Position Tracking of Magnetic Flux Leakage Steel Floor Inspection Equipment inside Large Drained Out-of-Service Above-Ground Liquid Petrochemical Storage Tanks

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Above-ground Storage Tank Service Life

Large above-ground storage tanks (AST) such as in Fig. 1 are employed along supply lines of oil and liquid petrochemical products to handle fluctuations in supply and demand. Typical ASTs are sheets of carbon steel welded into vertical standing cylinders of 6 to 120 meter diameter that hold 100 to 10,000,000 oil barrels. Carbon steel corrodes with exposure to common outdoor conditions and the stored product, causing damage that risks leaks, product contamination and loss, work-site hazards, environmental disaster and ultimately limits the service life of ASTs.

Figure 1: A typical AST this paper is concerned with (aprox. 12,600 oil barrels, found in North Fermantle, AU)

Inspection and maintenance of ASTs is often costly and mandated by consumers and local governments. However, as Pearson, Mason and Priewald show in Fig. 2, maintenance does increase the service life of ASTs and so increases the ultimate profit for the operator, and research has indicated that there is yet more improvement to be had from improving current methods and developing new ones.

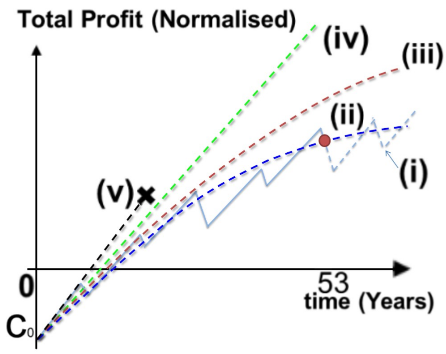

Figure 2: Operational profit profile offered by maintenance schemes:
(i): Example AST
(ii): Traditional out-of-service
(iii): Enhanced out-of-service
(iv): Continual in-service
(v): No maintenance

Maintenance of the interior of the shell and roof, and particularly the floor, are not feasibly accessed by workers unless the AST is brought out-of-service, so that the tank may be drained and prepared for maintenance operations from within the AST. This is hugely costly from loss of revenue and operational costs, so alternatives such as aquatic robots (which require additional installation) and ultrasound scanners installed in the flooring during construction are being investigated. However all are uneconomical for older ASTs that will potentially not last many inspections before being deemed too costly to repair and decommissioned.

Therefore, Silverwing NDT and this paper are concerned with improving current AST MFL inspection methods by developing position tracking software for some of Silverwing's larger magnetic flux leakage (MFL) scanning devices used to inspect the flooring inside out-of-service tanks, hoping to improve inspection and analysis time and accuracy and so reduce operation costs and out-of-service time. MFL is fast enough to offset the associated costs and delays of its inferior accuracy to technologies like ultrasound scanning.

Tank Inspection Procedure and Environment

Figure 3: 2 technicians using MFL scanners inside an AST: the smaller handscan (left) and the more advanced FM3D (right)

First, a review of traditional maintenance procedures is conducted. This describes the use of MFL scanners on the interior faces of a drained and cleaned AST, the specific MFL scanning devices in question, and the conditions inside an AST that any position tracking system would have to work and cope with. As seen in Fig. 3, this can be summarised as a push trolley that moves in a very straight line and must be lifted with some effort to cross steps and turn, inside a dark, laterally spacious, closed, largely (but not entirely) featureless, dry, metal cave with mostly smooth surfaces made of ablated or abutted welded coated or bare steel sheets with technicians using battery or portable generator powered inspection and repair equipment.

The MFL scanners are noted to already measure their own straight line distance travelled and move themselves at their own required speed, and it is emphasized that any position tracking system would be working to compliment the shortcomings of this existing system.

Evaluation of Available Tracking Technologies

Then, a selection of current technologies that measure distance are reviewed for their suitability to the challenge of calculating, tracking and plotting the location and movement of an MFL scanner inside an AST. In summary:

- Accelerometers – an integral system, meaning each measurement is the integral of all measurements since the first measurement, so errors accumulate, poorly complimenting the jockey wheel, which is also an integral system.
- GPS – no GPS satellite signal inside tank due to steel walls.
- EM navigation (RADAR, LiDaR, LORAN, Ubisense) – too inaccurate as the mandated <10mm resolution would require a >30GHz sample rate.
- Wiimote and other Camera based technology – currently cannot cope with the dirty industrial environment and inconveniently requires that the camera always face the LED array with an unobstructed view.
- Interferometry – very expensive, very flat, very clean mirrors required.
- Measuring lines with tachometers – forms a trip hazard that unacceptably lowers workplace safety, and struggles with obstacles.
- Ultrasonic Echolocation (SONAR) – air currents, temperature change and rebounds distort measurements, causing inconsistency, and questionable whether it would be able to reach the walls from the centre of a 60m radius AST.
- Ultrasonic Beacons – ultrasound is a mature and inexpensive technology for this purpose and is less affected by the problems of echolocation.

The conclusion of the review is that only ultrasonic beacons are suitable for the budget that would keep AST maintenance profitable, and so a strategy for how best to use this to locate and track the MFL scanners in an AST is persued. It concludes with a system based on how children are taught to count the seconds between the flash of lightning and the sound of its thunder to work out how far away the lightning struck. A beacon is placed on the MFL scanner, with multiple identical beacons surrounding. One at a time, beacons emit simultaneous pulses of radio, which are assumed to reach every beacon in the AST instantly, and ultrasound, which arrive a measurable time after. This measured time of arrival of the ultrasound pulse after the radio pulse correlates linearly with the distance the receiving pulse is from the transmitting pulse. The major advantages of this system are the low cost and simplicity of the beacons, the capability to track more than one moving beacon in the network, and the ease of compensating for knocked over or dying beacons.

Testing Ultrasound and Radio Beacons

It was then decided that this proposed system needed testing, so a test system of 1 receiver and 1 transmitter was built on a breadboard and controlled with Arduino Unos to test the range, accuracy and reliability of a single measurement. The test is carried out in an electronics laboratory, where it is found that despite the crude ultrasonic transmitter and receiver circuits, the test system performs above expectations, remaining linear, accurate and reliable over 6 meters. It should be noted that this was largely an audio engineering challenge performed by an undergraduate with no experience in audio engineering. Test results become unrepresentative as the lab the test was performed in was only 7 meters long and had immovable desks surrounding it, skewing results.

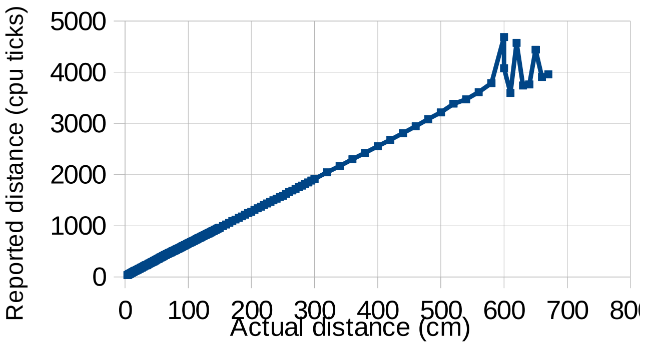

Figure 5: Demonstration of linearity and range of test system.

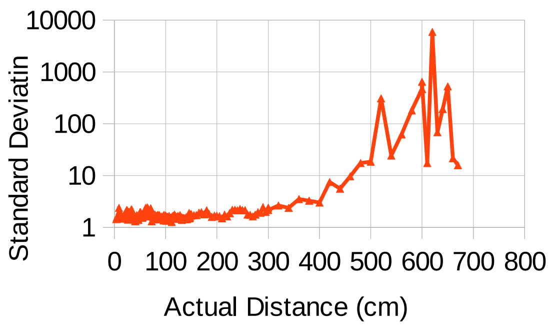

Figure 4: Standard deviation of each measurement demonstrates consistency of individual measurement (note the log scale)

Conclusions

To conclude, there is ongoing research into alternate materials and designs to steel ASTs, and there is ongoing research into alternate methods of extending AST service life, including alternate maintenance strategies, all of which are likely to render the improvements investigated in this report obsolete in the long run. However, in the short run, that research has yet to produce results, or requires installation that does not pay itself back for most ASTs in use right now. It is the opinion of this paper that a single inexperienced undergrad with a budget of <£100 was able to engineer a crude test system within 6 months that was almost accurate and reliable enough to meet the requirements of the real system, and so therefore a small team of professional audio, radio and software engineers with a budget of <£10,000 should be able to develop and deploy an inexpensive system that is capable of producing real results for Silverwing NDT within another 6 months.