Design of fuel measurement system for LNG powered VLCC

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Abstract. It is very difficult to measure the capacity of large LNG tank accurately, which is an important factor to restrict the large-scale LNG vessels. According to the hull structure characteristics and storage tank characteristics of VLCC, selected the type C of LNG fuel storage tanks reasonably. And then analyzed the particularities of the tank capacity measurement and the characteristics of metering equipment. According to the structure of type C tank and the tilting of the vessel during the operation, established the mathematical model of the tank capacity measurement. According to the mathematical model, designed and developed the tank capacity measurement software. The modeling scheme and software development program have some reference significance. It can provide a reference for the capacity measurement of type C tank on large LNG powered vessels in the future.

1. Introduction
International conventions are becoming more stringent for SOX and NOX emission standards. Including our country, many regions of the world have designated areas for restricted emissions.[4, 8, 9] LNG (Liquid Natural Gas) is clean energy, which meets the requirements of international conventions, and its operating cost is lower than the marine fuel oil. [10] LNG taking over the place of fuel oil has been put on the agenda, LNG powered ships have great market prospects and development space. MAN B & W and Wärtsilä have conducted effective research on LNG diesel and gas supply system, technology maturity, but now LNG powered ships are mainly used for small ships in the river and offshore.[1, 5, 6] Large-scale ocean vessels have large fuel storage tanks, the operation process is also affected by the inclination of the ship, accurate measurement of tank capacity is an important factor for restricting the development of large-scale LNG powered ships. [3] Based on the background, in this paper, through the rational selection of storage tanks, the research and software development of LNG tank metering system are carried out.

2. Lectotype and arrangement of lng storage tank
In this paper, the operating large oil tanker (VLCC) of a company as the object of study, And select Qingdao through the Singapore to the Middle East as a typical route. [7, 11] Table 1 shows the main parameters of VLCC.

| Main Parameters       | Value     |
|-----------------------|-----------|
| Total Length          | 330 m     |
| Operating Speed       | 15.6kn    |
| Type Wide /           | 60m       |
| Host Model            | ME-GI     |
| Dwt                   | 296600t   |
2.1 The lectotype of lng storage tank
The LNG tank of LNG powered ship is usually equipped with a separate tank, mainly divided into type A, B, and C. [2] Based on comparative analysis and ship research, type C and free-type of full-tank storage tank is selected as LNG tank for VLCC in this study. Type C of LNG storage tank is lower cost in construction and design, no maintenance. In order to reduce the shaking, easy to measure, marine LNG tanks are usually designed as cylinders in the middle, both ends of the hemisphere or ellipsoid head. In this paper, the design of the C-type tank is two ends of the standard ellipsoid, the middle part is a cylinder, as shown in Figure 1.

![Figure 1. The shape of type C tank.](image)

2.2 The arrangement of LNG tank
Two ways to arrange LNG storage tanks, one is the deck arrangement, the other is the cabin arrangement. According to the specification of natural gas powered ship and the characteristics of VLCC, select deck arrangement, the tail deck of the hull does not have enough space, so that the installation position of the LNG tank is set at the front main deck of the ship's superstructure. According to the comprehensive analysis of ship stability, safe operation, fuel transferring and fuel storage, the LNG tank is designed as two type C of tank, and its volumes is same. layout on the port and starboard respectively Design the 3D layout of storage tank on the deck of VLCC by solidworks 3D software, the effect is intuitive and clear. as shown in Figure 2. In short, the tank is arranged on the deck, conducive to ventilation, to prevent the accumulation of fuel gas, and the VLCC is more space than the main deck of the other vessels, sufficient to meet the relevant requirements of IGF.

![Figure 2. The LNG storage tank layout of VLCC.](image)

3. The specificity of storage tank capacity measurement and level measurement device
The significance of accurate tank capacity measurement in the operation of the ship: 1) During the voyage, know the storage quantity of each tank at any time, timely replace the storage tank, conducive to the stability of the ship and draught adjusting, to ensure sailing safety; 2) Timely know the remaining,
according to the daily consumption, calculate sailing time and distance accurately. 3) When fuel is filling, accurately calculate the total amount of fuel pre-injection and the bunkering quantity of the tank, control the bunkering process at any time, ensure safety, avoid disputes in the measurement process.

3.1 The specificity of storage tank capacity measurement
According to the characteristics of LNG and the layout of C-type tank, in this paper, the liquid level calculation method is used to measure tank capacity. According to the liquid level measurement, ship draft error and the Angle of Inclination, the volume of the tank is calculated by table of tank capacities or by computer software. However, the capacity measurement of LNG tank is very different from other fuel tanks: (1) LNG storage tank is a sealed pressure vessel, do not measure through measuring ruler and measuring tube. (2) LNG tank is in the low temperature (-163℃), and therefore cannot be measured with a common level gauge. (3) The normal storage level limit of LNG storage tank is 15-95%, the upper part is the gas, which should also be calculated within the tank capacity.

3.2 Level measurement device of LNG tank
The liquid level of LNG tank do not be measured manually, and therefore need to install the level gauge for measurement, the level gauge is usually installed in the middle of the cylinder. The temperature of tank is very low and the pressure of tank is higher, so the level gauge can not be directly in contact with LNG. The study uses a servo level gauge, the level gauge is a non-contact level gauge, able to be completely isolated with the measured medium, the level gauge is not damaged. As the fuel inlet is installed at the bottom of the tank, when the liquid level is low, the swirl is generated by bunkering, which will have an impact on the level gauge, the accuracy of the liquid level indication is affected, so the level gauge is mounted on the bellows. The continuous automatic level measurement device must be equipped in the LNG tank level measurement, the study uses LTD level gauge (Liquid level - temperature - density automatic measurement device). At the same time, the flow meter can be installed in the filling pipe to measure volume.

4. The establishment of the measurement model
In this paper, two type C of tanks are used for symmetrical and longitudinal arrangement. The main measurement parameters of the tank are shown in Table 2. In the operation, stowage, wind and waves will cause the ship to produce heel and trim, thus causing the measurement error.

| parameter                  | Value          |
|----------------------------|----------------|
| Cargo volume               | 2257.48m³     |
| The diameter of outer tank | 11300mm       |
| The length of outer tank   | 25600mm       |
| The diameter of inner tank | 11000mm       |
| The length of inner tank   | 20000mm       |
| Head thickness             | 15mm          |
| Head deep                  | 2800mm        |
| The size of strengthen circle | T1000×400mm |

4.1 The height error is caused by the heel
When bunkering at sea, the impact of sea water on the ship, causing the ship to shake left and right, fuel Level height Error of LNG Storage Tank is caused by the heel angle, as shown in Figure 3.

The cross section of the tank is analyzed, find the actual level height h:

$$h = r - (r - h') \cos \gamma$$  \hspace{1cm} (1)

formula: r represents the cross-sectional radius of the tank cylinder, h" is the height of the liquid level
measured after the tilt. $\gamma$ is the $y$-axis angle of the section before and after the tilt.

![Figure 3. Tank model 1.](image)

4.2 The height error is caused by the trim

When bunkering at sea, the impact of seawater on the ship, causing the ship to shake front and back, fuel level height Error of LNG Storage Tank is caused by the trim angle, as shown in Figure 4.

![Figure 4. Tank model 2.](image)

The volume of the ellipsoid:

$$V = \left(2257.48 - \pi \times 5.5^2 \times 20\right) \div 2 = 178.89 \quad (2)$$

Section formula:

$$y = -x^n \tan \alpha + h + 10 \tan \alpha - 5.5 \quad (3)$$

$$x = \left(h - 10 \tan \alpha - 5.5 - y\right) + \tan \alpha \quad (4)$$

When $y = -5.5, \ 0 < x < 20$;

The volume of the upper part of the left ellipsoid:

$$V_1 = 2 \int_{x_1}^{b} \int_{a}^{b - r^2 \tan \alpha} \left(1 - \frac{x^2}{a^2} - \frac{y^2}{b^2}\right) dy \ dx \quad (5)$$

The volume of the middle part:

$$V_2 = \frac{1}{2} \left(\frac{\pi r^2}{360} \times \csc \frac{b_1 + r}{r} - \frac{1}{2} r^2 \sin 2\csc \frac{b_1 + r}{r} \times \frac{r - h - 10 \tan \alpha + 5.5}{\tan \alpha}\right) \quad (6)$$

Total volume:

$$V = V_2 + 178.89 - V_1 \quad (7)$$

When $y = -5.5, x > 20$; and $x = 0, y < 5.5$;

The volume of the middle part:

$$V'_2 = \frac{1}{2} \left(\frac{\pi r^2}{360} \times \csc \frac{b_1 + r}{r} - \frac{1}{2} r^2 \sin 2\csc \frac{b_1 + r}{r} + \frac{\pi r^2}{360} \times \frac{2b^2}{2} - \frac{1}{2} r^2 \sin 2b^2\right) \times 20 \quad (8)$$

The volume of the upper part of the right ellipsoid:
\[ V_3 = 2 \int_0^b \left[ (x-20)^2 \right]^{1-(x-20)^2} \sqrt{1-\frac{(x-20)^2}{a^2}} \frac{y^2}{b^2} dy dx \]  

Total volume:

\[ V = 178.89 - V_1 + V_2 + 178.89 - V_3 \]  

When \( x=0, y>5.5 \);

The volume of the middle part:

\[ V' = \frac{1}{2} \left( \pi r^2 + \pi r^2 \frac{2\beta'}{360} - \frac{1}{2} r^2 \sin 2\beta' \right) \times 20 \]  

Total volume:

\[ V = 178.89 + V'_2 + 178.89 - V_3 \]  

5. **The design and function of metering software**

The software is in the Visual Studio 2013, using C# language for development. Based on the feature of C# is completely object-oriented, the LNG tank capacity measurement software is developed, which can run in the WINDOWS operating system.

5.1 **The design of main interface**

![Image](image.png)

Figure 5. The main interface of the software.

The main interface of the software is shown in Figure 5. There are three operation buttons: "parameter setting", "calculation results" and "exit system". Set the initial value of the LNG storage tank by clicking the "parameter Setting" button, click the "calculate results" button to get the result, click the "Exit System" button to exit the system.

5.2 **The design of parameter setting interface**

Click the "preferences setting "button, enter the initial value setting interface as shown in Figure 6.
Figure 6. The Initial value setting interface.

In this interface, can be set on the ship draft, the heel angle, the pressure of tank, the liquid level of tank, but set within a certain range. After the parameters are set, click the "confirm" button, the interface displays the tank level, as shown in Figure 7.

Figure 7. The metering interface.

5.3 The design of calculation results interface
Click the "Calculate Results" button, the background program is automatically calculated, the result of the operation is shown in Figure 8. The total capacity is the sum of two LNG tank capacity, the punching rate is the percentage of tank capacity. This also shows the estimated number of days that LNG is expected to burn.
6. Conclusion

In this paper, the measurement system of marine large storage tank is studied, the tank section is calculated according to the change of heel and trim angle, the mathematical model of the tank metering is established and the software is developed.

In this paper, software developers choose 67% of the maximum operating power, and the ship is affected by wind and waves, daily fuel consumption is different, while the port is different, fuel density and calorific value will be different. So when calculating, according to the actual situation, the related parameters should be corrected to ensure the accuracy of the results.

At present, the marine storage tank measurement of 300,000-tons VLCC is not yet mature. This paper has a certain reference for the mathematical modeling scheme and software development of the tank capacity measurement, which can provide a reference for the future measurement of large-scale LNG marine storage tanks.

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