

Calibration of storage tanks in the oil and gas sector based on the concept of digital metrology and big data analytics – Part I

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Abstract – In response to the digital transformation of metrology spearheaded by national and international quality infrastructure bodies, this paper lays the theoretical and methodological foundation for a new paradigm in the calibration of storage tanks within the oil and gas sector. Part I presents a structured framework that integrates the concepts of digital metrology, Industry 4.0, and distributed sensor systems into the domain of volumetric calibration. Emphasis is placed on the role of digital twins, metrological traceability in digital environments, and uncertainty quantification through software automation. The work systematically identifies the building blocks of this paradigm shift, ranging from intelligent infrastructure and real-time monitoring to semantic data integration and predictive analytics, establishing a basis for consistent, interoperable, and automated calibration practices. This foundational perspective serves as a precursor to the practical implementations and applied strategies elaborated in Part II.

Keywords: digital metrology, 3d laser scanning, storage tank calibration, measurement uncertainty, digital twin, industry 4.0

I. INTRODUCTION

In technical and economically demanding sectors such as the oil and gas industry, accurate volume measurement of storage tanks plays a key role in efficient inventory management and in maintaining metrological integrity. The calibration of these tanks represents one of the critical processes within the quality assurance chain, as it directly affects the accuracy of commercial quantity calculations, as well as compliance with national and international standards.

Until recently, calibration procedures were based on standardized methods utilizing discrete distance and geometry measurements through electro-optical devices, which allowed only a limited representation of the tank's

actual geometrical structure. Such traditional methods present several challenges: the duration of the process, limited data density, sensitivity to human factors, and limited capabilities for deformation detection and long-term monitoring of the tank's condition.

With the global trend of digitalization in metrology, led by major national metrology institutes and supported by initiatives such as EMPIR and EURAMET, there arises a need to transform the calibration process into an integral part of a broader framework of digital management of physical infrastructure. Here, the concept of digital metrology emerges, applying advanced sensors, numerical modeling, and automated data processing to improve the accuracy, repeatability, and transparency of measurement results.

Through the integration of virtual object modeling and the use of massively collected data (Big Data), a transition is enabled from static, isolated measurements to dynamic, digitally monitored, and adaptive systems. Big Data refers to the data or sets of records that are too large in volume to be operated using the existing database management tools and techniques [1]. The application of 3D laser scanning and the generation of high-density point clouds make it possible to create a detailed digital representation of the tank's geometry. These datasets are then analyzed using advanced software tools and machine learning algorithms to detect deformations, determine surface areas and volumes, and assess components of measurement uncertainty arising from environmental influences, object characteristics, sensors, and, most notably, the software components of the calibration system.

The motivation for this transformation stems from the need to ensure greater efficiency and scalability of the calibration process, higher reliability and traceability of results, the capability for continuous monitoring of tank condition during operation, and alignment with digital industry strategies such as Industry 4.0 and future Industry 5.0 models. Industry 4.0 addresses and solves some of the challenges facing the world today such as resource and energy efficiency, urban production and demographic

change [2].

The aim of this paper is to present the potential of modern technologies for enhancing the calibration process of storage tanks, with a particular focus on the application of laser scanning, measurement data analytics, and the quantitative management of measurement uncertainties resulting from the complex interaction between physical and digital factors. The proposed approach lays the groundwork for the development of intelligent, adaptive, and standards-compliant metrological systems within next-generation industrial environments.

II. STATE OF THE ART

In accordance with the International Vocabulary of Metrology (VIM), 3rd edition (JCGM 200:2012) [3], in a general sense, the calibration process is defined as an operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties, and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. Specifically in the context of storage tanks, as defined by the International Recommendation OIML R 71 [4], calibration of a tank refers to a set of operations carried out to establish, under specified conditions, the relationship between the liquid level in the tank and the volume of that liquid. This specific calibration process ensures the traceable and accurate determination of liquid volume based on the measured liquid level, which is of particular importance in the oil and gas industry where tank volume measurements have a direct impact on commercial transactions, inventory control, and regulatory compliance.

The tank calibration shall be carried out by the applicable ISO Standards, or national standards as required, or if appropriate standard is not available, according to another relevant and competent method. Taking into account different needs and purposes of measuring tank information, there are different ways of measuring the liquid level and other properties of the liquid, depending on the type of tank, the type of liquid, and the way the tank is used [5].

The calibration of storage tanks in the oil and gas industry is currently governed by a series of well-established international and national standards, which primarily define geometric and volumetric methods based on discrete measurements or volumetric transfer. These standards provide robust methodologies for conventional calibration but were developed in an era prior to the widespread adoption of 3D scanning technologies, digital twins, and advanced data analytics.

ISO 7507-4 [6] specifies the methodology for the calibration of vertical cylindrical tanks with diameters greater than 5 meters, using internal measurements with an electro-optical distance ranging (EODR) device. The

standard also defines procedures for the subsequent generation of tank volume tables. This method is applicable to tanks inclined up to 3% from the vertical, provided that the inclination correction is applied according to [7], ISO 7507-1:2003, Clause 11. Additionally, it is applicable to tanks with floating roofs or internal floating covers.

ISO 7507-5 [8] extends this approach to external measurements of uninsulated vertical cylindrical tanks with diameters greater than 5 meters, using EODR techniques. This standard also covers the generation of tank capacity tables and is applicable to tanks with conical bottoms (oriented upwards or downwards), as well as tanks with flat bottoms.

For horizontal cylindrical tanks, ISO 12917-2 [9] defines a calibration method based on internal EODR measurements, applicable to tanks with diameters greater than 2 meters. The procedure includes the preparation of tank capacity tables and is suitable for tanks inclined up to 10% from the horizontal, provided that appropriate inclination correction is applied.

In addition to geometric methods, ISO 4269 [10] defines a volumetric method for tank calibration based on the addition of batches of liquid. In this method, liquid serves as the volume transfer medium and is accurately measured using a certified flow meter. While effective for determining the total capacity of a tank, this method does not support the detection of local deformations or provide a detailed geometric model of the tank digital metrology and big data analytics.

While these standards form a solid basis for traditional calibration practices, they exhibit significant limitations in the context of modern digital metrology. This clearly highlights the need for either a revision of existing standards or the development of supplementary guidelines that can formally integrate modern digital technologies into tank calibration practices, thereby improving accuracy, efficiency, and traceability in line with the evolving requirements of the industry. The critical analysis of current standards clearly demonstrates that traditional calibration methods, while robust for their intended scope, are fundamentally limited in their ability to fully leverage modern digital technologies. The lack of integration with 3D laser scanning, automated data processing, digital twins, and real-time monitoring leaves a significant gap between conventional practices and the emerging capabilities of Industry 4.0/5.0 ecosystems.

In parallel, the broader field of metrology is undergoing a profound digital transformation, driven by initiatives such as EMPIR, EURAMET, and national programs led by key European National Metrology Institutes (NMIs). These efforts aim to develop digitally enabled, interoperable, and intelligent metrological processes that align with modern industrial needs. In this context, several key technological pillars are becoming increasingly relevant for tank calibration:

- the deployment of digital infrastructure to support traceable and transparent calibration workflows;
- the use of digital twins to enable continuous monitoring and predictive analysis of tank behavior;
- automated measurement systems to improve data quality and reduce human error;
- the adoption of software-driven solutions and Big Data analytics to enhance the modeling of tank geometry and the management of measurement uncertainties.

Furthermore, these developments are supported by strategic trends within European metrology, with ongoing projects actively exploring the harmonization of digital metrological frameworks across industries. The following sections provide an overview of these emerging approaches, highlighting their potential for transforming tank calibration and bridging the gap between conventional standards and next-generation digital methodologies.

A. Application of Digital Infrastructure in Metrology

According to various National Metrology Institutes (NMIs), the future of metrology can be shaped by focusing on data science, the development of new metrological services, and the emerging opportunities enabled by innovative technologies. We are amid a digital revolution that is challenging the metrology communities' working practices and paradigms for metrological traceability and reproducibility [11]. Leading institutes have redirected their research and development efforts toward the digitalization of measurement systems, data processing, software validation, and the implementation of Digital Calibration Certificates (DCCs), thereby opening new avenues for the calibration and control of complex structures such as storage tanks. It is also important to realize that DCC is not the only one pillar of digitalization in metrology so it must fit into the bigger concept of metrology digital for transformation. This means that the DCC concept must be designed to ensure interoperability, compatibility, modularity, and scalability while also establishing clear boundaries to ensure that metrology is always expressed clearly and comprehensibly. For this reason, several working groups focus on the development, implementation, and harmonization of DCC [12].

With the accelerated advancement of digital metrology, there is a growing need to redefine calibration methodologies in the direction of digitalization, automation, and integration with virtual models.

The following sections of this paper present the key elements expected to shape the future of digitally oriented calibration of storage tanks, in alignment with the strategic directions outlined by contemporary metrological developments across Europe.

B. Digitally oriented calibration of storage tanks

One of the fundamental principles of digital metrology is the establishment of a reliable and verifiable digital infrastructure. In the context of storage tank calibration, this implies that all stages, ranging from data acquisition (e.g., via 3D laser scanning), filtering, and point cloud analysis to volume computation, must be fully documented, validated, and digitally traceable. The implementation of Digital Calibration Certificates (DCCs), featuring digitally signed metadata on measurement conditions, instruments, and data processing algorithms, becomes a key prerequisite for maintaining confidence in digital measurement results. Digital twins enable the creation of virtual replicas of physical objects which are used to simulate structural behavior under various conditions [13]. The application of digital twins enables the modeling of tank behavior under real operational conditions, with continuous updates based on newly acquired scan data. These models integrate geometric features with parameters such as deformations, temperature gradients, and mechanical stresses. The development of a tank's digital twin supports dynamic monitoring of capacity changes, detection of localized structural anomalies, and the optimization of condition-based maintenance strategies. Digital metrology requires the development of novel methodologies for managing measurement uncertainty in environments where physical, software, and algorithmic variability coexist. In the context of digital tank calibration, it is particularly important to:

- consider environmental influences (e.g., temperature, hydrostatic effects),
- analyze uncertainty in point cloud processing,
- quantify software-induced error propagation.

It is essential to establish formal uncertainty models that encompass the entire digital calibration chain, from the measuring instruments to the final outputs.

Automated data processing, standardized protocols, and interoperability with laboratory and enterprise information systems represent foundational pillars of the digital calibration process. The calibration workflow must be designed to incorporate automated procedures for scanning, segmentation, volume computation, and seamless integration with platforms such as LIMS, ERP, and other monitoring systems. This approach ensures scalability, reduces human intervention, enhances operational efficiency, and minimizes the risk of human error.

For large-scale or geometrically irregular tanks, there is an increasing demand for modular and distributed measurement systems. A combination of multiple scan positions and sensor networks (e.g., for monitoring temperature, shell thickness, ultrasonic and visual inspection) enables a comprehensive understanding of the tank's structural condition.

Hybrid measurement architecture combining 3D geometric data, ultrasonic inspection results, and

environmental parameters, form the foundation for the next generation of digitally driven calibration systems. The future of storage tank calibration will be fundamentally shaped by the principles and technologies of digital metrology. The integration of digital twins, automated data processing algorithms, certified digital outputs, and system-level interoperability provides a clear pathway for transforming traditional calibration practices into a fully digital process.

To support this transition, it is essential to:

- develop harmonized standards and interoperable frameworks among metrology institutions,
- define digital protocols for verification, traceability, and documentation,
- extend calibration methodologies to encompass virtual and simulation-based environments.

Digital calibration of storage tanks thus becomes not merely a technical operation, but an essential component of intelligent digital infrastructures for measurement, decision-making, and operational control, fully aligned with the vision of Industry 4.0. In Chapter III, practical examples will be presented demonstrating the application of currently available Industry 4.0 concepts that are already in use and have the potential to significantly elevate calibration and inspection processes of storage tanks to the level of highly automated solutions, with considerable potential for further implementation and advancement.

III. CASE STUDIES

The calibration of storage tanks using 3D laser scanning technology produces high-density spatial data by capturing up to several million measurement points per second. The systematic exploitation of this “massive” dataset enables high-resolution reconstruction of internal surfaces, precise identification of localized deformations, and highly accurate volumetric computations. This study presents real-world applications in which terrestrial laser scanning has been successfully implemented in the metrological calibration of storage tanks, including both vertical and horizontal configurations. The quality of the results demonstrates that high-density spatial sampling not only enhances measurement accuracy but also facilitates complete digital traceability of the calibration process.

A total of three horizontal and three vertical tanks were included in the experimental campaign. The three vertical tanks are constructed from concentric belts of steel plates of varying thicknesses, a structural feature of critical relevance for future evaluations of deformation behavior under operational loads and thermal gradients. For all tanks included in the study, the elastic modulus corresponding to structural-grade steel was adopted as a reference parameter in subsequent numerical modeling procedures. The horizontal tanks are also made of steel, featuring flat circular end caps. In contrast to the above-ground design of the vertical tanks, the horizontal tanks are

installed underground.

The objective of the calibration process is to support high-precision volumetric quantification for commercial transactions and regulatory compliance, including routine verification and correction volume calibration tables.

A. Instrumentation and Setup

All 3D scans were conducted using a Leica RTC360 terrestrial laser scanner (Figure 1). The acquisition resolution was configured to 12×12 mm at distances up to 10 meters, with a single-point spatial accuracy of ± 1.9 mm in three-dimensional space. These parameters have a direct influence on the uncertainty budget, as they are explicitly considered in the estimation of registration uncertainty through the positioning accuracy of signal marker centers. Due to insufficient lighting conditions inside the underground tanks, the Visual Inertial System (VIS) functionality was not utilized. Instead, scan registration was performed using target-based referencing, with strategically placed black-and-white reflective markers inside the tanks.



Figure 1. Measuring systems, 3D laser scanner, Leica RTC360

Each horizontal tank was scanned from two interior scanner positions, strategically selected to ensure full surface coverage, including end caps and longitudinal shell curvature. In order to avoid shadowing effects caused by circumferential joints or weld seams, scanning was conducted from two scanner positions aligned along the vertical axis through the tank opening. The first scan was performed with the scanner positioned near the opening, while the second scan was conducted by vertically lowering the scanner by 1.5 meters relative to the initial position. The overlap between the two scans exceeded 90%, ensuring robust registration and full surface coverage. Despite the presence of an onboard Inertial Measurement Unit (IMU), environmental conditions were confirmed to be vibration-free during acquisition, thereby ensuring optimal data integrity. In the case of vertical tanks, the presence of internal elements such as heaters and measurement systems required a more careful selection of scanning stations, with the mandatory requirement that a minimum of three identical signal markers be captured from each scanner position. However, in all cases, the

number of measurement positions did not exceed four, considering the sufficient level of coverage of the tank bottom. The scans overlap was approximately 70%. This ensured the acquisition of a reliable measurement dataset suitable for automated processing of the densely captured point clouds.

The temperature monitoring of the tank shell was carried out using a spot-type thermal imaging sensor, enabling localized temperature readings across the wall surface. Measurements were performed in a structured grid pattern, where the density of measurement points was determined based on the sensor's resolution (e.g., 80×60 pixels for the FLIR TG165), the distance between the sensor and the tank surface (approximately 2 m for horizontal tanks and 10 m for vertical tanks), the field of view (FOV) of the thermal camera, and the desired spatial resolution, aligned with expected temperature gradients on the steel surface.

The measurement point density (points/m²) was calculated by projecting the sensor's pixel matrix onto the tank wall, with each pixel representing a single temperature data point. To ensure a representative thermal map of the tank shell, particularly in areas of critical relevance for volumetric analysis (e.g., near the tank bottom or in regions with pronounced temperature gradients), the distribution of measurement points was either:

- uniformly spaced, with a fixed interval between points (typically every 1 to 1.5 meters), or
- adaptively densified in zones where preliminary scans indicated high thermal variability.

As all tanks had original engineering drawings available containing information on shell thickness, these values were not measured in the field but were adopted directly from the design documentation. Their contribution to the measurement uncertainty was evaluated in accordance with ISO 7507-1, Annex D.

The inclination of the tanks was automatically incorporated into the geometric reconstruction process by utilizing scan-derived orientation data and fitted geometric surfaces.

IV. CONCLUSIONS

This paper establishes the theoretical, methodological, and conceptual foundation for a new paradigm of digital calibration of storage tanks in the oil and gas industry, through the integration of modern concepts of digital metrology. By applying 3D laser scanning, digital twins, and automated analysis of large datasets, the framework defines the pathways for high-resolution reconstruction of tank geometry, quantification of measurement uncertainty, and full digital traceability of the calibration process.

Through critical analysis of existing international standards, the study highlights their limitations in the context of modern digital technologies, emphasizing the need for their revision and/or extension. In this regard, the development of interoperable Digital Calibration Certificates (DCCs), standardized protocols, and formal

uncertainty models in digital environments represents a key step towards the full digitalization of calibration processes, in line with the evolving requirements of next-generation industrial ecosystems.

Digital calibration of storage tanks is no longer viewed merely as a technical operation, but as an integral component of intelligent digital infrastructures for measurement, decision-making, and operational control, fully aligned with the vision of Industry 4.0 and the forthcoming Industry 5.0.

In order to open the discussion for experimental investigation, this study also describes the data acquisition concept and technical resources employed in the calibration of six tanks—specifically, three horizontal and three vertical storage tanks—as representative examples. The experimental data, technical reports, specific measured tank characteristics, and case study examples are presented in a separate publication that directly extends this study by demonstrating the practical application of the proposed methodological framework under real industrial conditions.

The continuation of this study is directly linked to the paper titled Calibration of Storage Tanks in the Oil and Gas Sector Based on the Concept of Digital Metrology and Big Data Analytics – Part II.

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