Short range Ultrasonic Guided waves to complement API 653 based
Onstream Robotic inspection of Critical Zone of Atmospheric Storage Tanks.

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ABSTRACT

API 653 based onstream approach for inspection of tank Annular Ring/Critical Zone is effectively carried out using SHORT RANGE GUIDED WAVE Ultrasonic testing also commonly known as SRUT along with ROBOTIC Inspection. The Short-Range Guided Wave (SRUT) was designed to test the annular plate of above ground storage tanks (AST’s) while the tank remains in-service and for detecting corrosion under pipe supports. The technique is based on the concept of pulsing guided laminar waves into the base material from the chime area. The waves propagate up to three feet into the annular plate. When corrosion, pitting, erosion is present the ultrasonic waves mode converts and are received by the same transducer.

Annular rings under the tank shells are best inspected using Short Range Ultrasonic testing – SRUT guided waves to detect & locate localized metal loss due to corrosion or pitting under bottom tank plate mainly inaccessible annular plate region including critical zone of tank bottom that cannot be carried out by ROBOTS alone.

Although Short Range Ultrasonic testing – SRUT is primarily a new advanced screening technique still under development & used effectively on wall thickness range of 6 to 25mm, this test method can locate the discontinuity location and size to an accuracy of ±10%.

SRUT can detect discontinuities such as corrosion, pitting & erosion. Generally detected discontinuities are reported in the percentage remaining wall thickness

1. Introduction

The latest Short-Range Guided Wave Ultrasonic Testing (SRGUT) is Corrosion imaging system that has been designed specifically for the Petrochemical industry, offering a revolutionary view into oil and gas pipelines, pressure vessels and above ground storage tanks. Guided waves Technique” can be effectively utilized for the greatest cost savings on inspection expenditure for maintaining the integrity of Aboveground storage tanks typically constructed to API 650, API 620 and other standards.

By using SRUT a new door has opened for Petroleum & Refineries to effectively fast screen in-service tanks before unnecessarily taking them out of service for API code based fixed interval Inspections. RBI has long been used by Petroleum Industries to give more practical approach by focussing more on critical issues applying tools as “Probability of Failure” POF & Consequences of Failure (COF). RBI has saved a lot of revenue and defining inspection intervals more practically overruling API or other Code based remaining life-based formulas.
On the other hand, this novel and most easily adaptable technology have enabled fast screening of tanks before a costly decision is made whether to stop the unit and take a tank out of service for detailed international Inspection.

Hence for every owner-users of storage tanks, this is truly the most inexpensive and yet highly accurate onstream tank inspection technique to adopt without having to enter the tank thereby cutting down huge expenditure.

SRUT typically targets on highly stressed Critical Zone and beyond up to as much as 1 meter. inwards while the product is inside the tank and tank is in Service. Robotic Inspection does help similar way but not a standalone technique and highly expensive.

In this paper, we will demonstrate the work carried out successfully in the world’s leading international Refineries as ARAMCO & SABIC in Saudi Arabia and that this new technology is now being used for all tanks before deciding on costly Internal Inspections.

2. What is different this new technology has to offer?

Cost savings associated with using Guided Wave Ultrasonic techniques prior to internal inspections may include lower total inspection costs, lower turnaround costs, avoiding lost production opportunities, and avoiding vessel cleaning and decontamination costs. SRUT also avoids the safety hazards associated with confined space entry of vessels. An internal inspection requires tank to be taken out of service and cleaned, purged, gas tested.

NDE inspections as MFL, Ultrasonics, Leak Tests, Vacuum BOX Eddy current, Magnetic & Penetrant need physical access inside the tank.

SRUT on the other hand is an onstream Inspection technique capable of detecting both internal and external corrosion on Tank bottom which the most important area to be inspected for integrity of tank.


Inspection and maintenance are essential. There's no exception to this rule. Financial impact due to damage and production interruption could be substantial. Contents of the tank, weather or operating conditions can lead to leakages. Localized corrosion & deterioration can cause problems. To maintain the tanks intact and to take the right maintenance action at the right time requires in-depth expertise and accurate information from regular Inspections based on inspection Codes.
4. Tank Inspection Regulations

Storage tanks containing organic liquids, non-organic liquids, vapours and can be found in many industries. Atmospheric storage tanks are designed and built to the American Petroleum Institute code or other construction standards. Atmospheric storage tanks are used for storing crude oil, heavy oil, gas oils, furnace oils, naphtha, gasoline, non-volatile chemicals, etc. Low pressure storage tank on the other hand are used for storing light crude oil, light naphtha, pentane, some volatile chemicals, liquid oxygen, liquid nitrogen.

The construction code for the atmospheric storage tank is API STD 650, and for a low-pressure storage tank is API STD 620. These cover the minimum requirements for design, materials, fabrication, inspection and testing. The inspection and test plan (ITP) for storage tank construction needs to meet the requirements of either API STD 650 or API 620. The In-Service Inspection code for atmospheric storage tank is API STD 653. It is necessary for you to use this standard with the API Recommended Practice 575, which is titled “Guidelines and Methods for Inspection of Existing Atmospheric and Low-pressure Storage Tanks.” API STD 653 addresses only the atmospheric storage tank, but API RP 575 covers both atmospheric and low-pressure storage tanks.

5. Basic Tank Inspections

Following inspections are being carried out at definite frequency as per applicable inspection codes, RBI or Jurisdictional requirements.

5.1 External Inspection
All tanks shall be given a visual external inspection by an authorized inspector. This inspection must be conducted at least every five years or RCA/4N years (RCA is the difference between the measured shell thickness and the minimum required thickness in mils, and N is the shell corrosion rate in mils per year) whichever is less.

5.2 Internal inspection
A certified API inspector, along with an ASNT-certified examiner, must perform this inspection before the end of the corrosion life of the bottom of the tank or twenty years, whichever is less. If no corrosion rate is available, then they must perform the full inspection within ten years. An internal inspection may include a comprehensive visual inspection of the entire tank interior, ultrasonic-thickness testing of the bottom plates, magnetic-flux-leakage testing of the bottom plates, Vacuum-box testing of the bottom and shell-to-bottom weld seams, settlement surveys and, in some cases, fluorescent-magnetic-particle testing of the shell-to-bottom weld seam. Internal inspection is primarily to ensure that the bottom is not severely corroded and leaking & to identify and evaluate any tank bottom settlement.
5.3 Risk based inspection

5.3.1 RBI to determine inspection intervals and type & extent of inspection.

When an owner user chooses to conduct RBI assessment it must include systematic evaluation of both probability of failure & consequences of failure in accordance with API 580, API 581.

Identifying & evaluating potential damage mechanisms, current equipment condition & effectiveness of past inspection are important steps in assessing probability of pressure vessel failure. Identifying & evaluating process fluids, potential injuries, environmental damage & equipment down time are important steps in assessing consequence of pressure vessel failure.

5.3.2 Probability assessment

Probably of assessment should be based on all kinds of damage that could be reasonably expected to affect a Tank or Vessel in a service. Includes internal/external metal loss from localized general corrosion, all forms of cracking, other forms of metallurgical, corrosion & mechanical damage (fatigue embrittlement, creep) effectiveness of inspection tools & techniques in finding potential damage mechanisms. Additionally, the effectiveness of the inspection practices, tools, and techniques for finding the potential damage mechanisms must be evaluated.

5.3.4 Consequence assessment

The consequence of a release is dependent on type and amount of process fluid contained in the equipment. The consequence assessment should be in accordance with API 580, Section 10 and must consider the potential incidents that may occur as a result of fluid release, the size of a potential release, and the type of a potential release, (includes explosion, fire, or toxic exposure.) The assessment should also determine the potential incidents that may occur as a result of fluid release, which may include health effects, environmental damage, equipment damage, and equipment downtime.

5.4 Cathodic protection Survey

Where exterior tank bottom corrosion is controlled by a cathodic protection system, periodic surveys be conducted as per API 651. Owner/operator shall review the survey results & shall assure competency of personnel performing surveys.

5.4.1 Tank Bottom Inspection is most critical for above ground Storage tanks.

As per API 653 If the minimum bottom thicknesses, at the end of the in-service period of operation, are calculated to be less than the minimum bottom renewal thicknesses in API 653
Table 4.4, or minimum acceptable risk determined by RBI assessment the bottom shall be lined, repaired, replaced, or the interval to the next internal inspection shortened.

<table>
<thead>
<tr>
<th>Minimum Bottom Plate Thickness at Next Inspection (in.)</th>
<th>Tank Bottom/Foundation Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>Tank bottom/foundation design with no means for detection and containment of a bottom leak.</td>
</tr>
<tr>
<td>0.05</td>
<td>Tank bottom/foundation design with means to provide detection and containment of a bottom leak.</td>
</tr>
<tr>
<td>0.05</td>
<td>Applied tank bottom reinforced lining, &gt; 0.05 in. thick, in accordance with API 652.</td>
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</tbody>
</table>

Table 4.5—Annular Bottom Plate Thicknesses (in.) (Product Specific Gravity < 1.0)

Due to strength requirements, the minimum thickness for tanks in service with product specific gravity less than 1 requiring annular plates (other than seismic loading), minimum thickness of annular plates is as per API 653 Table 4.5, plus any CA. as shown above.

5 API 653 based latest onstream Inspections

These methods can be used, under the right circumstances, to supplement or in lieu of invasive and turnaround inspections, usually at much lower cost. Cost savings associated with using OSI techniques in lieu of internal inspections may include lower total inspection costs, lower turnaround costs, avoiding lost production opportunities, and avoiding vessel cleaning and decontamination costs. On-stream inspection also avoids the safety hazards associated with confined space entry of vessels.

7.1 These are API 653 based Robotics Inspection & Short-Range Guided Wave (SRUT)

8.1.2 Robotic Inspection

Robotic in-service tank bottom inspection allows for inspection according to the API 653 standards while tank remains service.

This independent tank bottom inspection device uses UT sensors to detect any variations in tank bottom thickness. The scan provides with an API certified inspection of tank bottom.

The inspection utilizes a remotely controlled hydraulic robot specifically designed to inspect in-service tank floor bottoms. The robotic navigation system is equipped with robot and navigation transducers. The robot follows a predetermined digital inspection grid and collects up to a million ultrasonic scans of the tank bottom to perform computerized data analysis. By using the Robotic Tank Inspection, the tank bottom inspection takes significantly less time & is safer and reliable.

The latest most valuable technique developed for fast accurate 3D mapping of tank internal condition from outside is Short Range Guided wave called SRUT.

The special SRUT probe is placed away from the area of interest (generally concealed surface) to scan up to 1m of material length without losing adequate sensitivity and adaptable to wall thickness range of 6 to 25mm. This test method can locate the discontinuity and size & can detect discontinuities such as corrosion, pitting & erosion. Generally detected discontinuities are reported in the percentage remaining wall thickness and categorized into various severity level.

Short Range Ultrasonic testing (SRUT) probes uses multiple frequencies and thus it can identify all indication providing the efficient generation of the guided wave in the plates. The linear and newly designed matrix array probes allow optimizing of the guided wave excitation in the material with ability of 3D control of the ultrasonic beam.
SRUT inspection provides the highest degree of signal optimization capturing of the CB-Scan image of the cut off sample taken out of the annular ring & the sample contains the real corrosion damages and artificial defects. (See Fig. 2)

9.1 Important advantages of this latest advancement are as below.

- Rapid detection of corrosion & erosion including sizing in accessible areas annular rings.
- More Accurate than LGUT.
- Defects detected with a dimensional accuracy within 0.040” for both length & width.
- High speed corrosion screening.
- Incremented scans for flaw location.
- Can inspect thin & thick materials.
- Light weight portable & be used on Alloys, composites
- Allows for rapid scanning of annular rings, under support & hard to access locations
- 100% of surface area (up to 2m length) can be scanned with single inspection scan

9.3 How short-range guided waves (SRUT) technology works?

Ultrasonic waves are transmitted in the form of pulsed guided laminar waves using special ultrasonic probes. When laminar waves hit discontinuities, they are mode converted the reflection of the waves are detected by the transducer.

10. SRUT inspections projects in Saudi Arabia refinaries

10.1 Inspection Overview

Annular rings under the Tanks shells were inspected at SABIC Petrochemical, Saudi Arabia & ARAMCO Refinery, Saudi Arabia using Short Range Ultrasonic testing – SRUT guided waves to detect & locate localized metal loss due to corrosion or pitting under bottom tank plate mainly inaccessible annular plate region including critical zone of tank bottom.

10.2 SRUT carried on in service Tanks in conjunction with POBOTIC inspection

The Short-Range Guided Wave (SRUT) was conducted on several tanks to focus on tank bottom critical Zone, Annular plate condition and rest of the tank bottom region. The results were compared with robotic Inspection findings and confirmed. All tanks that showed metal loss beyond minimum thickness requirement of API 653 for Annular plate, Critical Zone area & Tank bottom were taken out of service and readings further verified by A Scan Ultrasonic Inspection and the results were in agreement.
This saved lot of expenditure that would have incurred unnecessarily on code based Internal Inspections on good tanks. ARAMCO & SABIC and other major petroleum refinaries around the world are now considering full utilization of the excellent fast and very accurate screening tool to evaluate their tanks before taking out of service for costly Internal Inspections.

10.3 Examination procedure used

SRUT Guided wave inspection was conducted to test the annular plates of above ground Storage Tanks (AST's) No 760-S-1 IBN ZAHIR, while in service using SONATRON ISONIC 2005 Equipment for determining the integrity of tank annular plates where the highest probability of corrosion is present to help prioritize out of service tank maintenance requirements.

![Figure 3. Above Ground Storage Tank ATS 760-S1 with critical zone of Interest](image)

Short range guided laminar waves were pulsed into the base material from the chime area (projection of annular plate) using appropriate SRGW-1 DGH893 MATRIX transducer propagating ultrasonic waves into the annular plate to focus on integrity of critical zone area for metal loss due to areas of localized or scattered corrosion, erosion or pitting. In areas of localized metal loss due to corrosion, pitting & erosion, the mode converted waves were picked up by the same transducer. The graphic Figure below in Fig 4 depicts the sound reflects at top side or underside corrosion providing a C-scan image of the defect.
SONATRON ISONIC 2005 with SRGW-1 DGH893 MATRIX transducer could produce adequately high-resolution real-time colour image of internal/external corrosion maintaining sensitivity along the critical zone and beyond.

Using SONATRON A-Scan set including the spectrum analyser for ultrasonic signals & CB-Scan for the performing SRGW (short range guided wave) inspection and imaging was satisfactorily performed along the entire circumference.

10.5 Calibration Standard to simulate tank annular plate
Calibration standard was prepared to simulate tank annular plate to shell joint 8 mm thick Steel of acoustically similar material (same as tank under inspection) with one-meter extension to ensure adequate sensitivity in entire CRITICAL ZONE area. Artificial defects were produced with metal loss of 60% of plate thickness (See Fig. 6)

10.6. Calibration

Calibration was performed by scanning along the projection of calibration plate to pick up 60% metal loss with adequate sensitivity using A scan. TCG was established using 60% slot to establish correction in amplitude

Figure 7  Calibration block A-Scan CB-Scan Scan presentation

10.7. Inspection procedure

Areas, which shall be scanned, were cleaned to become free from loose scales and heavy rust deposits. The annular ring was divided into 88 segments and each segment was 1 meter long. The metal loss found was reported for further evaluation

10.8 Couplant
Couplant used was water soluble gel UCA-2M to give maximum acoustic transmission between transducer face and material under examination.

10.9 Inspection Coverage
Testing shall be carried out from the chime ing plate to analyse the internal condition of annular ring & critical Zone area. As near to 100% of the tank Annular Plate should be inspected given constraints from geometry and the technology itself.

The nominal plate thickness of the protruding plate was determined by ultrasonic thickness inspections at 3 points where the scan would be carried out in Anti-clockwise direction. The details were recorded on UT report.

10.11 Scanning
SRUT scans were taken on total of annular ring consisting of 88 segments each in anti-clockwise direction. (As Figure 8 below)

Fig. 8 ATS 760-S-1 Tank Bottom
Prior to scanning the extension of annular plate was cleaned to remove lose debris to facilitate movement of probe without interruption. Scanning was performed to detect and size any metal loss due to corrosion pitting and compared it with reference TCG curve to determine % metal loss in areas of corrosion.

10.12 Scanning Data

Incremental scanning was carried out along the full Annular Plate extension from outside of tank and Encoded Complete sequence of A-Scans are recorded along with CB-Scan defect images. CB Scan imaging and recording is performed through continuous capturing of wall thickness and the reflector’s coordinates along the probe path. It provides two dimensional presentations of data displayed as top view and cross-sectional view of the inspection item. Off-line evaluation of CB-Scan record was done with sizing of defects at any location along the stored image - coordinates and projection dimensions.

The CB Scan record data of both wall thickness measurement and locations in digital mode for each scanning line was captured and presented below.

See Fig 9, 10, 11 & 12

Figure 9  C-Scan high-resolution real-time colour image of annular plate Segment 1, 2 & 3
Fig. 10 C-Scan high-resolution real-time colour image of annular plate Segment 12, 15 & 40

Fig 11 C-Scan high-resolution real-time colour image of annular plate Segment 41, 43 & 53
### Segments Length (mm) Metal Losses in Terms of Percentage

<table>
<thead>
<tr>
<th>Segment</th>
<th>Length (mm)</th>
<th>Minimum Thickness Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
<tr>
<td>6</td>
<td>1000</td>
<td>2% Metal Loss AT ≥ 0.4%</td>
</tr>
</tbody>
</table>

#### 11. Results/Recommendations

The metal loss detected due to corrosion was evaluated as per minimum thickness requirement API 653 code Tables 4.4 & 4.5 for ATS Annular ring area, Critical Zone area and rest of the bottom plate region. Tank was taken out of service and the Robotic measurements and SRUT findings were confirmed with ultrasonic A Scan measurement and were in agreement.

### 12. Conclusion

- **Short-Range Guided Wave Ultrasonic Testing (SRGUT)** is latest revolutionary Corrosion Imaging system that offers best solution for maintaining above ground storage tanks integrity.
- **SRUT** is highly accurate fastest 3D Mapping Tank inspection Technology that saves lot of expenditure by avoiding unnecessary code based Internal Inspections.
- SRUT has proven to be an excellent fast screening tool without affecting production and safe to use.
- Improvers safety by pinpointing problematic areas

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Fig 12. ATS 760-S-1 Tank Bottom Metal loss indicates along critical zone in various segments.
• SRUT has higher accuracy compared to LRUT
• Petroleum Industry has benefited itself with this novel accurate & reliable inspection technology to safeguard its critical vessels and storage tanks in minimum time at low cost and without taking vessel out of service

13. Future for this new Technology

Petroleum Refineries Chemical storage facilities around the world can now look forward to full utilization of this new revolutionary invention of reliable fast and highly accurate screening tool to help inspect critical components including Storage tanks & vessels to improve overall safety & reliability at minimal costs

Acknowledgements

References