Journal of Civil Engineering and Architecture 18 (2024) 148-153
doi: 10.17265/1934-7359/2024.03.006

Modern Corrosion Mapping of Storage Tank Bottoms—Notable Advancements in Critical Zone Coverage, Inspection Efficiency and Data Integrity

Andrew J. Simpson and Matthew A. Boat

Eddyfi Technologies-Eddyfi UK Ltd, Clos Llyn Cwm, Swansea Enterprise Park, Swansea, SA6 8QY, UK

Abstract: Every day, an NDT (Non-Destructive Testing) report will govern key decisions and inform inspection strategies that could affect the flow of millions of dollars which ultimately affects local environments and potential risk to life. There is a direct correlation between report quality and equipment capability. The more able the equipment is—in terms of efficient data gathering, signal to noise ratio, positioning, and coverage—the more actionable the report is. This results in optimal maintenance and repair strategies providing the report is clear and well presented. Furthermore, when considering tank floor storage inspection it is essential that asset owners have total confidence in inspection findings and the ensuing reports. Tank floor inspection equipment must not only be efficient and highly capable, but data sets should be traceable and integrity maintained throughout. Corrosion mapping of large surface areas such as storage tank bottoms is an inherently arduous and time-consuming process. MFL (magnetic flux leakage) based tank bottom scanners present a well-established and highly rated method for inspection. There are many benefits of using modern MFL technology to generate actionable reports. Chief among these includes efficiency of coverage while gaining valuable information regarding defect location, severity, surface origin and the extent of coverage. More recent advancements in modern MFL tank bottom scanners afford the ability to scan and record data sets at areas of the tank bottom which were previously classed as dead zones or areas not scanned due to physical restraints. An example of this includes scanning the CZ (critical zone) which is the area close to the annular to shell junction weld. Inclusion of these additional dead zones increases overall inspection coverage, quality and traceability. Inspection of the CZ areas allows engineers to quickly determine the integrity of arguably the most important area of the tank bottom. Herein we discuss notable developments in CZ coverage, inspection efficiency and data integrity that combines to deliver an actionable report. The asset owner can interrogate this report to develop pertinent and accurate maintenance and repair strategies.

Key words: Storage tank, tank bottom, CZ, MFL, stars, corrosion, corrosion-mapping, efficiency, coverage, paperless reporting, data traceability.

1. Introduction

In 1988 Saunderson [1] was tasked with improving the probability of detecting corrosion defects on the floors of ASTs (above ground storage tanks). Prior to Saunderson, the practice of floor inspection involved obtaining sample spot UT (ultrasonic) thickness measurements over the whole floor area in a sparse grid-like pattern. By its very nature, manually sampling by UT is a time-consuming, non-comprehensive approach, prone to human error [1]. To improve the inspection strategy, Saunderson proposed MFL (magnetic flux leakage) as a viable alternative.

In subsequent years MFL as a technology and an application for storage tank floor inspection has been globally recognised, validated, and an accepted means to inspect tank floors providing excellent detection capabilities whilst offering rapid, efficient and comprehensive coverage.

MFL and its application is continually evolving. Ongoing technological advances—needle changes in key system components, next generation signal processing

Corresponding author: Andrew J. Simpson, Product Manager/Technical Engineer – MFL Technologies, academic title (if any), research fields: magnetic flux leakage.

and breakthroughs in research—mean that MFL is now a primary consideration for inspection of large, ferrous surface areas such as storage tank floors.

Furthermore, complementary inspection technologies have been discovered that may supplement MFL based inspections to negate inherent limitations, such as determining surface origin classification. These supplementary technologies even afford defect classification such as material loss or material gain [2].

Today, MFL based technologies are eminently capable of delivering highly accurate and reliable reports that a recipient can have confidence in when generating optimal maintenance and repair strategies. These reports are generated via rapid, efficient, and accurate tank floor inspection equipment capable of CZ (critical zone) coverage, and in some instances sizing. Moreover, report recipients are now able to fully interrogate data sets, understand reporting decisions and have complete reporting clarity and thus gain confidence to formulate key repair or remaining life decisions.

2. CZ Coverage

Inspection of the region that exists between the tank shell and the bottom plates—often referred to as the CZ—is a pivotal aspect of any tank floor inspection. Damage mechanisms that affect the integrity of the tank are often located in the CZ. It is essential that this area is inspected thoroughly with high accuracy via suitably capable equipment.

When considering an MFL based tank floor inspection, traditional methods of inspecting the CZ often entail secondary equipment such as extensive manual UT (often referred to as a UT scrub). Alternatively a complimentary MFL technology could be employed that may not be as capable as the primary technology used to perform the tank inspection. In some cases, a combination of secondary methods is required to ensure complete annular and CZ coverage. This process is fallible and may rely heavily on the integrity of the inspector and the inherent dead zones of the inspection equipment employed to inspect the tank floor.

Today, it is possible to inspect the CZ with state-of-the-art powerful technologies that utilise the latest generation of MFL capabilities in a curved scanning capacity capable of offering curved scanning. This ensures any remaining dead zones are minimal and that the UT scrub requirement is minimal and adheres to regulations [3].

3. Inspection Efficiency

Time is often an important factor in tank inspection. This is not limited to the time required to perform the inspection, but the time required for the post-inspection factors including report delivery and implementation of maintenance and repair strategies. Many factors influence total inspection efficiency, chief amongst those include:

(1) Coverage: what areas of tank floor remain unscanned by primary technology? Wherever possible it is highly desirable to utilise the primary equipment for the entirety of the tank floor inspection, the reasons being:

a. To reduce set-up times and ensuing data manipulation when generating reports.

b. To guarantee data accuracy and performance consistency for all plate thicknesses.

c. To reduce the fatigue human factor.

(2) Data Accuracy: how accurate are sizing estimates if provided? If accuracy is unsuitable, additional time may be spent in prove up data amendment and manual note taking.

(3) Paperless Reporting: A lack of communicative equipment and software packages will likely lead to a manual note taking requirement. By its very nature this is inefficient and fallible.

(4) Acquisition Speed: what is the optimal physical speed at which the equipment may operate to capture accurate and reliable data?

(5) User Dependency: Unintuitive equipment and software can complicate and prolong the inspection.

Moreover it can reduce report confidence.

(6) Total Inspection Platform: It is essential the transition stages from mobilisation to system setup, data acquisition, report generation and submission are efficient, seamless, reliable, repeatable and intuitive.

3.1 Coverage

In an ideal world, the primary mode for tank inspection would be able to reduce CZ inspection via UT scrubbing to the minimum requirement (as specified by external standards such as EEMUA 159). It should also offer capabilities that account for typical and common tank components such as pipework, roof supports, etc. This would mean tank floor dead zones would be reduced to a minimum and greatly reduce the reliance placed upon complementary technologies. This leads to an improvement in the seamless quality and reliability of the inspection, as powerful state-of-the-art equipment had been utilised.

For example, if the primary tank floor scanner equipment were capable of curved scanning and provided functionality to add custom scans at any angle, then the coverage will increase from Fig. 1 to that shown in Fig. 2.

Furthermore, the data presented in the report would be seamless and intuitive and require little explanation. This means decisions can be taken immediately and with confidence.

3.2 Acquisition Speed

For finance and health and safety reasons, it is essential that the inspection duration required for tank is minimised. The rate at which tank floor inspection equipment can garner pertinent asset information is an important consideration for minimising inspection duration. However, it is pivotal that the rate of acquisition does

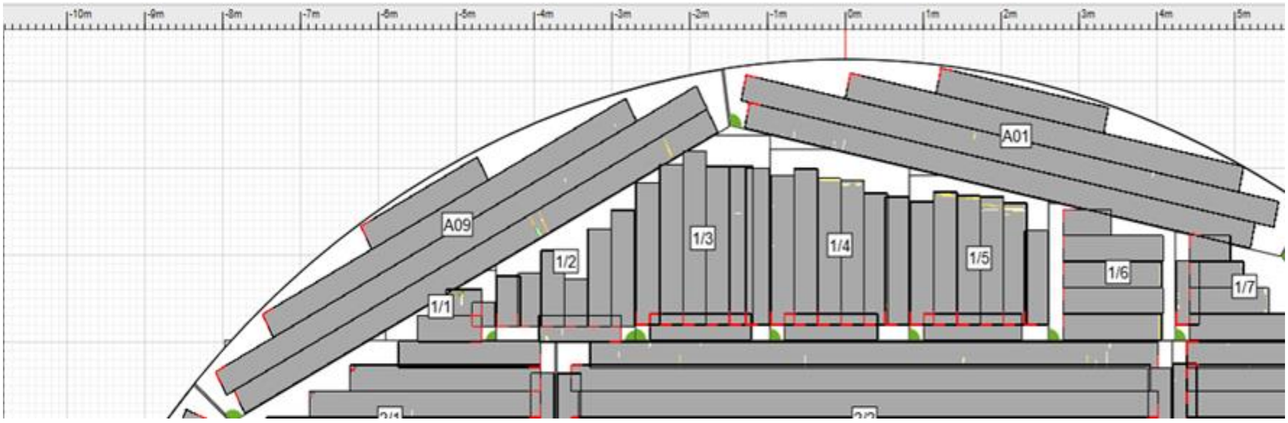

Fig. 1 Tank floor coverage achieved with primary MFL equipment without curved scanning and adding custom scan capability.

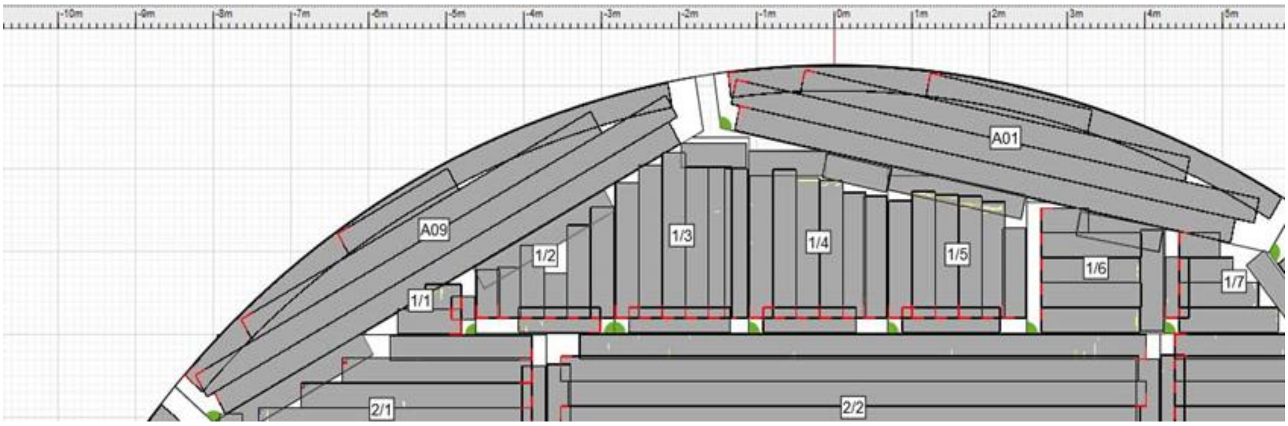

Fig. 2 Tank floor coverage possible with primary equipment capable of a curved angled scanning.

not compromise data quality. It is therefore essential that modern-day tank floor inspections are performed with state-of-the-art equipment capable of providing an exceptional signal-to-noise ratio performance, acquired at a rate that does not compromise the inspection quality and the ensuing report reliability.

3.3 Data Accuracy

Due to the severity and implications of tank failure, it is of paramount importance that acquired inspection data are accurate. MFL has traditionally been seen as a *screening* technique; however, continual advancement in MFL has progressed to the next level in terms of data accuracy.

However, as with all inspection techniques, it must be understood that limitations remain due to tank conditions and inherent restrictions. Modern operators need to understand the current technology and the technological limitations of their equipment. They also must be aware of the environment in which it is to be applied. Finally, manufacturers must design equipment that can efficiently, reliably, and accurately compensate whilst maintaining operator consistency. Compensation techniques may include capabilities where indications of interest may be rapidly and precisely relocated for further investigation.

3.4 Paperless Reporting

Today manual notes are still prevalent in tank inspection, but why?

Manual notes not only adversely affect inspection efficiency but more importantly can negatively affect inspection quality. For example, confusion may arise as to the location and reference point of a manual note or which in-tank photograph to include at which point. Manual notes also cause confusion when a defect is found with a complementary inspection technique and should be applied to the final report.

Tank inspection equipment must be developed with its application foremost. This means if additional information and amendments are required for report inclusion, then platforms must seamlessly integrate to negate the need of the manual note. This reduces the error and improves report confidence.

Acquisition software for example, may include features that allow operators to add information to precise coordinates or even include indication of prove up values. This added information may vary from which image to include in the report, to the addition of a corrosion area detected by a complementary technology. With such features, a robust communication tool is developed that seamlessly links in-tank and out-of-tank activities, resulting in clear reporting actions not prone to error. The end goal should be upon completion of data acquisition, the data (including information to submit in the report) are accurate, reliable, and ready to be included into a report without any further, off-site amendments.

3.5 User Dependency

Operator consistency and experience is a primary consideration for reliable and accurate tank inspections. Inspection technology must be designed and developed to assist the tank inspector in all related matters to ensure accuracy and validity of results.

Such design capabilities may include system and operator interaction. Software features may be developed to recognise a calibration and inspection plate thickness mismatch. In this instance, the software may prohibit data acquisition unless corrected by human interaction. This is particularly prevalent when considering annular and inner plates which tend to vary in thickness.

Further examples that may adversely affect the inspection quality involve the validity of equipment calibrations themselves. At present, software must be developed to prohibit ill-performed calibrations.

3.6 Total Inspection Efficiency

Efficient and accurate data acquisition is the primary requirement of any tank inspection. However, to ensure optimal efficiency, it is essential that each transition phase from mobilisation to demobilisation, report submission and analysis is seamless and infallible.

This includes the entire timeline of the inspection. From developing a tank floor scanner that is easy to transport, assemble and use, to gathering actionable data and completing the cycle by presenting the data in a form desired by report recipients. Stakeholders can then take the data and the report with the aim of interrogating, analysing and implementing repairs functions (such as repair plates). From this, they are able to generate reliable and optimal maintenance and repair strategies.

To realise this state, it is essential that acquisition and reporting platforms are designed and developed in tandem, and that data are transitioned seamlessly.

An efficient scanning solution is one that minimises waiting time for inspectors and stakeholders who are held up by previous steps.

4. Data Integrity

Report recipients must be confident that all inspection operations have been performed in accordance with regulations and associated work procedures. The ability for report recipients to have inspection visibility, analyse and interrogate data sets ensures inspections are performed to the highest standards.

Examples of inspection integrity may range; and may include inspection companies providing:

- Inspection Statistics: examples include the quantity and location of system verification (prove up), identification of equipment used for prove-up, range of coverage, etc.
- System Conformance: System calibration dates and quality information may be provided so that system performance is assured for the duration of the inspection.
- Inspection Decisions: Visibility on actions that affect corrosion location and classification.

Clearly such an approach will improve inspection confidence and quality and allow inspection companies to provide reporting clarity thus allowing report recipients to realise inspection decisions.

5. Report Analysis

Analysing a report represents a key aspect in achieving inspection confidence. Through analysis, decisions can be understood, and questions can be raised.

For example, if a tank floor scanner is suitably evolved to classify indications in terms of surface origin and potential severity (shown in Figs. 3 and 4), it is essential that the validation—or prove-up—is performed at regular locations throughout the tank floor to account for tank variability (plate composition, etc.).

1	Plate ID	Plate Ref	Report EPL (%)	Plate Thickness (mm)	Remaining (mm)	Status	X (mm)	Y (mm)	Dim X (mm)	Dim Y (mm)	Surface	STARS (V)	MFL (V)
2	4/1	Bottom Right	40	6	3.59	MFLA	7163	219	33	14	Top	3.61	1.42
3	4/3	Bottom Left	40	6	3.59	MFLA	4539	720	33	13	Top	1.48	1.42
4	5/1	Bottom Right	49	6	3.09	MFLA	4456	78	33	11	Top	4.41	1.86
5	5/1	Bottom Right	44	6	3.34	Accepted	4254	858	56	24	Bottom	0.28	1.63
6	5/1	Bottom Right	41	6	3.57	MFLA	4129	720	61	13	Top	1.2	1.44
7	5/4	Bottom Left	43	6	3.44	MFLA	2514	847	42	14	Top	4.63	1.55
8	5/4	Bottom Left	43	6	3.44	MFLA	2219	1735	38	13	Top	3.41	1.55
9	5/4	Bottom Left	40	6	3.62	MFLA	2300	973	42	14	Top	4.31	1.4
10	5/4	Bottom Left	40	6	3.62	MFLA	2206	1682	38	13	Top	3.08	1.4
11	6/1	Bottom Right	52	6	2.91	Accepted	359	1793	33	12	Top	2.92	2.01
12	6/1	Bottom Right	45	6	3.3	Accepted	471	1781	38	15	Top	3.59	1.68
13	6/1	Bottom Right	42	6	3.46	MFLA	588	1868	33	13	Top	2.01	1.54
14	6/1	Bottom Right	42	6	3.48	Accepted	665	1045	120	110	Top		
15	6/1	Bottom Right	40	6	3.63	Accepted	568	697	38	14	Top	4.48	1.39
16	6/4	Bottom Left	63	6	2.2	MFLA	7672	1062	42	12	Top	4.58	2.67
17	6/4	Bottom Left	62	6	2.29	Accepted	7499	694	38	13	Top	1.69	2.57
18	7/1	Bottom Right	40	6	3.59	MFLA	5274	821	28	12	Top	1.93	1.42
19	7/4	Bottom Left	45	6	3.3	MFLA	4277	1676	33	10	Top	3.39	1.68
20	7/4	Bottom Left	45	6	3.32	MFLA	5512	1263	52	13	Top	2.51	1.66
21	13/2	Bottom Left	42	6	3.49	MFLA	6088	1632	19	4	Bottom	0	1.46
22	13/2	Bottom Left	40	6	3.58	MFLA	6088	1693	103	4	Bottom	0	1.35

Fig. 3 Example of inspection statistic visibility. Image provides details on how much prove up and where the prove up has been performed affording report recipients' inspection confidence.

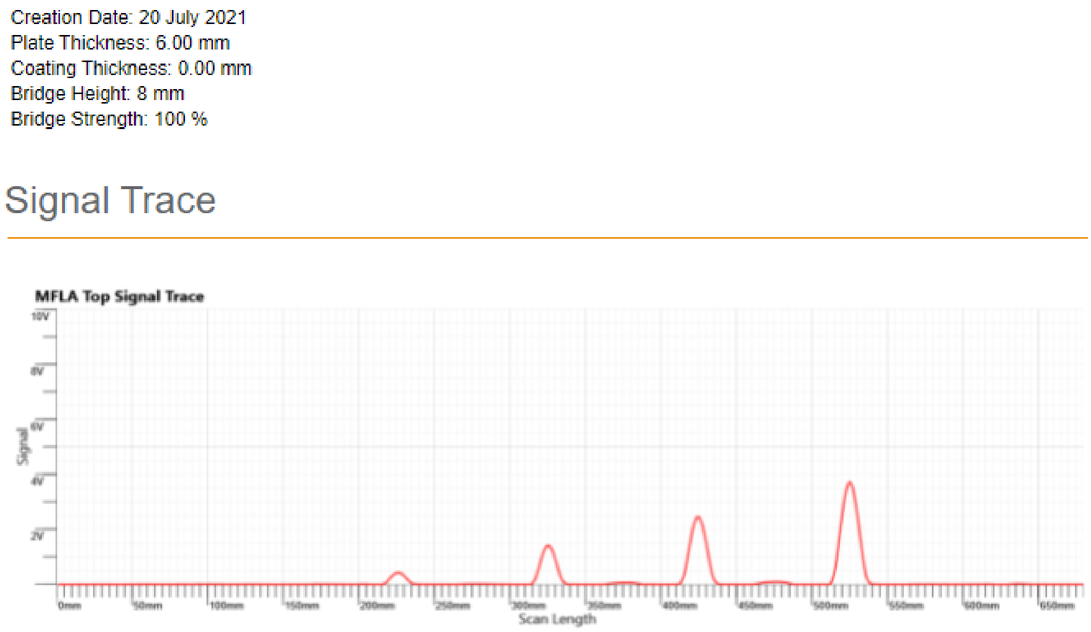

Fig. 4 Example of system calibration. Pertinent information such as calibration date and plate thickness and calibration signal response quality, is provided reducing inspection plate and calibration mismatch error.

Allowing a report recipient to see where prove-up was performed and how frequently it was done adds confidence to the inspection report. Moreover, if the technique and associated data that provided the prove-up data are also included in the final report the recipient has full knowledge of the decision.

6. Conclusions

Clearly tank inspection is a multi-faceted process. There are many factors to consider when developing an optimal maintenance and repair strategy. Continuing technological advancements, research-led development and increased market demands have necessitated and compelled the continual evolution of all factors associated with tank inspection.

Inspection tools available today for MFL focused devices are now at such a state where optimal maintenance and repair strategies are eminently possible. Moreover, such strategies can be delivered in a hitherto efficient and accurate manner.

References

[1] Saunderson, D. H. 1988. "The MFE Tank Floor Scanner—A Case History." In *Proceedings of the IEE Colloquium on Non-destructive Evaluation*, 28 January 1988, London, UK.

[2] Neil Pearson Silverwing (UK) Ltd. 2017. "Discrimination of Top and Bottom Discontinuities with MFL and the Surface Topology Air-Gap Reluctance System (STARS)." *Non-Destructive Testing* 49 (2): 48-51.

[3] EEMUA Publication 159. 2017. Above Ground Flat Bottomed Storage Tanks—A Guide to Inspection, Maintenance and Repair. London: EEMUA Publication 159.