*Research Article*

# A Compact Non-Intrusive Measurement System for Critical Dimensions and Calibration Chart Generation of Underground Fuel Tanks

**İlker Değirmencioğlu[1*], Savaş Barış[2], Yusuf Kaya[3]**

[1] Asis Automation and Fueling Systems Inc., Orcid ID: https://orcid.org/0009-0007-2756-3910, e-mail: ilker@asis.com.tr
[2] Asis Automation and Fueling Systems Inc., Orcid ID: https://orcid.org/0009-0006-3135-8293, e-mail: sbaris@asis.com.tr
[3] Asis Automation and Fueling Systems Inc., Orcid ID: https://orcid.org/0009-0007-6101-9978, e-mail: yusufkaya@asis.com.tr
[*] Correspondence: ilker@asis.com.tr; Tel.: +902162665521

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## Abstract

*This paper presents a compact, non-intrusive measurement system designed for determining the critical dimensions and generating calibration charts of underground fuel tanks via a 2-inch access port. The system employs a laser electronic distance measurement (EDM) device located outside the Zone 0 hazardous environment, with the beam directed into the tank through a mirror-based tilt mechanism. A key contribution is the ability to generate accurate calibration charts. Mirror tilt actuation is controlled via a linear actuator, where the non-linear relation between displacement and angular rotation can be resolved either through a lookup table or analytically as the mechanical linkage properties are known. The methodology involves coarse scanning for tank geometry estimation followed by targeted high-resolution scans at critical angles to derive diameter, length, dome geometry, and inclination. Real-world results demonstrate volumetric* *accuracy better than 0.2%, with an expected performance of 0.3% [1] in calibration chart generation, confirming that the system meets industrial standards for underground storage tank metrology, including OIML R 71.*

**Keywords:** CalibeX-Pro, Calibration Chart, Underground Fuel Tanks, Laser EDM, ATEX, Explosion-proof, Non-destructive Inspection, OIML R 71

## 1. Introduction

Underground fuel storage tanks require accurate dimensional measurements for maintenance and capacity verification. Access such tanks is often limited to small inspection ports, and internal environments may be hazardous due to flammable vapours, typically classified as ATEX Zone 0. Conventional measurement approaches include emptying the tank and filling it stepwise using calibrated containers, while measuring the liquid height, or alternatively using calibrated flow meters during fuel transfer. These methods are time-consuming, often taking several hours depending on the tank size, and carry significant operational risk since they involve transferring actual fuel. Furthermore, they require the presence of an additional storage tank or auxiliary infrastructure to handle the liquid.

Optical measurement techniques, such as laser scanners and LiDAR-based systems, have also been explored for tank geometry mapping [7,8,9]. While these methods can provide highly detailed surface data, they are not practical for tanks with very limited access, such as those with inspection ports as small as 2 inches.

In contrast, the method presented in this paper is rapid, non-intrusive, and does not require fuel transfer, achieving complete measurements in less than half an hour. Beyond generating a calibration chart for volumetric verification, the system also provides measurements of critical tank dimensions, including cylinder diameter, tank length, dome geometry and inclination. The device operates through access ports as small as 2 inches, while all electronics are housed in a Zone 1 certified Ex-d enclosure, ensuring compliance with explosion-protection standards [4,5]. The system integrates a laser distance meter, precision pan and tilt actuation, mirror-based deflection, and a custom 3-D reconstruction algorithm, achieving sub-percent volumetric accuracy under real-world conditions.

The approach aligns with recognized industrial and metrological standards, including OIML R71 guidelines for volumetric accuracy in capacity determination [1]. By integrating these standards into a compact, rapid, and safe measurement system, the method provides a practical solution for modern underground fuel tank metrology.

This paper extends the intellectual property foundation of European Patent EP2212658A1 (Kaya, 2010), which is assigned Asis Automation and Fueling Systems Inc. [2]
The present work significantly advances that concept by;

i. Using axial rod-driven mirror deflection for compact, in-aperture optical steering
ii. Enabling measurement of tanks beyond horizontal cylindrical geometries
iii. Reducing device size for small access ports
iv. Replacing purely empirical lookup tables with an analytical model of the actuation linkage where linkage parameters are known
v. Introducing a proprietary 3-D reconstruction algorithm for full geometric recovery and calibration-chart generation.

The current system also implements an ATEX-compliant explosion-proof architecture and mirror-based optical deflection; together these improvements yield sub-percent volumetric accuracy in real-world tests and extend the practical applicability of the patented idea.

## 2. Materials and Methods

### 2.1 Materials

The system consists of two main components:

i. An external Ex-d protected enclosure housing all electronic and optical elements.
ii. A mechanical extension that fits through the 2-inch access port into the tank.

The enclosure contains a laser distance meter aligned with a protective safety glass. The laser beam passes through this window into the tank interior. At the lower end of the mechanical shaft, approximately 50 cm below the entry port, a mirror reflects the laser beam at adjustable tilt angles.

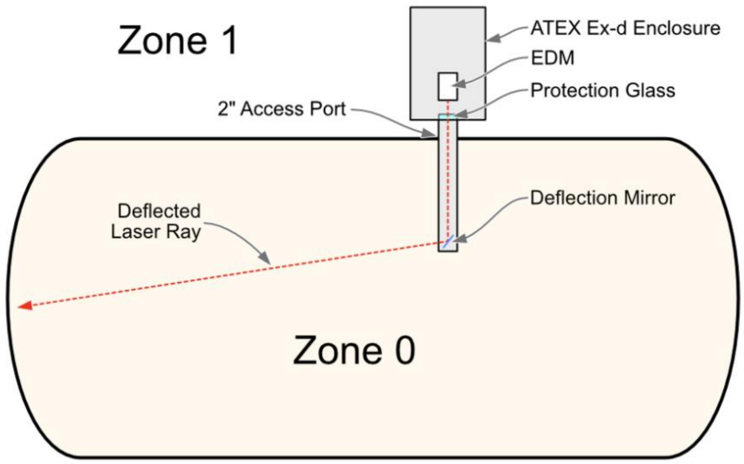


*Figure 1: Schematic overview of the compact non-intrusive measurement system.*

### 2.1.1 Pan and Tilt Mechanisms

The pan axis corresponds to the axial rotation of the main shaft, which enables circumferential scanning of the tank's inner surface. This motion is driven by a single motor through a reduction gear. The entire shaft assembly, including the tilt mirror, EDM, and the linear actuator, is rotated together. To ensure angular accuracy and minimize the effects of mechanical backlash or motor inconsistencies, a high-precision rotary encoder measures the pan position. As absolute tank orientation is not required for volumetric analysis, homing of this axis is unnecessary.

The tilt axis is realized through a linear actuator that adjusts the mirror angle by axially moving a control rod. Approximately 25 mm of actuator stroke corresponds to about 180° of optical beam deflection, achieved through only 90° of actual mirror rotation. The mechanical coupling between actuator displacement and mirror tilt is non-linear. To address this, both a lookup-table-based calibration or an analytical model derived from the known linkage geometry may be used. Also, a dedicated linear encoder is integrated on the actuator to provide accurate position feedback.

The EDM unit is mounted outside the tank in the Zone 1 environment inside the Ex-d Enclosure, directing a laser beam through a sealed optical window toward a deflection mirror positioned inside the tank below the access port.

To establish a repeatable reference for the tilt axis, a homing sensor is implemented using a photo detector mounted near the EDM head. When the mirror is precisely perpendicular to the laser beam, the reflected signal triggers the sensor, defining the mechanical zero of the tilt axis. This homing process is critical to ensure accurate reconstruction of the scanned geometry. Because the tank inclination is also a required parameter, tilt measurements must be referenced to the device body, as the system incorporates an inclinometer to determine the tank's true orientation relative to the device.

#### 2.1.2 Explosion Protection

To comply with ATEX Zone 0 [3,4] safety requirements, no active electronics are placed inside the tank. All electronic components, including the EDM, motors and motor drivers, actuators and control electronics are housed within a certified Zone 1 Ex-d enclosure, which provides flameproof protection while allowing full control of the scanning mechanism. The EDM laser unit is certified according to ATEX/IECEx optical safety standards (Ex op is) [5,6], ensuring that the emitted laser energy cannot ignite the Zone 0 atmosphere, even in the event of a component failure.

Only passive mechanical components, including the main shaft, tilt mirror, linear actuator rod, and deflection mirror extend into the tank. These elements transmit motion and optical energy without introducing any electrical hazard. The laser beam passes through an optical window, designed to withstand flame propagation while maintaining optical clarity. Mechanical components are fabricated from metal alloys certified as non-sparking, further mitigating ignition risk in the hazardous environment.

The mirror redirects the beam across the inner tank surface, while the returning reflection travels along the same path to enable distance measurement without any electronics in the Zone 0 area.

The mechanical and optical interface is designed to avoid contact with tank surfaces and eliminate any risk of sparks or frictional hazards. The linear actuator remains entirely outside Zone 0, providing precise and repeatable tilt control for the mirror. This arrangement ensures that high-precision measurements can be performed safely while fully complying with ATEX/IECEx regulations, thereby minimizing operational risk [3,4,5].

### 2.2 Methods

The measurement procedure begins with a coarse scan across both pan and tilt axes. From this initial dataset, the tank axis orientation is estimated by minimizing the spread between maximum and minimum distances along X and Y planes. Subsequent detailed scans are performed at computed pan angles, especially those perpendicular to the tank cylinder axis, to capture cross-sectional profile. By collecting distance data across incremental tilt angles, the system reconstructs tank sections and evaluates circularity versus ellipticity. Additional scans at around 90° offset allow for full reconstruction of the tank length and dome geometries. Ceiling measurements combined with inclination sensor data provide the overall tank tilt.

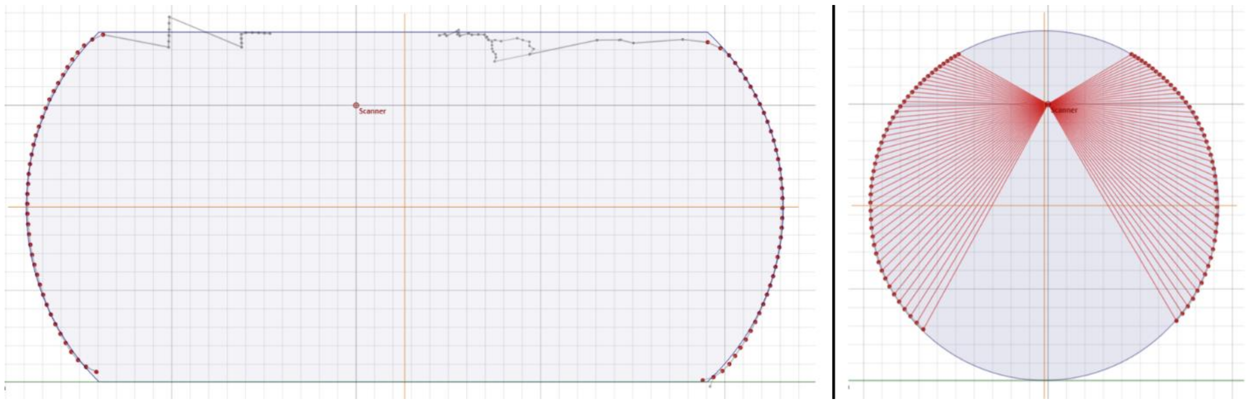


*Figure 2: Cross-sectional scan views obtained from the analysis software.*

Figure 2 illustrates how the mirror-deflected laser beam sequentially samples the tank's inner surface to reconstruct its full geometry. Each point shown in red indicates a valid laser distance measurement, from which circular or elliptical cross-sections are fitted to extract tank geometry parameters such as diameter, length, and dome curvature.

After the tank model and critical dimensions are determined, the internal volume is divided into horizontal slices, with slice planes oriented such that their normal vectors are parallel to the gravity vector measured by the inclinometer, ensuring that the calculated liquid levels correspond to actual fuel surfaces rather than the tank's geometric axis. The volume of each slice is computed using standard geometric integration between successive cross-sections, allowing accurate determination of cumulative capacity as a function of fill height. By incrementally summing these slice volumes, a detailed calibration table is generated, linking liquid level to contained volume in accordance with metrological standards [1].

## 3. Results

To evaluate measurement repeatability, five consecutive scans were performed on the same underground fuel tank without altering the setup or environmental conditions. The measured diameter, length, and computed volume are listed in Table 1.

| Scan No | Diameter (mm) | Length (mm) | Volume (Lt) |
|---|---|---|---|
| 1 | 1888.1 | 4095.8 | 10468 |
| 2 | 1887.1 | 4095.1 | 10447 |
| 3 | 1888.4 | 4097.1 | 10465 |

| | | | |
|---|---|---|---|
| 4 | 1888.7 | 4097.4 | 10469 |
| 5 | 1888.2 | 4096.5 | 10462 |

*Table 1. Repeatability of tank dimension and volume measurements obtained from five consecutive scans using the proposed system.*

The measured tank diameter and length showed standard deviations of 0.56 mm and 0.93 mm, respectively, corresponding to less than ±0.03% relative variation. The computed tank volume exhibited a repeatability of ±0.10% (1σ = 8.7 L). These results confirm that the proposed scanning system provides highly stable geometric measurements suitable for precision volume estimation.

The high repeatability of the geometric measurements demonstrates the system's mechanical stability, precise actuation, and consistent optical alignment. Considering that typical tank calibration tolerances allow volumetric deviations up to ±0.3% [1], the obtained ±0.10% repeatability confirms that the proposed system not only meets but also exceeds standard metrological expectations for underground tank inspection and calibration chart generation.

This work provides a robust, compact, and rapid solution for underground fuel tank metrology, extending previous patent concepts (EP2212658A1) [2], through mirror deflection, analytical actuation modelling, and advanced 3D reconstruction. The system demonstrates that accurate, safe, and efficient tank measurement is achievable in real-world industrial conditions, providing operators with both volumetric and geometric insights.

## Discussion and Conclusion

The experimental results confirm that the proposed measurement system achieves sub-percent volumetric accuracy, with real-world tests yielding better than ±0.1% deviation, surpassing the expected ±0.3% benchmark [1]. This validates both the mirror-based deflection mechanism and the proprietary 3D reconstruction algorithm, demonstrating that precise geometric information can be obtained even through restricted access ports as small as 2 inches.

The system's analytical tilt modelling, combined with pan/tilt encoders and homing procedures, ensures repeatable measurements across sessions. Unlike conventional methods that require transferring fuel or extensive manual measurement, the system provides rapid assessment of critical tank dimensions, including cylinder diameters, tank length, dome geometry, and inclination, in a single operation less than thirty minutes.

This not only reduces operational risk but also provides detailed geometric data that cannot be obtained by simple volumetric methods.

Comparison with other optical methods shows that while terrestrial LiDAR and laser scanning offer high-resolution data [7,8,9], they are impractical for tanks with minimal access. The proposed solution bridges this gap by combining explosion-proof design, precise actuation, and optical deflection to achieve high accuracy in constrained conditions.

From a practical standpoint, the system enables efficient calibration chart generation, detection of tank deformations and assessment of tilt, supporting operational decisions and metrological verification. With all electronics located in a Zone 1 Ex-d enclosure and certified optical components, ensures safe deployment in hazardous environments without limiting measurement precision.

## 4. Acknowledge

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