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New Method for Calibration of Horizontal Fuel Tanks

V. Knyva, M. Knyva
Department of Electronics and Measurements Systems, Kaunas University of Technology, Studentu St. 50, LT-51368, Kaunas, Lithuania, phone: +370 37 300535
mindaugas.knyva@ktu.lt

***Abstract*—Nowadays, when price of the fuel increases rapidly each day, the accurate control of the fuel tanks in the fuel stations becomes of a great importance. The underground horizontal fuel tanks in the stations can be easily deformed during the installation or affected by geological or other reasons, thus full volume and volume chart of the tank can be corrupted. Under these circumstances the recalibration of the tank volume chart becomes very important. For the calibration of horizontal fuel tanks in Lithuania the liquid filled method is used. In this article a new method, based on inside 3D laser scans of horizontal fuel tank and advanced data processing, was presented.**

***Index Terms*—Calibration, Fuel storage, laser, level measurement.**

I. Introduction

Nowadays, when price of the fuel increases rapidly each day, the accurate control of the fuel tanks in the fuel stations becomes of a great importance. The underground horizontal fuel tanks in the stations can be easily deformed during the installation or affected by geological or other reasons, thus full volume and volume chart of the tank can be corrupted. Under these circumstances the recalibration of the tank volume chart becomes very important. For the calibration of horizontal fuel tanks in Lithuania the liquid filled method is used.

In this article a new method, based on inside 3D laser scans of horizontal fuel tank and advanced data processing, will be presented.

II. Calibration of horizontal fuel tanks

Horizontal tanks can be calibrated by using standard [1] or verification techniques [2]. In Lithuania the last mentioned method is used. The verification technique is followed by these steps:

1) *Inspection of the fuel tank;*
2) *Preparation of measurement gear and fuel tank for verification;*
3) *Fuel tank test;*
4) *Primary verification of fuel tank;*
5) *Volumetric calibration;*
6) *Preparation of graduation table.*

In this article the volumetric calibration of fuel tank will be explored in order to show other alternative ways, which can be used in the volumetric calibration practice. In general - volumetric calibration is performed by adding liquid, usually cold water to a fuel tank in small volumes (see figure 1). It depends of the volume of the tank and may vary from 50 to 400 liters. The liquid can either be metered in a calibrated flow meter or poured from a calibrated volumetric prover. Basically, in fuel tank calibrated flow metering systems are used. After the new volume is added the level is measured and recorded by electronic level gauge. All temperature corrections, provoked by the water temperature change must be indicated in the graduation table. If the fuel tank service conditions for hydrostatic pressure are different from the calibrating conditions, the volume error will occur. Thus corrections for hydrostatic pressure must be made. For those fuel tanks which were installed on different angles from which they were calibrated (installation angles may vary because of geological reasons or wrong installation) must be made one more correction in order to obtain a precise data. If the tank inclination is different from the calibrated condition, there will be errors in the reported volume. The volumetric calibration has the limitations which with some corrections gives satisfactorily results. Therefore it is important to mention, that volumetric calibration process requires a certain amount of water subject to the fuel tanks capacity and when the process is finished the fuel tanks must be cleaned again to avoid further incorrect tank usage.

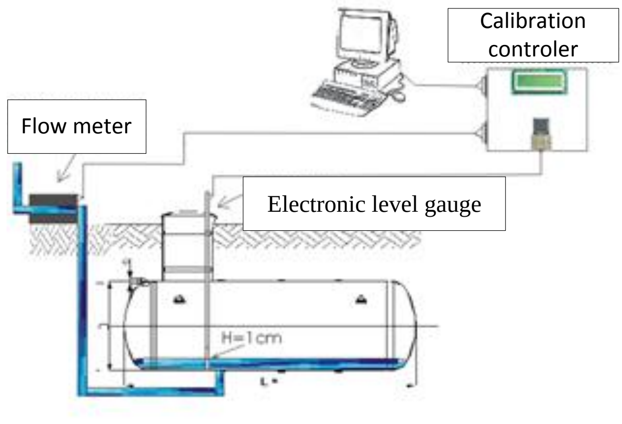

Fig. 1. Calibration of horizontal fuel tanks.

III. 3D laser scan of fuel tank

A new approach to the calibration of horizontal fuel tanks

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is based on the 3D laser scans. A tank can be scanned from inside using accurate laser [3], [4]. The 3D picture of the scanned tank presented in the figure 2. Volume of the fuel tank can be calculated and measurement uncertainty can be estimated from scanned results using data processing algorithms.

As the aim of this article is to show the advantage of the 3D method, the time saving and water waste problems will be analyzed further. Practice of calibration time shows that while calibrating 30-40 m^3 fuel tanks using liquid fill method take 4 to 5 hours. 3D scanner can scan whole tank in 5 minutes [4]. A full tank scan requires 2 or 3 scans. The number of scans depends on the volume of the tank. Data processing takes another 5 minutes. The calibration with preparations takes around 30–45 minutes.

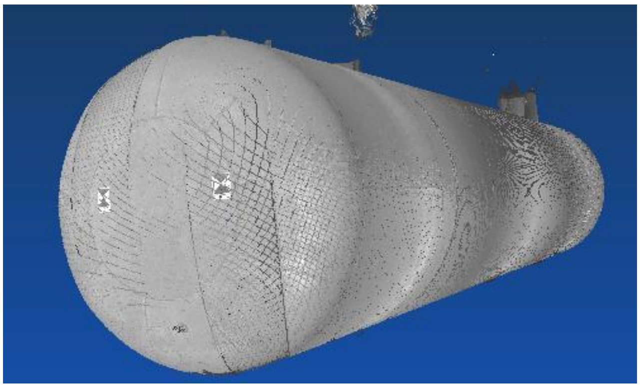

Fig. 2. 3D scan of the fuel tank.

New scanning technique eliminates water in calibrating process. As usage of water is very important in calibrating fuel tanks, it generates water waste and delivery difficulties in locations such as small villages or speedways. A car-tanks must be used for water transportation, thus additional time and money are required to fulfill the process. Calibration of the 40 m^3 fuel tank costs around 30–35 Lt (8-10 Euro) per 1 m3 of the tank. Whole tank 1200–1400 Lt (320–400 Euros). Water adds another 300–400 Lt (85–115 Euros) to the calibration expenses.

IV. VOLUME CALCULATIONS OF 3D SCANNED FUEL TANK

Due to the undisclosed agreement the authors of this article have signed, the calculation algorithm will be described in a simplified form. Algorithms for finding “0” point, “rubbish” points filtering, linearization of scanned data will be skipped.

Scanned 3D tank can be divided into 2D layers as showed in figure 3. Area of fuel tanks 2D layer can be calculated using equation [3]

$$A_j = \frac{1}{2}\sum_{i=0}^{N-1}(x_{i,j}y_{i+1,j} - x_{i+1,j}y_{i,j}), \quad [m^2], \tag{1}$$

where A_j –area of j layer, $j = 1, \dots H_{max}/\Delta h$, $H = 1, \dots H_{max}(cm)$ fuel tanks filling level, H_{max} – maximal filling level, Δh - scanning step (mm), x_i and y_i – j perimeter points coordinates of j layer (m), N - j layer’s point number of perimeter.

Then volume of the fuel tank can be calculated as sum of all 2D layers

$$V_H = V_{H-1} + \sum_{j=(H-1)\cdot M+1}^{H\cdot M} A_j \cdot \Delta h, \quad [dm^3], \quad M = \frac{10}{\Delta h}, \tag{2}$$

where M – number of layers in 1 cm.

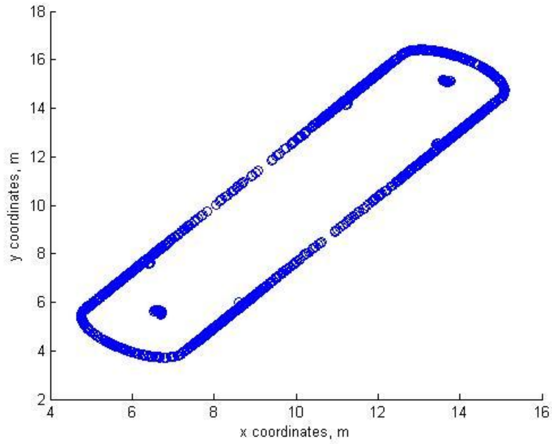

Fig. 3. 2D layer of fuel tank.

V. UNCERTAINTY ESTIMATION

Standard uncertainty of the fuel tanks calibration using liquid fill method must be less or equal $\pm 0.3\%$ as described in standard [2]. The uncertainty of the 3D scanning method can be calculated as follows.

An absolute standard uncertainty of fuel tanks j layer area A_j can be expressed [5]

$$uA_j = 2 \cdot uC_j \cdot \frac{A_j}{C_j}, \quad [m^2], \tag{3}$$

where uC_j – absolute standard uncertainty of j layers perimeter, C_j – perimeter of j layer:

$$C_j = \sum_{i=0}^{N-1} \sqrt{(x_{i,j} - x_{i+1,j})^2 + (y_{i,j} - y_{i+1,j})^2}, \quad [m], \tag{4}$$

$$uC_j = \sqrt{uX_j^2 + uY_j^2}, \quad [m], \tag{5}$$

where uX_j – absolute standard uncertainty of measurement of X axis coordinates of j-layers perimeter, uY_j – absolute standard uncertainty of measurement of Y axis coordinates of j-layers perimeter:

$$uX_j = \sum_{i=0}^{N-1} uX_{i,j}, \quad [\text{m}], \tag{6}$$

$$uX_{i,j} = \sqrt{uX_{D_{i,j}}^2 + uX_{\theta_{i,j}}^2 + uX_{\varphi_{i,j}}^2}, \quad [\text{m}], \tag{7}$$

$$uX_{D_{i,j}} = u(D) \cdot \frac{x_{i,j}}{D_{i,j}}, \quad [\text{m}], \tag{8}$$

$$uX_{\theta_{i,j}} = -u(\theta) \cdot D_{i,j} \cdot sin(\theta_{i,j}) \cdot \cos(\varphi_{i,j}), \quad [\text{rad}], \tag{9}$$

$$uX_{\varphi_{i,j}} = -u(\varphi) \cdot D_{i,j} \cdot cos(\theta_{i,j}) \cdot sin(\varphi_{i,j}), \quad [\text{rad}], \tag{10}$$

where $uX_{i,j}$ – absolute standard uncertainty of j layers perimeters i point X coordinates measurement, $uX_{D_{i,j}}$ – absolute standard uncertainty of j layers perimeters i point X coordinates distance from laser measurement, $uX_{\theta_{i,j}}$ – absolute standard uncertainty of j layers perimeters i point X coordinates measurement of horizontal angle, $uX_{\varphi_{i,j}}$ – absolute standard uncertainty of j layers perimeters i point

X coordinates measurement of vertical angle, $x_{i,j}$ – X coordinate of j layer perimeters i point, $D_{i,j}$ – distance from coordinate center to j layer perimeters i point, $u(D)$ – absolute standard uncertainty of distance measurement, $u(\theta)$ – absolute standard uncertainty of horizontal angles measurement, $u(\varphi)$ – absolute standard uncertainty of vertical angles measurement.

Same equations are used for estimation of Y coordinates measurement absolute standard uncertainty

$$D_{i,j} = \sqrt{x_{i,j}^2 + y_{i,j}^2 + z_{i,j}^2}, \quad [\text{m}], \tag{11}$$

where $x_{i,j}$, $y_{i,j}$, $z_{i,j}$ –perimeter coordinates of j layer i point:

$$sin(\varphi_{i,j}) = \frac{z_{i,j}}{D_{i,j}}, \tag{12}$$

$$\cos(\varphi_{i,j}) = \sqrt{1 - sin^2(\varphi_{i,j})}, \tag{13}$$

$$sin(\theta_{i,j}) = \frac{y_{i,j}}{D_{XY_{i,j}}}, \tag{14}$$

$$D_{XY_{i,j}} = \sqrt{x_{i,j}^2 + y_{i,j}^2}, \tag{15}$$

$$\cos(\theta_{i,j}) = \sqrt{1 - sin^2(\theta_{i,j})}. \tag{16}$$

Absolute standard uncertainty of distance measurement can be expressed

$$u(D) = \frac{\Delta D}{2\sqrt{3}}, \quad [\text{m}], \tag{17}$$

where ΔD – scanner distance measurement linearity error.

Absolute standard uncertainty of horizontal angles measurement can be expressed

$$u(\theta) = \frac{\Delta\theta}{2\sqrt{3}}, \quad [\text{rad}], \tag{18}$$

where $\Delta\theta$ – scanners accuracy of horizontal angle measurement.

Absolute standard uncertainty of vertical angles measurement can be expressed

$$u(\varphi) = \frac{\Delta\varphi}{2\sqrt{3}}, \quad [\text{rad}], \tag{19}$$

where $\Delta\varphi$ – scanners accuracy of vertical angle measurement.

And finally absolute standard uncertainty of the fuel tanks filling level H and volume V_H can be expressed

$$uV_H = \sum_{j=1}^{H \cdot M} uA_j \cdot \Delta h, \quad [dm^3], \tag{20}$$

where $H = 1, \dots H_{max}(cm)$, M – number of layers in 1 cm.

Fuel tank expanded absolute uncertainty

$$UV_H = 2 \cdot uV_H. \tag{21}$$

VI. EXPERIMENTAL MEASUREMENT RESULTS

For experimental verification of the 3D scanning method, mathematical/programical model of scanned data processing algorithm were created in MATLAB. In order to perform the process faster, the application was converted to C language which is used in LABWINDOWS/CVI environment. Mathematical/programical data processing model was validated using techniques explained in author's article [6].

Experimental 3D laser scans were performed with 4 different fuel tanks. Volume of 1 was 15 m^3, 2 -45 m^3, 3 - 30 m^3 and 4 - 100 m^3.

For all fuel tanks relational error between 3D scanning method and volumetric water filling method were calculated. In figure 4 dependence of relational error according to filling level of the tank were presented. As can be seen from the 4 figure negative relational error dominates in the level range. This can be explained by scattering of scanned data after merging few scans. Filtration of this data can reduce relational error.

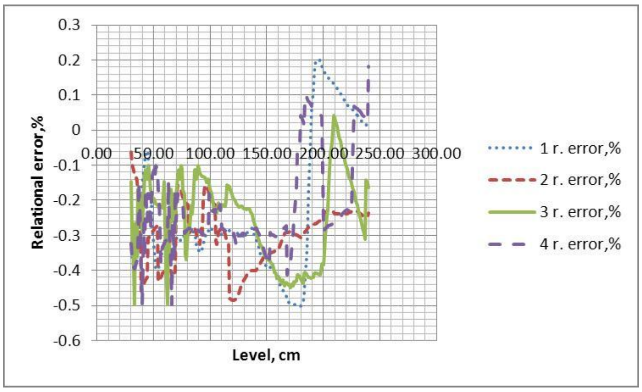

Fig. 4. 3D scanning vs. water filling measurement relational error.

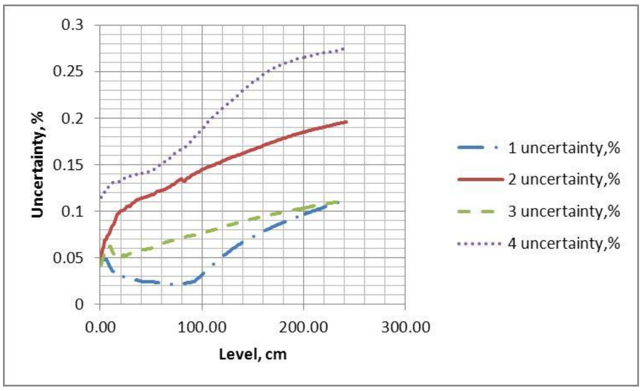

Fig. 5. Absolute standard uncertainties.

As can be seen from figure measurement expanded absolute standard uncertainty's of all fuel tanks fits $\pm 0.3\%$ boundary as required by standard [2] and Lithuania's verification methodic [1].

This article presented a new approach to calibration of horizontal fuel tanks. This practice is very useful in solving time and water waste problems and after some adoption 3D scanning method can be used for calibration of vertical tanks or various form tanks.

VII. CONCLUSIONS

1. New method for calibration of horizontal fuel tanks using 3D laser scanning techniques and data processing algorithms presented, fuel tank volume measurement expanded absolute standard uncertainty estimated. Main advantages of the 3D method – time and water savings were analyzed. Experimental measurements showed that using 3d

scanning technique calibration time can be reduced 3-4 times.

2. Experimental results showed that measurement expanded absolute standard uncertainties of 4 different volumes (1 - 15 m^3, 2 -45 m^3, 3 - 30 m^3 and 4 - 100 m^3) fuel tanks fits $\pm 0.3\%$ boundary as required by standard and Lithuania's verification methodic

3. In comparison between volumetric liquid fill and 3D scanning methods relational error stays around $+0.2 \div -0.4\%$. This can be explained by scattering of scanned data after merging few scans. Filtration of this data can reduce relational error.

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