Sonomatic SONAR Robotic Storage Tank Inspection Capability – September 2021

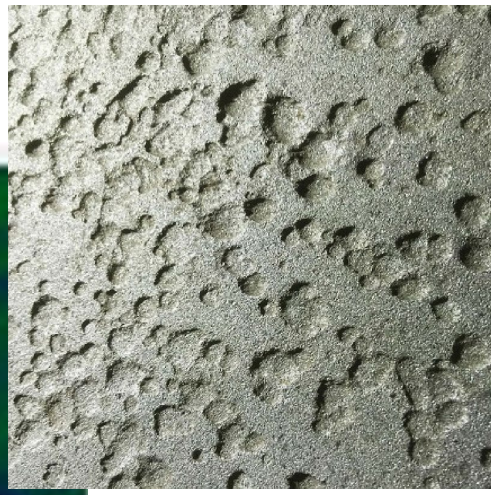
People / Safety / Quality / Innovation

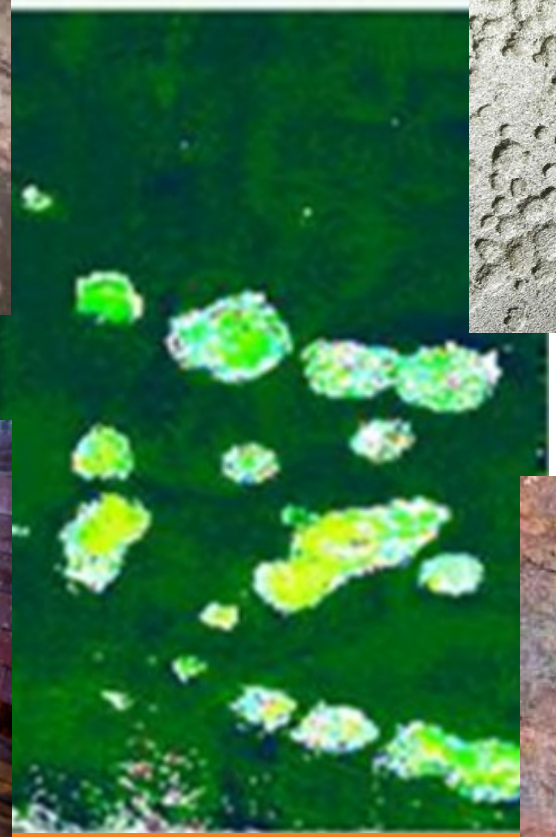
Global Footprint

Sonomatic | Vertech & Geo Oceans | Abseil Access | Inspection Associates Inc. | FTI-INTL | Blue Ocean Marine Services

Advanced Robotic Tank Services

- Objective of an In-Service Robotic Tank Floor Inspection
  - Detect floor plate minimum thickness
  - Record product side and soil side corrosion
  - Assess the tanks condition according to minimum thickness results
  - Prepare fitness for service certificate





Advanced Robotic Tank Services

- Desludging (and Waste Management)
- Comprehensive in-service inspection
  - Tank shell and roof
  - Annular plate
  - Shell to floor welds
  - Advanced robotic UT tank floor inspection
  - Internal Visual Inspection (dependent on product type)
  - Settlement Survey

Tank Floor Online Inspection approach

- Primary inspection is ultrasonic thickness measurement over selected regions on the floor
- Coverage of ultrasonic inspection will be determined prior to the start of project and can depend on tank size
- Supplementary inspection of the annular plate using Short Range Ultrasonics (SRUT) and Multiplexed Phased Array UT (PAUT)
- Sonomatic is evaluating Acoustic Emission (AE) for scan planning of the floor prior to the robotic inspection

Shell to Annular Plate Inspection

Short Range Guided Wave:

- Tank Floor Annular Plate Testing
- Testing Concrete Coated Interfaces
- Testing Under Pipe Supports
- Tank Dyke Piping Interfaces
- Scan Under Vessel Supports

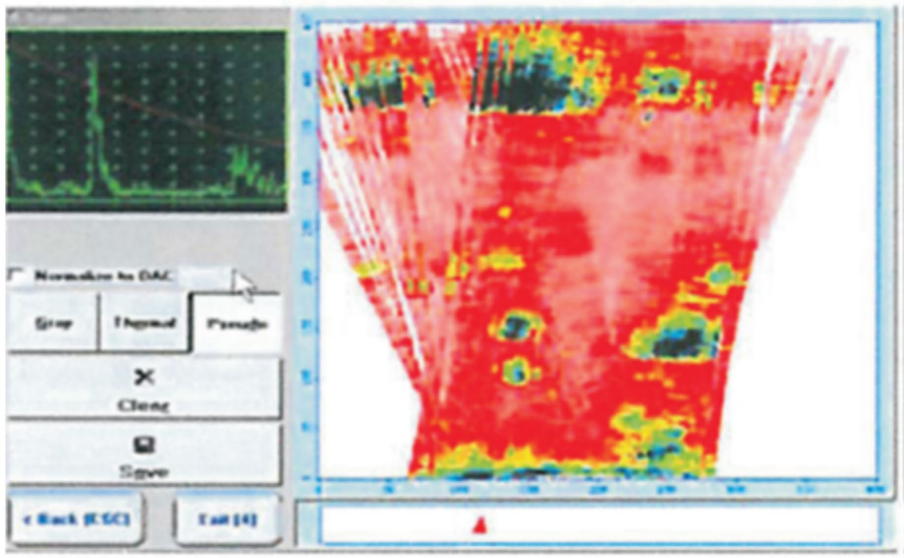
Some limitations exist when using this technique including:

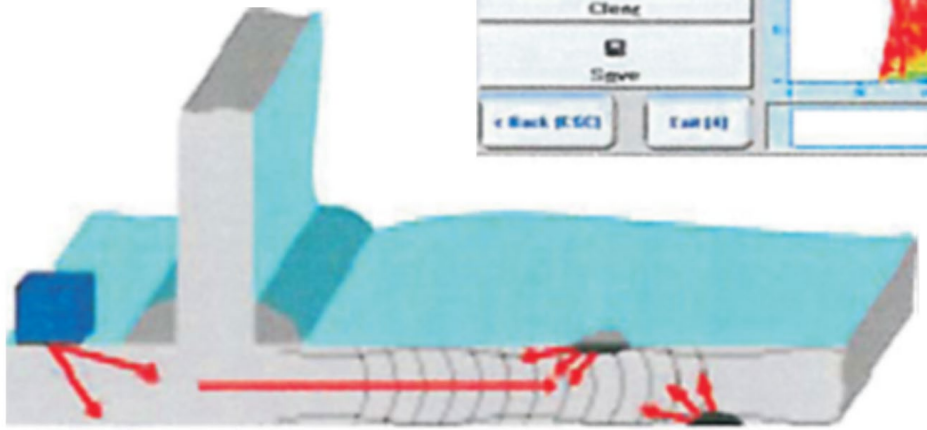
- Top or Bottom Side Differentiation
- Must have 1.5” Space for Probe Placement
- Screening Technique – Does not Quantify Material Loss

Phased Array Weld Inspection

- Inspect the Shell to Annular Plate Weld
- Assess the condition of the the internal and external weld (cracking)

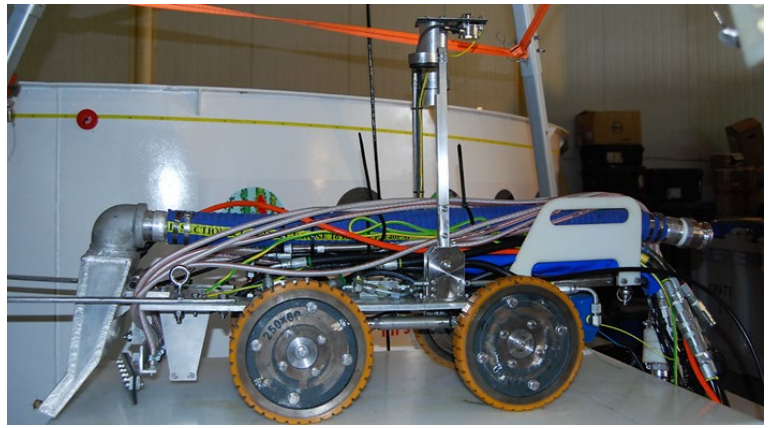
Data collection: Tank Critical Zone - OnLine

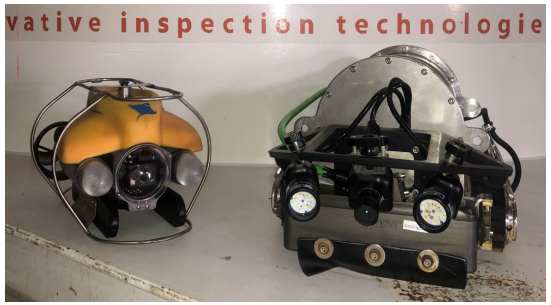


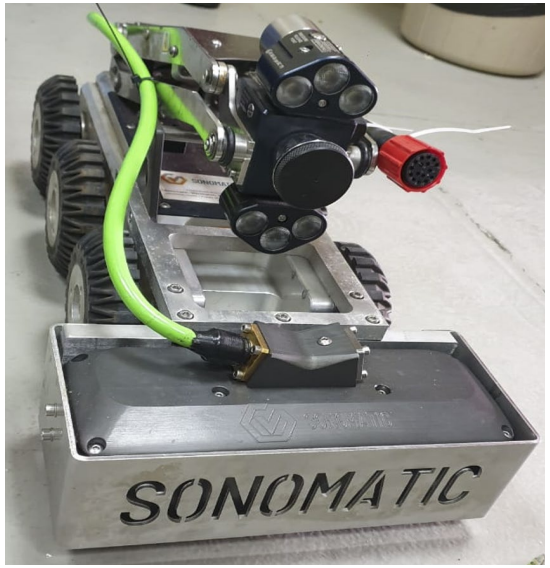


Robotic Inspection Tools

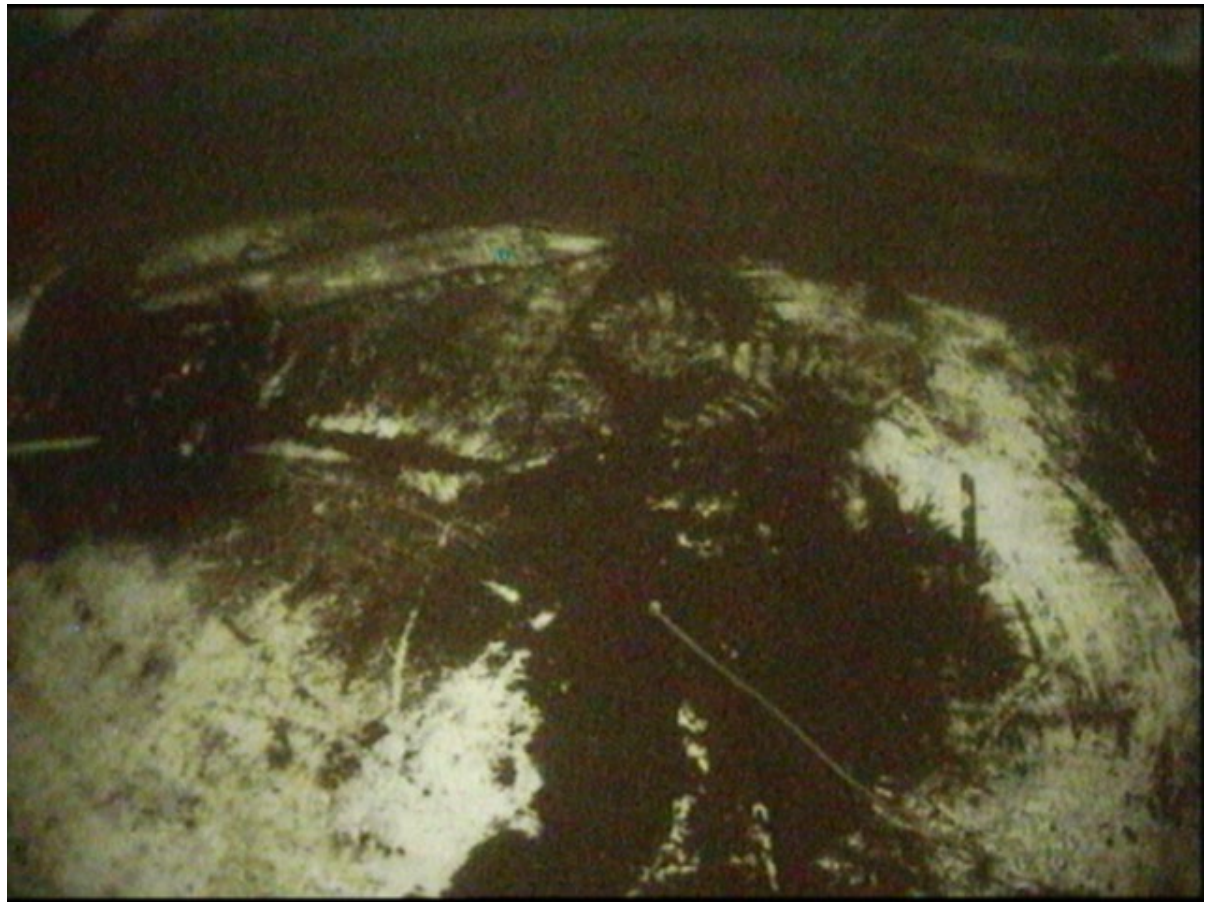
- Different robots according to tank type
  - Hydraulic for heavy hydrocarbons
  - Electric for light hydrocarbons/water
  - Manual Inspection Tool
  - ROV Visual Swimmer
- Ultrasonic inspection
- Suction and discharge for cleaning



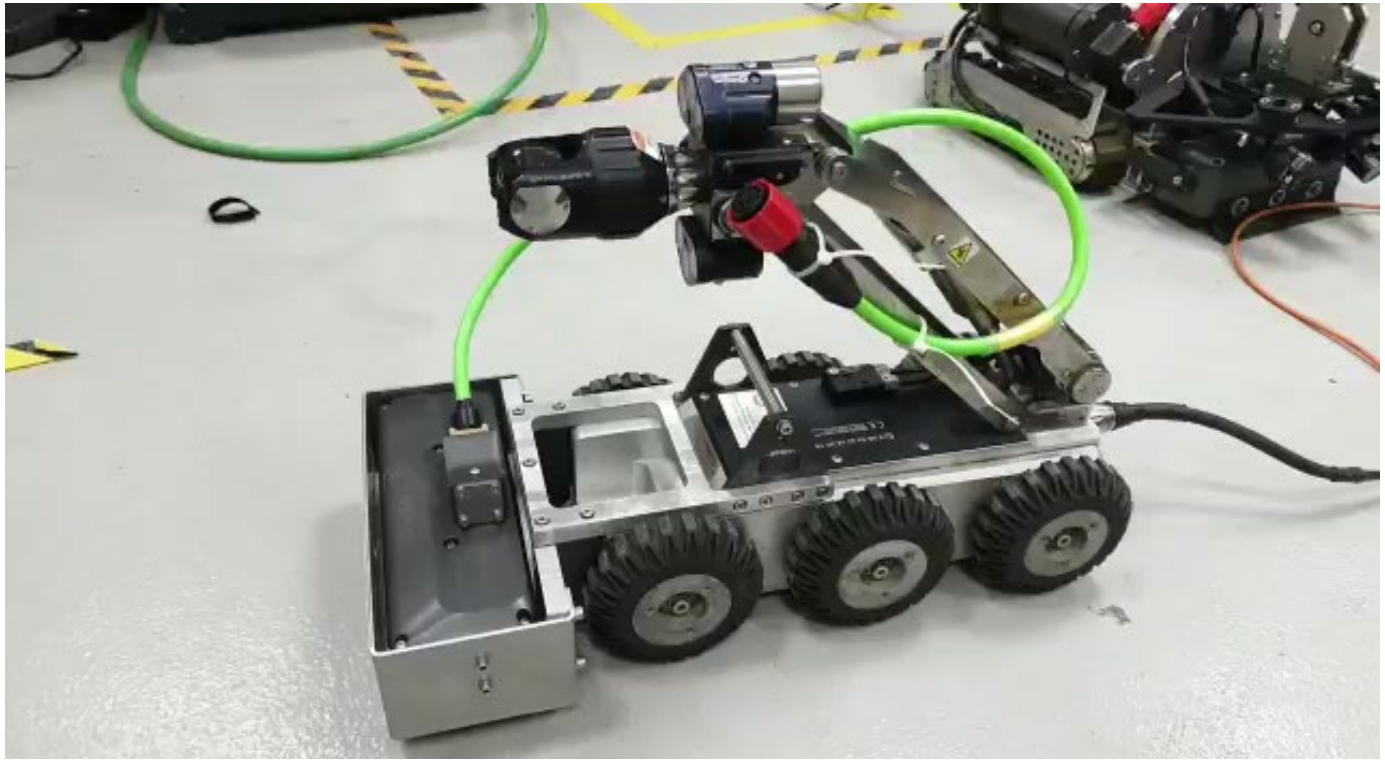


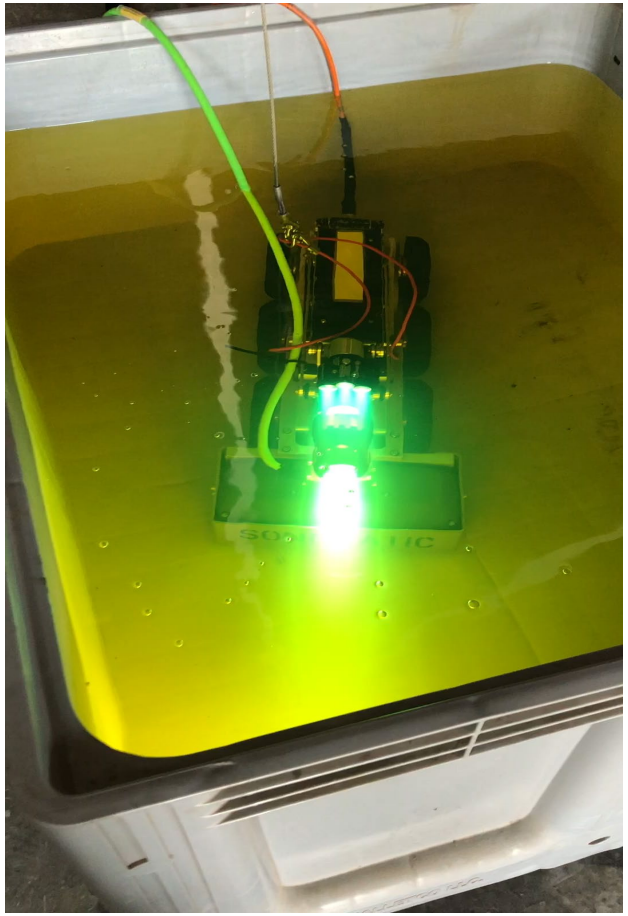


E-Lite Robotic Inspection Tool



J5 Robotic Inspection Tool





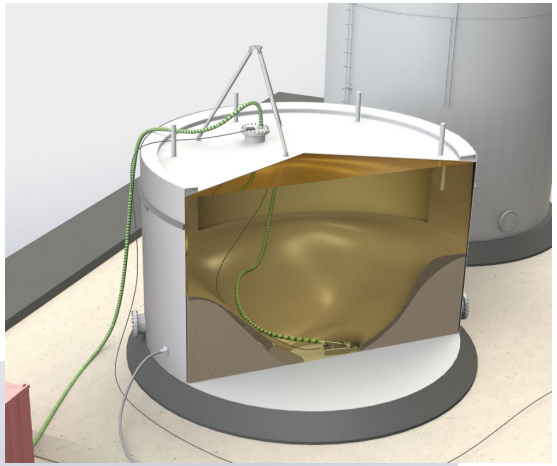
Hydraulic Robotic Inspection Tool

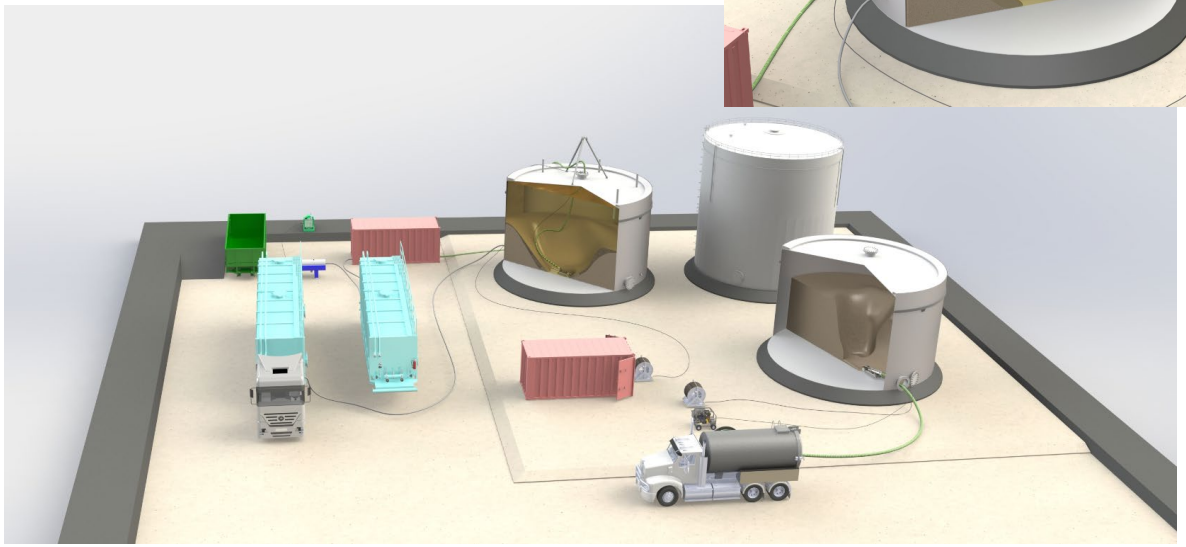
Robotic Operational Safety Systems

- Emergency Shutdown
- Nitrogen Purge Control
- LEL Monitoring
- O2 Monitoring
- Nitrogen Pressure Monitoring
- Personnel Gas Monitors
- Temporary Manway Pressure Monitor
- Electrical Redundancies
- Grounding and antistatic system

Cleaning and de-sludging

- Effective cleaning is essential for reliable ultrasonic inspection
- Cleaning system options depending on specific requirements
  - Scraper/brushes ahead of probes
  - Suction ahead of probes
  - Filter and discharge clean fluid ahead of probes
- Heavy sludges removed by pumping out of tank

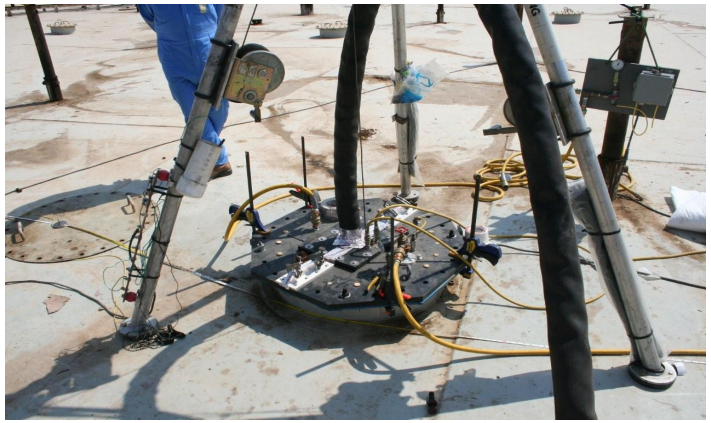




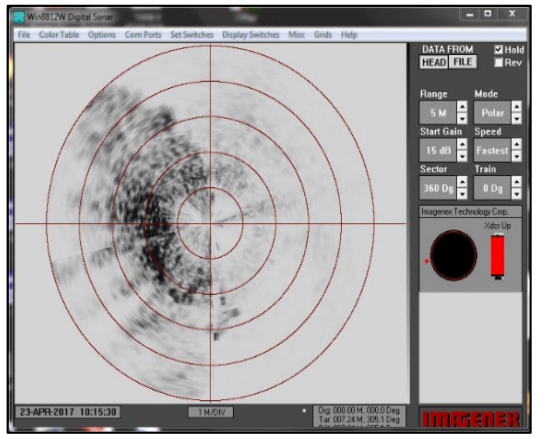
Set Up

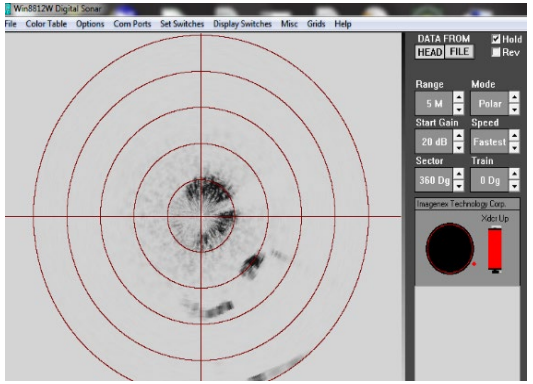
- Control room is set up within 10m from the tank shell
  - Controls and supplies pressure to hydraulic robot
  - Controls UT, Smart Navigation, Sonar and Safety Components
- Robot is lifted to roof level
- Roof top equipment is set up for deployment
- Robot is lifted by a tripod over the deployment manway
- Robot is lowered through the manway via a tripod and winch system until the robot reaches tank bottom
- Manway is sealed with a temporary manway cover
- Robot is connected to Control Room

Field deployments

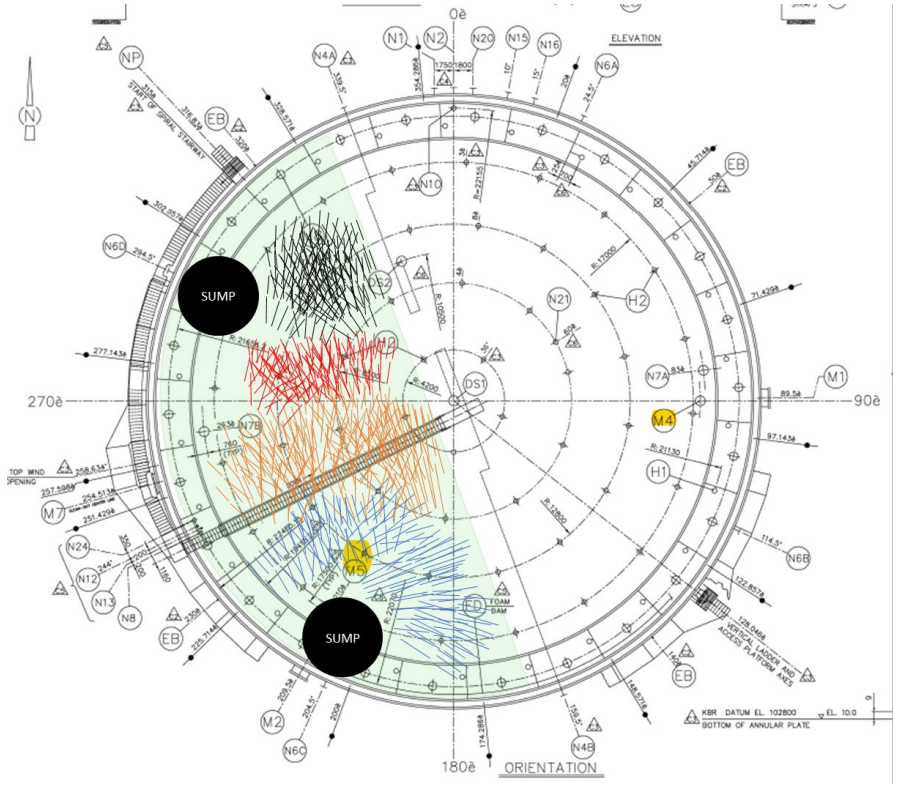


Sonar plots: 4 m to 6 m range in crude.



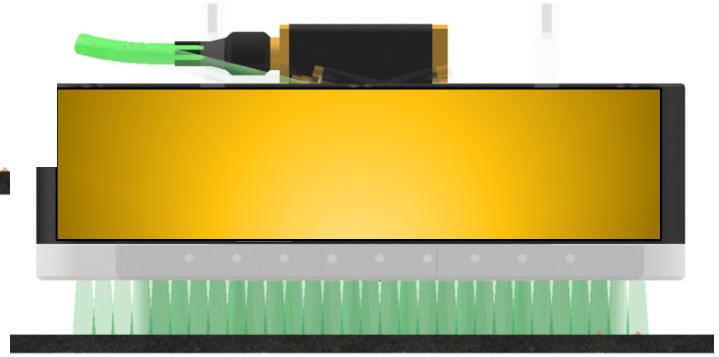


Tracking



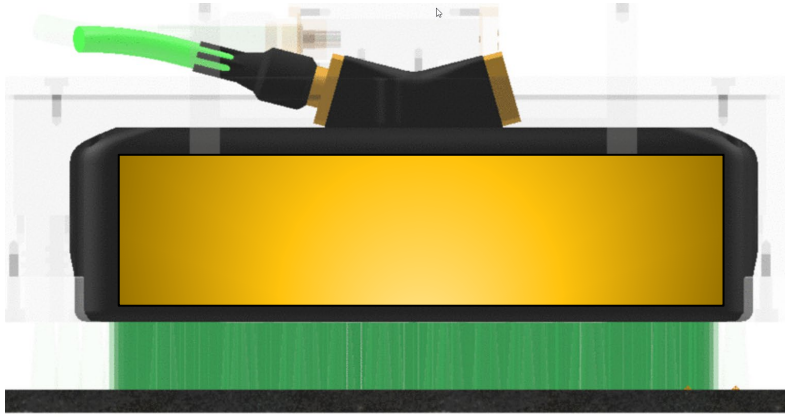
Ultrasonic probe types

8x 10 mm Ø probes



Larger probe arrays (e.g. 30x) - Coverage (300 mm)

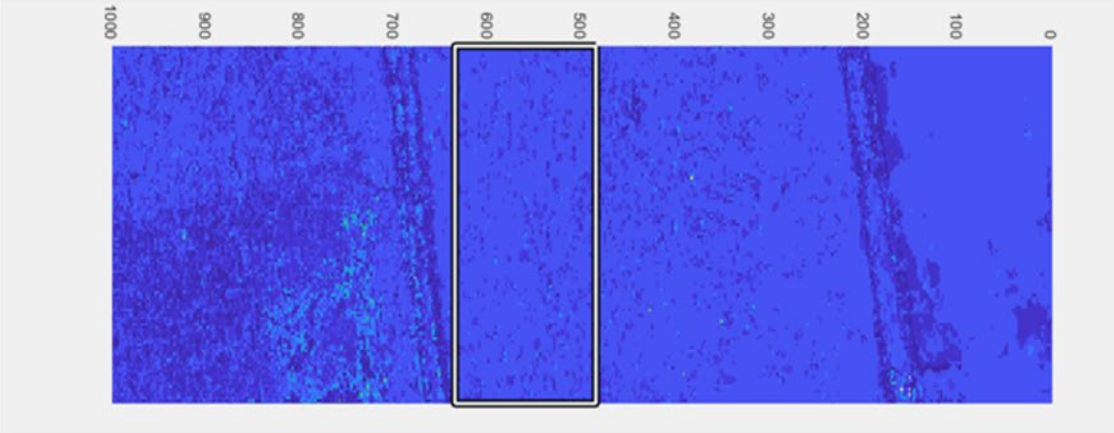
128 x 2 mm phased array - Resolution (256 mm)

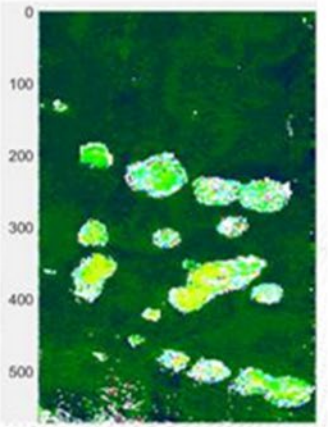


PAUT / SIMS
Improvements from IUK Project

Improvements of the new system

- Inspection time reduced by approximately 50%.
- Analysis time reduced by 75%.
- Improvements in visualization of scans and automated analysis.
- Near ‘real-time’ first pass data analysis.





Validation of PAUT$_2$

- API Standard 653 Annex G outlines the qualification process for carbon and low alloy steel tank floor examinations for above ground storage tanks, this standard was used as a guideline to assess the performance of the 5MHz 128 Element Phased Array system used in the inspection of Crude Oil storage tanks.

- Images represent the API Plates examined, a composite image of the UT data showing detection of the artificial flaws, machined in the API plate and data set showing near through thickness flaws detected.

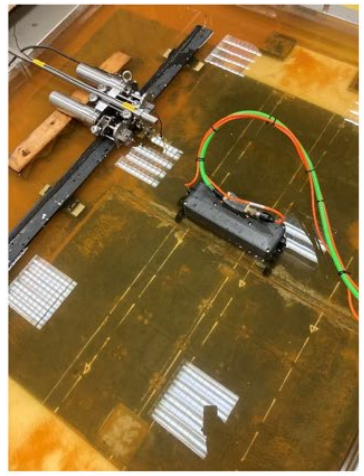
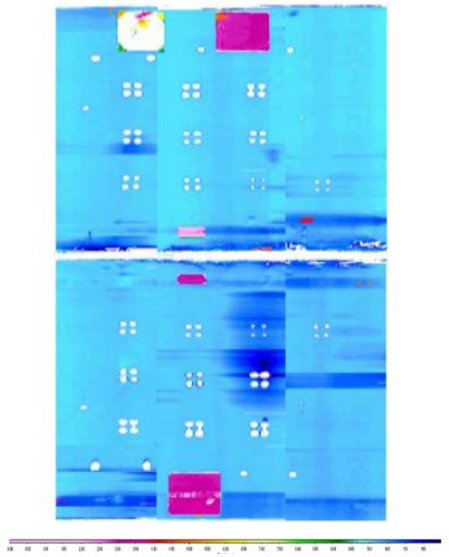
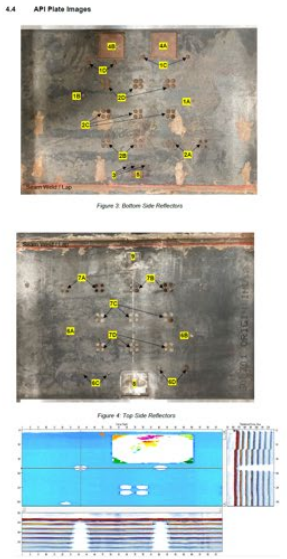


Figure 1: API Qualification Plate and PA MUX System





- Developments and technology validation exercises continue within Sonomatic for variations of the tank inspection transducer to include performance enhancement in various products and higher content of sludge and sediment.

Comparison Out of Service and In Service[1]

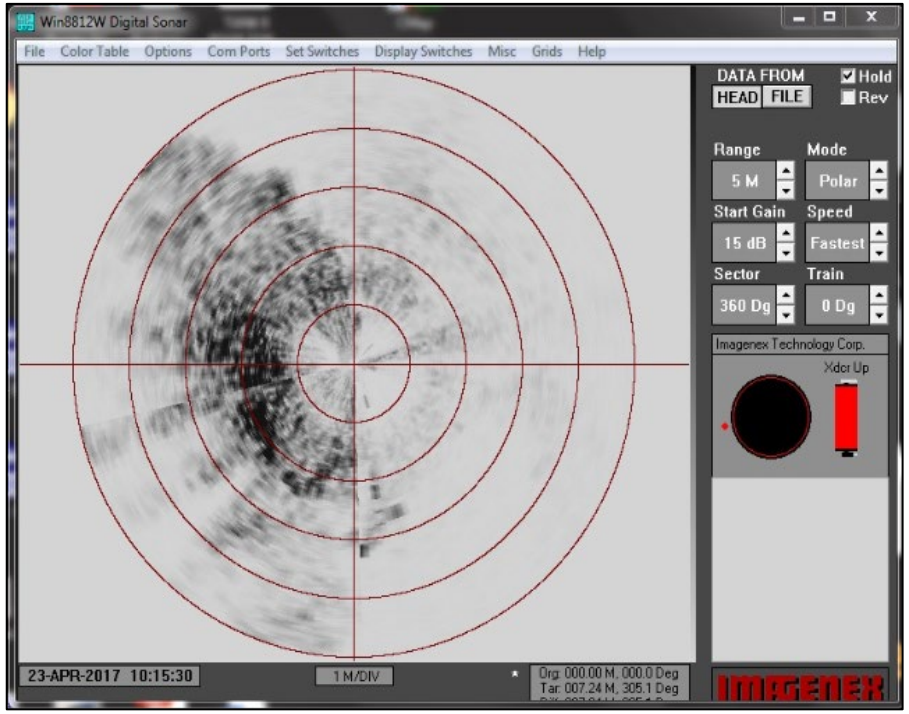
- Sonomatic completed in-service inspection of a 80 m diameter crude oil storage tank 600,000 barrel capacity, major benefit to keeping in-service
  - Limited alternative storage
  - Cost and time of out of service inspection
- In-service since 2002
- Inspection on similar tanks showed some external corrosion
- Potential for both internal and external corrosion

Comparison Out of Service and In Service[1]

- Inspection Planning
  - Some degradation expected but with reasonable margins on integrity
  - Inspection to allow estimates of minimum thickness and remaining life
  - 5% coverage for internal ultrasonic inspection
  - Screening of annular ring with SRUT
  - 100% coverage of floor by acoustic emission before the robotic inspection started

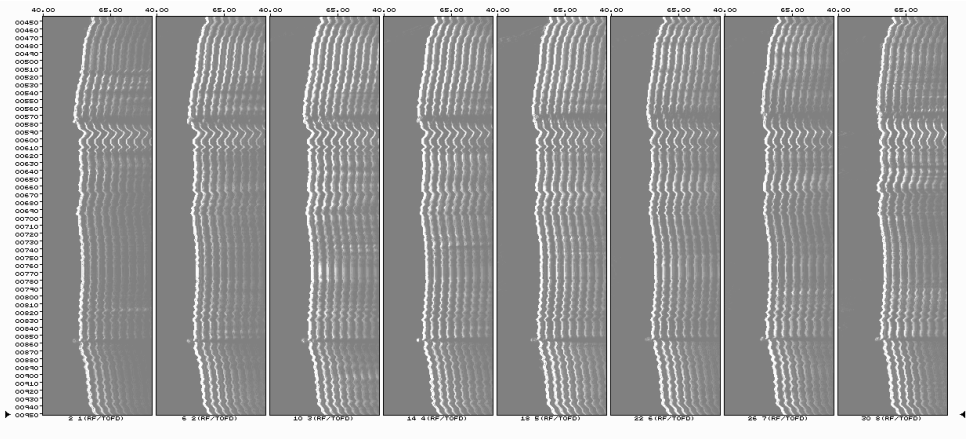
Comparison Out of Service and In Service[1]

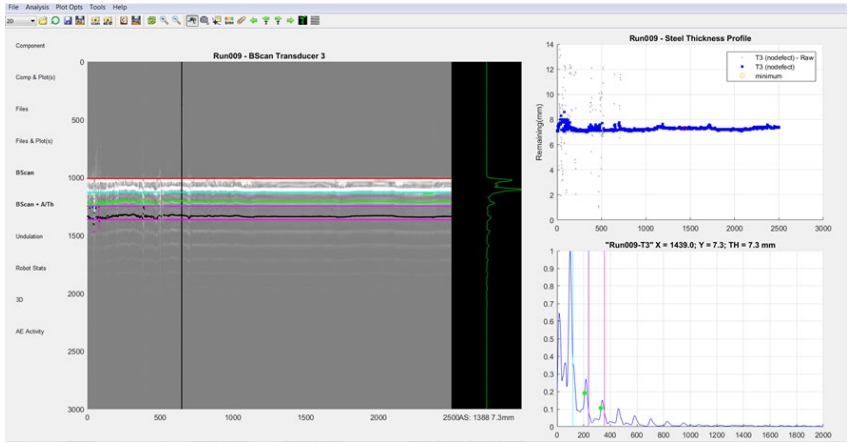
- Substantial cleaning required
- Sludge visible in sonar scans from robot
- Cleaning process
  - Remove sludge in region of inspection by suction and pumping to dispersion at higher level in the tank
  - Pumping clean fluid from higher in the tank ahead of the probe bank
  - Brushes ahead of probe bank
  - UT data indicates if cleaning sufficient



Comparison Out of Service and In Service[1]

- Ultrasonic inspection used 8 x transducers
- Data collection on Sonomatic Microplus System
- A total of 521 scans were collected, representing approx 5% coverage
- High dynamic range data collected to allow for amplitude variation associated with liquid quality and surface condition
- New module developed in Sonomatic's SIMS software specifically for analysis of tank floor data

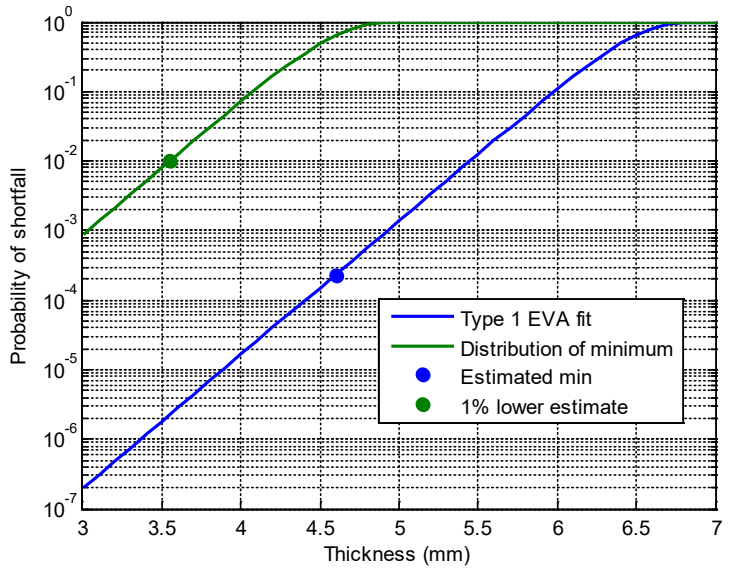




Comparison Out of Service and In Service[1]

- Ultrasonic thickness measurements showed some evidence of soil side corrosion
- Minimum thickness measured was 4.8 mm (nominal 7 mm)
- HOIS RP Statistical Analysis used for the evaluation
- Minimums from all scans with evidence of corrosion used in the analysis

- EVA expected min thickness = 4.6 mm
- Estimated 1% probability min <3.55 mm
- Remaining life to API 653 limit of 2.5 mm estimated as 4.5 years
- Service justified for a further 2 years



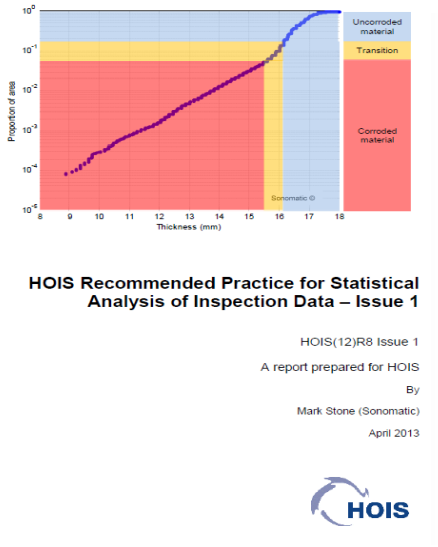
Comparison Out of Service and In Service[1]

Just over 3 years later the tank was removed from service and internally inspected.

The results of the two inspections were as follows:

Item	Out of Service	Robotic In-Service	DELTA
Tank Nominal		7 mm	
Tmeasured April 2017		4.8 mm	
Statistical Prediction on Tmin		3.55 mm	
CR Conservative case		0.323 mm/yr.	
Tminimum Jul 2020	2.20 mm	2.53 mm	0.3 mm
% Loss from Nominal	68.57 %	63.91%	4.66%

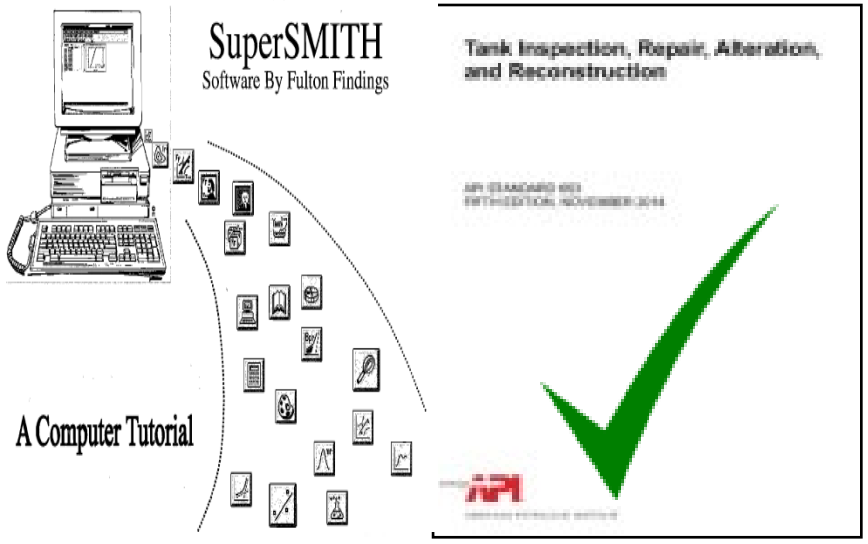
Comparison Out of Service and In Service[1]



The In-Service Robotic Inspection of the 80m Crude Oil Tank with sludge up to 1m in some locations provided data that when projected forward to the time of the Out of Service Ultrasonic Readings was deemed to be incredibly accurate and comparable. A difference of 0.3mm could be considered to be within the uncertainty of a manual UT reading and the % difference between the two methodologies was less than 5%.

COS Tank Case Study EVA Only2

A 78 metre Diameter COS Tank XXX was required to have a robotic Tank Floor Inspection conducted to extend the endorsement as the tank was due major overhaul but could not be removed from service due to operational ullage requirement. Just over 1 year later the tank was removed from service and internally inspected. The results of the two inspections were as follows:



Item	Out of Service	Robotic In-Service	DELTA
Tank Nominal	7 mm	7 mm	
Tmeasured Robotic		5.2 mm	
Statistical Prediction on Tmin		5.004 mm	
CR Conservative case	0.192 mm/yr.	0.18 mm/yr.	0.012
Tminimum at OOS Date	4.20 mm	4.79 mm	0.59
% Loss from Nominal	40.00 %	31.5%	8.5

The In-Service Robotic Inspection of the 78m Crude Oil Tank with sludge up to 3m in some locations provided data that when projected forward to the time of the Out of Service Ultrasonic Readings was deemed to be incredibly accurate and comparable. The difference between the two methodologies of 0.59 mm thickness 8.5% of nominal were derived with basic EVA statistics rather than the upgraded statistics used today

Summary

- In-service inspection of storage tanks offers significant benefits
- Robotic inspection of the tank floor is a viable alternative to out of service inspection
- Suitable for tanks where the floor is unlikely to need repairs
- Sampling methods and statistical analysis support limited coverage inspection
- Inspection and robotic technologies now available to allow a safe and practical approach that provides reliable information for effective integrity management

Questions? - Contact

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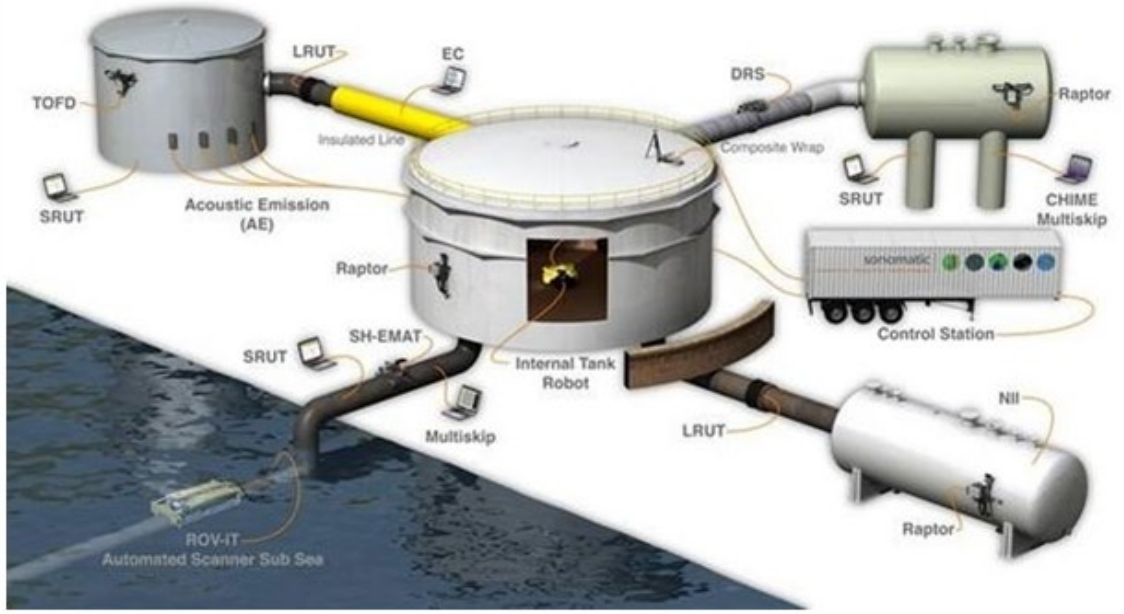


Robotic Tank Inspection
Five Year Innovations

- Inspected 80m Crude Oil Storage Tank Floor with Robotic Equipment

2017

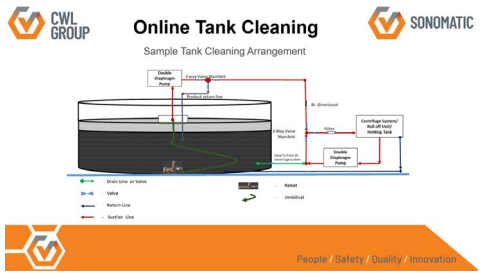
- Re-engineered Control room Electrical and Visual Systems

2018

- Improved Emergency Shut Down System through additional system redundancy

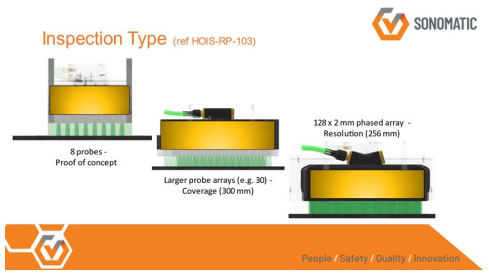
2019

- Introduced Tank Cleaning and Pumping Services to Sonomatic Applied Technologies



2020

- Inspected 100m Crude Oil Tank
- Tank Floor Coverage % Improvement
- Higher Resolution Ultrasonic (PAUT) Data System
- Partially Automated Data Analysis (SIMS)



2021

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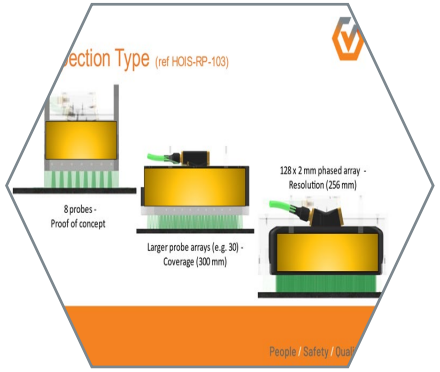
Robotic Tank Inspection Five Year Technology Roadmap

CWL GROUP

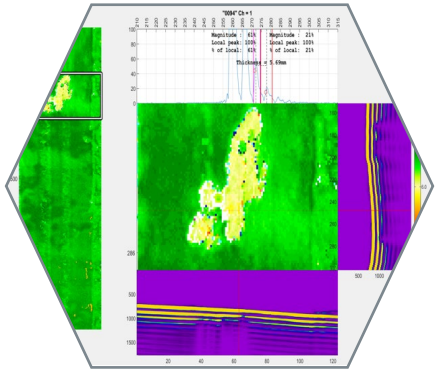
SONOMATIC

- Inspected 100m Crude Oil Tank
- Tank Floor Coverage % Improvement
- Higher Resolution Ultrasonic Data
- Partially Automated Data Analysis



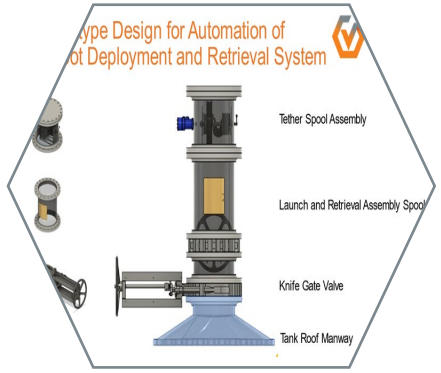
2021

- Fully Automated Data Analysis
- Higher Capacity Sludge Pumping System (Cleaning)
- Sludge Profiling prior to inspection



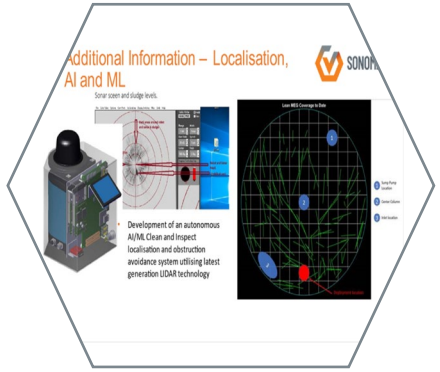
2022

- Automated Umbilical Launch and Retrieve System
- 3D Navigation System
- Regional and Global accepted Certification



2023

- Autonomous Software Development
- Semi Autonomous Robotic Ultrasonic Data Collection



2024

- Autonomous Robotic Ultrasonic Data Collection
- Achieve Robot AI/ML

2025

People / Safety / Quality / Innovation