NONDESTRUCTIVE INSPECTION OF ABOVE GROUND STORAGE TANKS

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Abstract The present paper discusses the nondestructive inspection techniques currently available for the inspection of above ground storage tanks and the authors' experiences in the inspection of oil storage tanks of size ranging from 8 to 18meters diameter and height of up to 17 meters in Papua New Guinea. Application of various inspection techniques such as visual, ultrasonic thickness measurement and flaw detection, penetrant, magnetic particle, magnetic flux leakage etc., their advantages, and limitations are discussed. The application of robotics for data acquisition in the tank is also discussed. Inspection carried out on various oil storage tanks reveal that sudden and catastrophic failures can be prevented if a documented inspection program is utilized from the design stages and continued through out the service life of the storage tanks.

Keywords: Aboveground storage tanks, Nondestructive inspection, Robotics

INTRODUCTION

Storage tanks are found in almost all industries such as petroleum, chemical, fertilizer, and power. Much of the industrial development and prosperity has been achieved from its ability to process and store the natural resources of the world [Mark, 1991]. Safe operation of the tanks during its service is a grave concern to the industries and the communities that surround these massive storage facilities.

Corrosion is the single biggest cause of failure in tanks. Only in exceptional cases the tanks are designed for corrosion free and therefore some allowances has to be added to the design stress of the tank thickness to compensate for expected corrosion rates over the planned life of the tank. Problems will arise if this allowance is insufficient, or more commonly if the unexpected changes to the tank operation occur. Even a change in the source of fluid supply can have a detrimental effect. There are many degradation phenomena that affect the health of tanks, which include normal corrosion and erosion processes and abnormal occurrences.

Corrosion can be controlled by careful material selection, design and the application of electrochemical methods. By establishing a comprehensive inspection program, much of the natural corrosion and erosion can be detected long before it becomes a hazard to a safe work place.

The authors have carried out nondestructive testing on many aboveground oil storage tanks in Papua New Guinea. Some of the important and typical aboveground storage tanks nondestructively tested are:

* Aviation gas storage tank, 402 m^3 capacity, 8 m diameter, 8 m height, wall thickness-shell & roof of 6 mm with floor thickness of 8 mm.

* Petrol storage tank, 4330 m^3 capacity, 17.5 m diameter, 18 m height, wall thickness - floor 6 mm, shell bottom strake 16 mm, middle strakes 12 mm, top strakes 6 mm with roof thickness of 6 mm.

* Diesel storage tank, 4200 m^3 capacity, 18 m diameter, 17 m height, wall thickness - floor 6 mm, shell bottom strake 16 mm, middle strakes 10 mm, top strakes 6 mm with roof thickness of 5 mm.

Our experiences in testing of these tanks using visual inspection (VT), Penetrant testing (PT), Magnetic particle testing (MT) and Ultrasonic testing (UT) are discussed. Magnetic flux leakage, an advanced NDT technique developed to detect the under floor corrosion in tanks is also discussed along with suggestions for improvement in the following sections. Advantages of using robotics for tank inspection in general with a few robotic scanners that are currently used for testing and mapping the results are also discussed for the benefit of readers.

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NONDESTRUCTIVE INSPECTION TECHNIQUES

Nondestructive inspection (NDI) has a well-established role in the maintenance of aboveground fluid storage facilities [Stephen and John, 1991]. The purpose of NDI in tanks during its service is quite different to the purpose of NDT during its fabrication and manufacture. Inspection of tanks during service involves detection of corrosion, wall thinning and associated failures. With the advancement of computer and instrumentation technology, NDI techniques have developed rapidly into highly reliable inspection tools. One of the most important advantages is the increased accuracy and reproducibility of data [Mark *et al.*, 1993]. Further, mechanization of inspection techniques greatly improved reliability, possibility of full coverage and availability of a complete inspection record, which greatly improved the condition monitoring of tanks. Our experiences in testing of these tanks, application of ultrasonics and other NDI techniques are discussed below.

Visual Inspection

Visual inspection (VT) is probably the first method of NDI employed by inspection personnel and it continues to be the most widely used of all NDI methods. It provides a means of detecting and examining a variety of surface flaws such as corrosion, contamination, surface discontinuities etc. in tanks. VT should be applied before all thickness measurement is carried out. Depending on the accessibility and sensitivity requirements, VT is conducted as direct visual examination or using aids such as mirrors, magnifying glass etc. Some of the anomalies that were detected during a VT on some of the tanks inspected are:

* Blister- rounded elevation of surface associated with blister corrosion

* Pitting - small craters on the surface

* Scratch - shallow mark, groove or furrow on the surface

* Discoloration - a change in the normal color of the surface

* Dent- a surface mark caused by sharp tools

* Gouge - material gouged out from surface

* Pinholes- fine holes open to surface, caused due to corrosion

Usual discoloration and blisters that were observed on tank surfaces and floors during our inspection are shown in Fig.1. Like other NDT methods, VT should also be performed in accordance with a written procedure to obtain reliable test results.

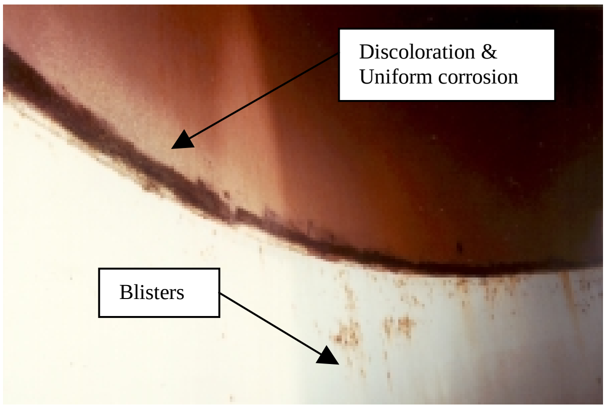


Fig.1 Photograph showing discoloration, blisters and uniform corrosion in one of the tank walls

Ultrasonic Thickness Measurement

Ultrasonic has been used to monitor corrosion and wall thinning of tanks and plant components for more than forty years. Today's ultrasonic devices are solid state and remain stable under variety of temperature environments unlike the earlier devices, which drift as the unit warms up. Transducers have also improved from the original quartz based devices. Today's artificially polarized ceramics provide vastly improved performance characteristics that enable accurate measurement of wall thinning of tank walls.

There are three types of instruments used for testing tanks. The thickness meter, flaw detector and automated scanner.

Thickness meter: This device is available in a number of forms. Most of the meters used today are digital and are very compact battery operated devices. Many of the units available have data-logging capability and most use dual transducers.

Flaw detector: The portable flaw detectors are relatively small and lightweight. Some of these have digital read out capability in addition to a time base trace which, may either be analog or digital. An ultrasonic thickness testing of a tank floor using microprocessor based ultrasonic equipment with A-scan is shown in Fig. 2.

These instruments can be used for thickness testing with conventional compression or angle beam transducers for flaw detection of welds in the tanks and associated pipelines. Transducers are the key component in the testing instrumentation. The importance is that the required result (range and accuracy) must be achieved. In general two forms of transducers are used for the measurement of corrosion thinning of tanks, either single or dual crystal units. Transducers of narrow band, wide band, varied damping, and focused are available for specific applications. Typically, lower frequencies are used to optimize penetration when measuring thick, highly attenuating, or highly scattering materials, while higher frequencies are suitable to achieve good resolution in thinner, non-attenuating and non-scattering materials.

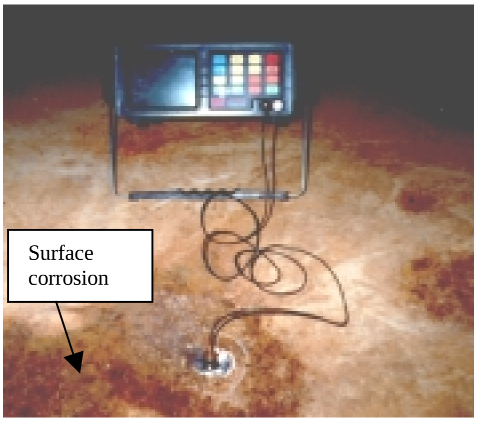


Fig. 2 Ultrasonic instrument with normal beam probe placed on the wall floor to measure the remaining wall thickness

Fig. 3 shows the CRT pattern obtained from the tank floor using a transducer of 2.25 MHz frequency, 12.5 mm diameter. At the same spot measurement was also taken by using a transducer of 5.0 MHz frequencies, 12.5 mm diameter (Fig.4).

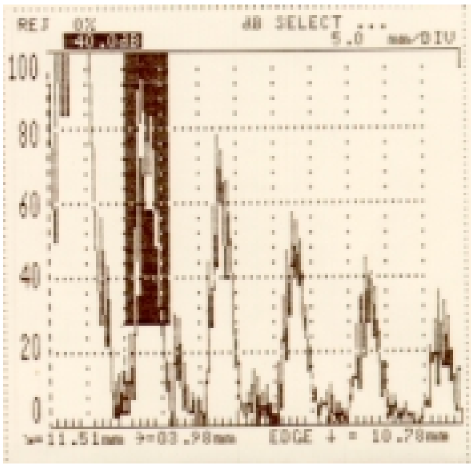


Fig.3 CRT pattern obtained from tank floor by using 2.25 MHz transducer

The 2.25 MHz transducer measured the floor thickness as 10.78 mm where as 5.0 MHz transducer measured the thickness as 10.55 mm. At the same spot digital ultrasonic thickness gauge indicated the floor thickness as 10.56 mm. It is obvious that the resolution obtained from the higher frequency transducer was superior than that obtained using 2.25 MHz transducer.

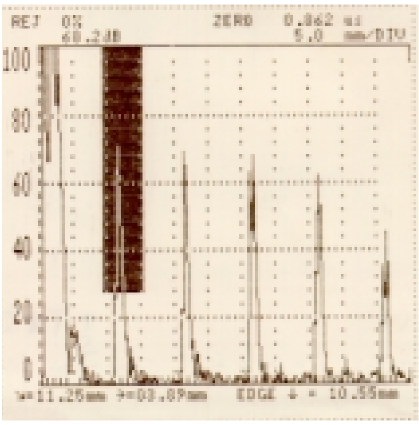


Fig. 4 CRT pattern obtained from tank floor by using 5.0 MHz transducer

Ultrasonic thickness testing with A-Scan displays often are preferred to digital displays because of its ability to display information from low amplitude signals and waveform characteristics. This often allows the inspector to distinguish between true wall loss and pattern of corrosion and irregularities. The inspector can also detect an interface at tightly adhering corrosion product. Such corrosion product might be included in the thickness display. Figure 5 show the CRT pattern obtained from a tank, under-floor corroded region. At this region the ultrasonic digital thickness gauge gave erratic readings from which the real thickness of the floor could not be obtained. Testing on this spot using ultrasonic flaw detector revealed the irregular back surface of the tank leading to multiple scattering and multiple echoes. The minimum remaining wall thickness of this region as 5.85 mm as measured by the ultrasonic flaw detector.

When the tank wall is epoxy lined, the thickness measurement is difficult. The lining should be removed at selected spots in order to obtain reliable thickness measurements. The weld joints in the shell plates are also important to inspect periodically to insure that they are free from any flaws and erosion. Ultrasonic angle beam examination is used to test the welds in the tank.

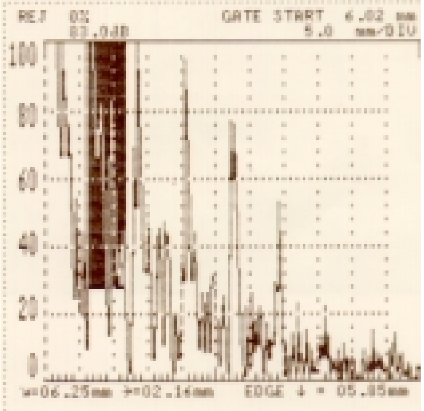


Fig. 5 CRT pattern shows multiple echoes due to irregular under-floor corrosion

Prior to carrying out the testing of tanks, it is essential to carry out calibration of the instrument using a reference standard matching the acoustic properties of the tank material. Acoustic velocity can vary significantly between different types of materials, and even different form of same materials. Trying to keep a supply of calibration blocks for each material type and grain structure would be difficult. Fortunately in the case of corrosion monitoring of tanks, the concern is more on the rate of corrosion i.e., the loss of wall thickness over time and hence with the available instrumentation an accuracy of 5% in absolute thickness can be easily achieved [Rusing and John, 1993].

Another important aspect of ultrasonic testing is to establish a proper procedure taking into account the service requirement of the tank. The procedure for ultrasonic equipment with digital displays must include requirements to follow-up and questionable measurements with suitable analytical equipment in case equipment with digital display is used for data acquisition. The ultrasonic technician shall be able to distinguish between a stable digital presentation and an erratic, questionable measurement. If all the thickness measurement information needed is to be analyzed, equipment with a digital and A-scan presentation must be used.

Penetrant Testing

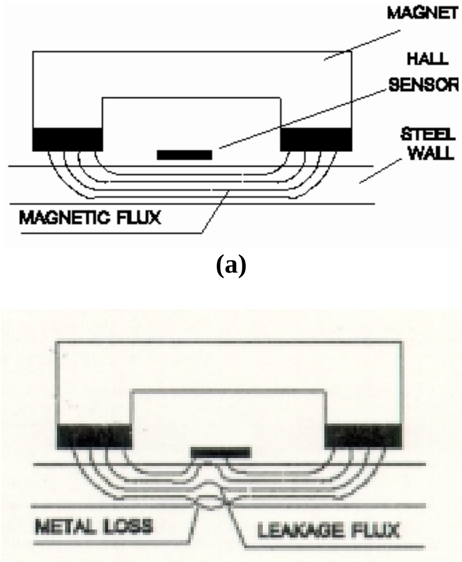
Penetrant testing (PT) is useful for detection defects in the tank for defects that are open to surface such as fine pinholes, inter and trans-granular stress corrosion cracks and fatigue cracks. PT is useful during repair of tank floors, walls for testing of welds. Another application of PT is to detect through and through defects during leak testing. Penetrant applied on the other side of the tank floor can be detected through a pinhole by applying developer from the accessible side. The disadvantage of PT is that it requires very thorough surface cleaning.

Magnetic Particle Testing

Magnetic particle testing (MT) is especially useful for detection of surface and subsurface defects in welds in the tank wall and associated pipes. MT can also detect defects that are developing from the other side of the tank wall. Authors have used magnetic particle testing to detect under-floor corrosion defects in the tank on suspected locations on many tanks. MT is fast as compared to PT and it requires comparatively low surface cleaning.

Magnetic Flux Leakage Technique

Magnetic Flux Leakage (MFL) technique is used to detect under-floor corrosion loss in tank floors (Fig. 6). In this technique a strong magnet is used to establish a magnetic flux in the material to be inspected. When there is no defect the uniform flux remains in the metal wall as illustrated in Fig. 6a. In contrast, flux leakage occurs when there is a defect due to corrosion or erosion. Near the defect the flux "leaks" out of the metal (Fig.6b).



(a)

(b)

Fig. 6 Principle of Magnetic Flux Leakage technique applied to determine the tank under-floor corrosion defects

Sensors, which, can detect this flux leakage are placed between the poles of the magnet and generate an electric signal proportional to the magnetic leakage flux. Defects causing a leakage flux exceeding a predetermined threshold are detected. The amount of leakage flux is dependent on depth, orientation, type and position (topside/ bottom-side) of the defect. Limitation of this technique is that defects exhibiting various combinations of volume loss and depth can produce the same flux leakage level and therefore truly quantitative depth information cannot be obtained. Hence for accurate sizing of the defects ultrasonic testing shall be applied after detection.

Application of Robotics

Many of the existing inspection programs for storage tanks rely on the gathering of data by inspectors using hand-held digital thickness meters or ultrasonic flaw detector. The information gathered is normally taken in localized spots, which are often very hard to reproduce and relocate. Moreover, the data gathered is limited in its volume and may not represent the true state of the tank healthiness. The process of obtaining this information is a very slow and tedious one, and can be expensive and dangerous considering the risk. The inspectors are normally placed in a man-lift or a scaffolding or ladder. The alternative is to automate the inspection program by using a robot to acquire the needed information [Pechacek *et al.,* 1989 and Raad 1997]. This eliminates the risks involved in the manual inspection. Some of the robots that are currently used for the inspection of tanks are discussed below.

Mapscan: Mapscan applies a mechanical link between transducer and computer to record the thickness data for each predetermined measurement position. The thickness readings are stored on disk and after the scanning is completed, the data are plotted in a wall thickness map showing thickness profile as color-coded image.

High reproducibility of Mapscan (within 0.3 mm wall loss) enables accurate monitoring and calculation of corrosion rates. Corrosion phenomena such as general wall thinning, pitting corrosion, flow accelerated corrosion, hydrogen induced corrosion and Mapscan has revealed hot hydrogen attack.

Long range ultrasonics (LOROUS): LORUS is part of a carefully composed on stream tank inspection tool, containing Acoustic Emission corrosion activity measurement, and mechanized ultrasonic wall thickness mapping for areas having limited access such as annular plates [Hoppenbrouwers *et.al.*, 1999]. LOROUS examination results are documented in an easy to understand, color coded, 2D top view corrosion maps. Projection images show the area of the annular plate region in top view and form a permanent document for recurrent inspections.

Floorscanner: Having access only to the top surface of the floor under-floor corrosion cannot be found by visual inspection. The Floorscanner is developed for inspection of inner plates for underfloor corrosion from to side [Stakenhoef *et al.*, 1999].

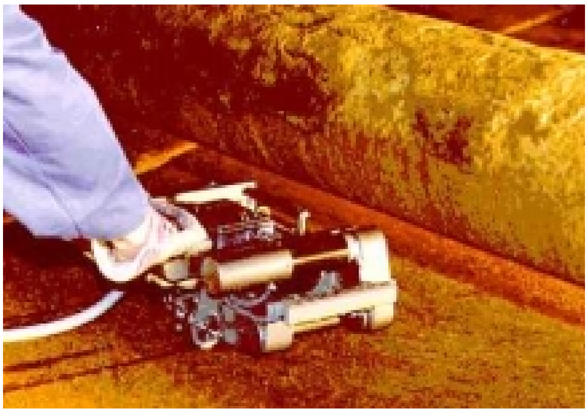


Fig. 7 Floor-scanner inspecting under-floor corrosion

A typical floor scanner (Fig. 7) operate with a scanning speed of 40 cm/s and scan width of 25 cm and it can inspect 250...500 m^2 per day. At hard-to-access areas (below heating coils, at annular plates close to the tank shell) a mini version of this scanner may be used. The remaining areas in the tank such as near welds and corners may be inspected by manual ultrasonics.

Application of robotics enable all the obtained data, including position information, to be stored in computer my means of specially developed reporting software called "FLOOR MANAGER" the results of the tank inspection may be presented.

DISCUSSION

Many NDI techniques are currently available to monitor the state of health of aboveground storage tanks during service. Visual inspection is one of the most widely used inspection techniques which involve almost no expenditure and it can be applied any number of times during online and shutdown. VT has been applied to detect abnormal indications on the surface such as discoloration, rust etc. VT has been found to be useful in applying prior to the application of other NDI techniques to assess the general condition of tanks in order to determine the extent of other inspection techniques that may need to be applied on the tanks.

Next to VT, UT is the most important NDI technique for tank inspection. UT was used to detect wall thinning due to corrosion and erosion, flaws in the welds, and under-floor corrosion. The advantages of UT are that, only one side accessibility is sufficient to detect defects on the far surface of tank wall, it is accurate and less time consuming. Another advantage of UT is that the ultrasonic probe can be integrated with an automated scanner and thus automated testing can be performed.

From the authors' experience, an accuracy of up to 0.01 mm could be obtained by digital ultrasonic thickness gauge (model MX-3, Dakota Ultrasonics). On areas of nonuniform or irregular corrosion, the ultrasonic thickness gauging was found to be unreliable. On these areas it is advisable to use normal beam testing using an ultrasonic flaw detector having A-scan presentation, from which the corrosion pattern and irregularities on the back-wall surface can be evaluated.

On some of the tank floors, the testing using digital thickness gauge and normal beam probe did not give reliable results. These areas were tested using angle beam with a single probe or two probes (pitch-catch) technique to detect under-floor corrosion [Thavasi *et al.*, 1997].

Surface NDI techniques such as PT and MT were used as complementary technique to VT. They were found to be useful for the detection of defects on selected areas during repair and maintenance.

Manual testing and data collection were found to be very tedious, risky and time consuming. Authors are of the view that wherever possible, the possibility of applying automated scanner or robotics for data acquisition should be explored. There will be many advantages in using robots for tank inspection: large areas can be inspected in shorter time, reliable data, the scanner does not get tired, it can't lose its grip, and once calibrated it has a much higher degree of accuracy during operation than that of manual operations.

CONCLUSION

VT has been found to be useful for the detection of surface defects and other imperfections appearing on the tank surfaces during day-to-day operation and maintenance.

UT is found to be the most important NDT technique useful for the evaluation of wall thickness (on floor, shell, roof and associated piping) due to corrosion and erosion.

Robotics / scanners are recommended for large area scanning to obtain reliable data and to eliminate the risks involved in the manual testing.

By the application of the right NDT technique, procedure and comprehensive inspection program, the health of the aboveground storage tanks can be monitored, operations can be carried out with confidence and sudden failures can be averted.

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