reference electrode are integrated with the video so that the condition is immediately viewable with the image on a video overlay display on both the lid-mounted LCD display and on the digital VCR LCD display. The digital VCR is a Sony GV-D900, integrated into the control console and responsible for recording inspections onto a standard 60 min digital video cassette. In addition to the reference electrode overlay, the overlay also features heading, depth [accurate to 30.48 cm (1′)], time, date, and focal range of the camera, if the operator feels it necessary to view these parameters.

Presently, this system is in the midst of redesign to accommodate a number of additional desirable features. Firstly, it is evident that since the mission of this system, which differs substantially from the conventional remotely operated vehicle platform, requires superb videography, the stability and manoeuvrability are critical; note that these also affect the ability to swim highly-baffled tanks, as seen in Fig. 4, which are ~ 40.64 cm diameter. Specifically, the current ability to translate vertically (auto-hover) will be expanded to include the horizontal plane, as well, so that entire tank wall may be mapped intelligently. Secondly, the current system is fixed with a 7.62 m, neutrally buoyant tether. Initially, scientists of Naval Research Laboratory, USA, thought it would be necessary to have a rear facing, black and white camera, along with rear auxiliary lights. After hours of testing in simulated baffled tank areas, it has been determined that these features are not necessary and have consequently been removed. Now that the power requirements for the vehicle have been reduced, the overall cable diameter can now be reduced, allowing for further

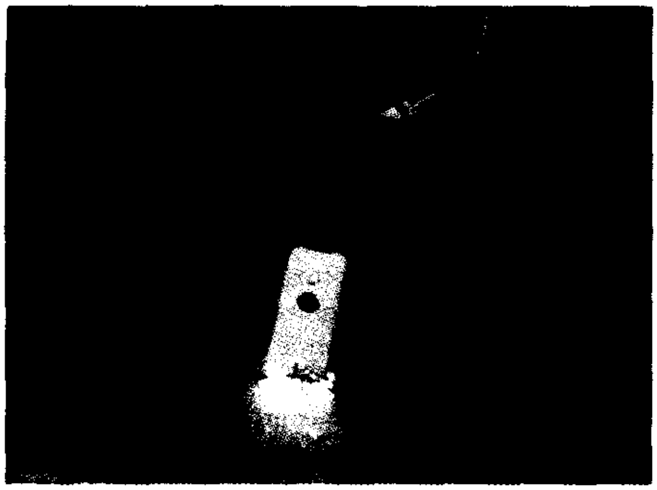

Figure 4. Remotely operated paint inspector being manoeuvred through a simulated baffled ballast tank mock-up at the NRL, Florida.

mobility of the system. The cable rigidity and buoyancy are the top priorities on the redesign of this system.

Another feature to be added is a semi-auto ballasting feature. Since seawater density is seasonally variable and the ROPI may be deployed in more than one geographical location, mission-specific auto ballasting is necessary, critical to stable videography. Finally, it is possible that a pycnocline may be encountered, which would create difficulties for such a small platform. In an effort to minimise on-site labour and difficulties, the semi-auto ballasting feature should add both stability and versatility.

3. CORROSION DETECTION ALGORITHM

Finally, an image analysis algorithm called the corrosion detection algorithm has been developed which is intended to provide an analytical tank assessment. The computerised video images recorded via either the ROPI or ISIS, are transferred to a computer, which uses proprietary and state-of-the-art technology to provide the coatings inspector with a per cent damaged coating. Using ROPI and ISIS in conjunction with the image analysis algorithm, it is expected that a repeatable and objective evaluation of the coatings damage may be achieved. This represents a significant development in tank coatings inspection since to date, human inspectors have been expected to accurately distinguish tank damage from 0 to 10 per cent within 1 per cent of the actual. This ability is not only difficult, but is subjective, especially where different inspectors are involved.

The corrosion detection algorithm comprises four major steps beyond the acquisition of images:

Step 1. Image preprocessing

Step 2. Edge detection

Step 3. Data fusion and damage visualisation

Step 4. Damage quantification

During image preprocessing (*Step* 1), a wavelet-based de-noising method is employed to remove noise in the raw image data that results primarily from the low-level lighting and large surface areas acquired from the inspection. The de-noising method specifically removes this noise, while only minimally affecting other image edges that is important to corrosion detection.

Following de-noising, *Step* 2 of the corrosion detection algorithm employs wavelet-based edge detection, which first creates two images that represent the strongest edges, in the horizontal and vertical directions, respectively. These are then size-filtered to remove the edges associated with larger objects, such as pipes and ladders (and places where two walls meet). Next, these edge representations undergo Boolean operation so that images are anded and added to create the edge imagery that are used in the *Step* 3 of the automatic-corrosion detection algorithm.

Fusing the results of the edge detection (*Step* 2) with additional information results in the output of a binary image where pixels associated with areas of corrosion in the original image are assigned the value 1, while other pixels are assigned the value 0. To accomplish this, information from the and image, the add image, a gray scale image (a gray scale depiction of the original image) and a colour image (the original image) are fused. The binary images that are created during *Step* 3 adequately represent the corrosion and its spatial distribution in the original image.

The damage quantification by the corrosion detection algorithm involves assigning per cent corrosion value to the analysed image. This is performed by simply dividing the number of on pixels by the total number of pixels that are in the binary image generated during data fusion and damage visualisation (*Step* 3).

To avoid any speculation on the accuracy of this corrosion detection assessment, Naval Research Laboratory, USA, has tested the corrosion detection algorithm in a laboratory environment. A uniform surface with a known surface area, simulating a newly painted tank surface, was videoed. Numerous areas of simulated damage with known surface areas were introduced onto the uniform surface to simulate coatings damage. These areas, ranging in increments from 0 per cent damage, wrt the uniform surface, up to a total of 10 per cent damage were videoed and then run through the corrosion detection algorithm. The output of both the edge detection routine and the gray scale routine can be seen in Figs 5 and 6. Following along those lines, Figs 7, 8, 9, and 10 are actual frames captured from video taken aboard the USS SAIPAN in May 2001 and run through the corrosion detection algorithm. These are the fused output from both the edge routine and the gray routine. Knowing that the corrosion detection algorithm can output an accurate damage assessment in a controlled environment, gives confidence in its onboard performance. It is important to note that the algorithm discerns between edges introduced due to a failed coatings system and edges inherent in a tank due to structural members (T-beams) and corners (adjoining walls).

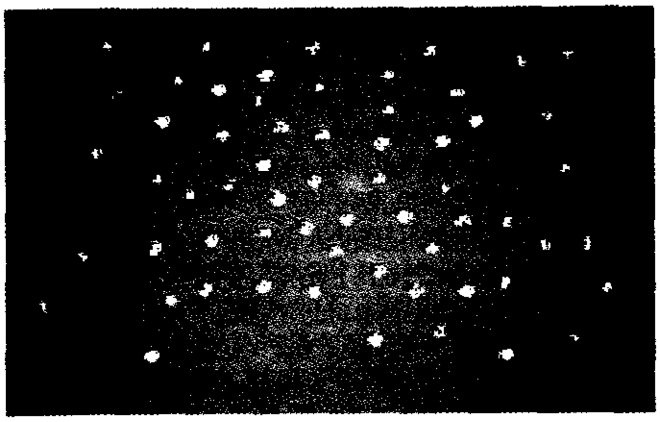

Figure 5. Edge algorithm output routine from 1.5 per cent calibration panel.

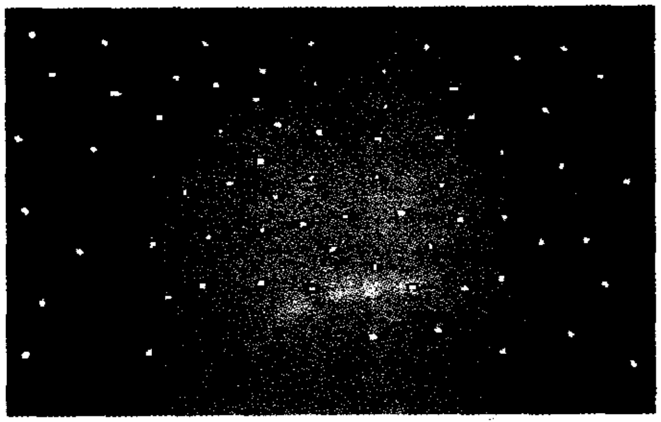

Figure 6. Gray scale output routine from 1.5 per cent calibration panel.

Figure 7. Processed image of overhead in seawater ballast tank.

Figure 8. Fused output of Fig. 7 with a damage assessment of 0.8 per cent.

Figure 9. Processed image of bulkhead in seawater ballast tank.

Figure 10. Fused output of Fig. 9 with a damage assessment of 2.4 per cent.

Also, a distinction is made between the actual corrosion damage and staining from rust.

4. CONCLUSIONS

The remote tank inspection instrumentation and methodology is also an ongoing effort. The ISIS system is nearly complete from a hardware perspective and has been deployed on many ships to date. The ROPI system, to reach full potential, will require further advancement, particularly through certification, for use in fuel-carrying tanks. Current testing continues with this system at the NRL Key West Test Site to understand the problems that will be encountered when this system is finally introduced into the US Naval Fleet service. These systems will provide the US Naval Fleet the ability to quantitatively inspect tanks for a fraction of the cost of conventional methods, thereby saving a huge amount of money in maintenance of the overhead.

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