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Accuracy Verification of a Diaphragm Gas Meter

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***Abstract* - Metrology is a key factor in manufacturing and social life as well. One of the most common measuring equipment is flow meters, which can detect and measure the passing flow accurately. Diaphragm gas meters are simple tools that can measure the gas volume used in families. Nowadays, consuming gas is becoming increasingly popular in areas where it is difficult to use electricity, so designing and building a gas supply system is necessary. To manufacture a gas meter for each family, studying and calculating a sample of gas meters must be conducted. Based on the model of a diaphragm gas meter G1.6, this study calculated the error of this equipment to approximately +1%, based on some important parameters, such as ratio, gas volume, then proposed manufactured error permission of the valve, the part mostly decided the accuracy of the gas meter. Calculations were also verified by results from a testing process using the bell jar method. The findings of this research could be used as a reference for calculating, designing, and manufacturing a diaphragm gas meter further.**

Keywords: Diaphragm gas meter, Gas flow calculation, Accuracy evaluation, Bell jar method.

I. INTRODUCTION

Measuring the flow of liquids and gases is one of the important fields in science, production, and life. It is not only popular in the transportation network of oil, gas, fuel, etc., but also in industrial equipment to control the flow involved in various production processes such as reactors and textile factories, clean water supply equipment, etc. Not as common as liquid flow measuring devices, gas flow measuring instruments (referred to in this article as “gas meters”) still retain an important position in the quantification and control of gases for various uses such as gas supply in industry and civil use. Depending on certain technical and usage conditions, gas meters have many different types such as rotor type, piston type, turbine type, and diaphragm type [1].

Diaphragm gas meters are the most used type due to their simple structure and operation. Figure 1 is a diaphragm gas meter, model G1.6 imported from China.

Figure 1: Diaphragm gas meter G1.6

The structure of the G1.6 diaphragm gas meter is shown in Figure 2. There are two diaphragms made from rubber material in the casting of the meter. They have a truncated cone shape, dividing the measuring system into four chambers. Gas pressure from the supply line acts on the surface of the two diaphragms, causing them to bulge, which in turn transmits motion to the four-bar linkage mechanisms, which in turn rotates a four-compartment valve. Each chamber of the valve communicates with a chamber. At the same moment, there is at least one compartment connected to the air inlet and one compartment connected to the air outlet. When the valve rotates, the mechanical transmission also operates because it is connected to the pin on the valve cover. The mechanical transmission is designed as a 10-digit gear, helping to display the amount of gas passing through the meter with a resolution of 1 liter.

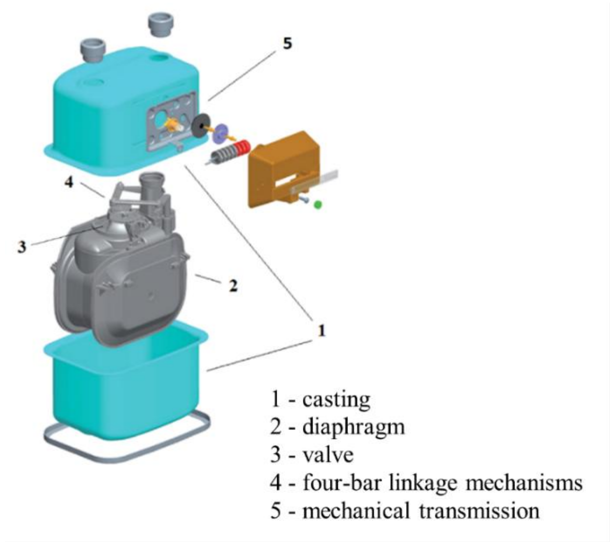

Figure 2: Structure of G1.6 meter [2]

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An indispensable factor in evaluating whether a measuring instrument is accepted in practice or not is accuracy. The accuracy of measuring equipment depends on many factors such as measurement method, manufacturing and installation parameters, etc. For diaphragm gas meters, these factors determine the accuracy of the instrument. The main tool is the precision of the membrane, the valve, and the four-bar mechanisms.

Diaphragm gas meters operate on the principle of measuring the volume of gas flowing through the diaphragm. Thus, the accuracy of the diaphragm has a great influence on the measurement results. The accuracy of the diaphragm depends on the upper diameter and lower diameter (aluminum disc diameter). This precision is entirely due to manufacturing.

To measure the volume of gas flowing through the meter, we need a four-bar linkage mechanism. The larger the swing angle of the rocker arms in the four-bar linkage mechanisms, the larger the measured gas volume. In addition, the length of the lever arms, connecting rods, and rocking rods also affect whether the measurement is more or less. Thus, the accuracy of the four-bar linkage mechanisms depends not only on manufacturing parameters but also on the installation process.

The two diaphragms and the four-bar linkage mechanisms both affect the accuracy of the device. However, the overall accuracy can be completely uncontrolled because the error, if any, is only a systematic error. The most important factor in determining the quality of a diaphragm gas meter is the manufacturing accuracy of the valve. The purpose of this article is to calculate the required manufacturing accuracy of the valve, thereby stipulating the accuracy of the device. The G1.6 diaphragm gas meter was also verified by the bell jar method. The test results proved the validity of the calculations. The calculation results are used to serve the process of designing and manufacturing membrane-type gas meters, putting this device into mass production to serve life.

II. EVALUATE THE ACCURACY OF THE GAS METER

2.1 Calculation of the diaphragm gas meter

The transmission ratio of the gas meter is determined by the parameters of the gears, worm, and worm wheel (Figure 3). The gear ratio of the clock is [3]:

$$i = \left(\frac{Z_2}{Z_1}.\frac{Z_4}{Z_3}\right).\left(\frac{Z_6}{Z_5}.\frac{Z_8}{Z_7}.\frac{Z_{10}}{Z_9}\right) \quad (1)$$

From the dimensions of a diaphragm chamber in Figure 4, the actual gas volume is:

$$V_{real} = 2.\frac{1}{3}\pi h\left(R^2 + Rr + r^2\right) \quad (2)$$

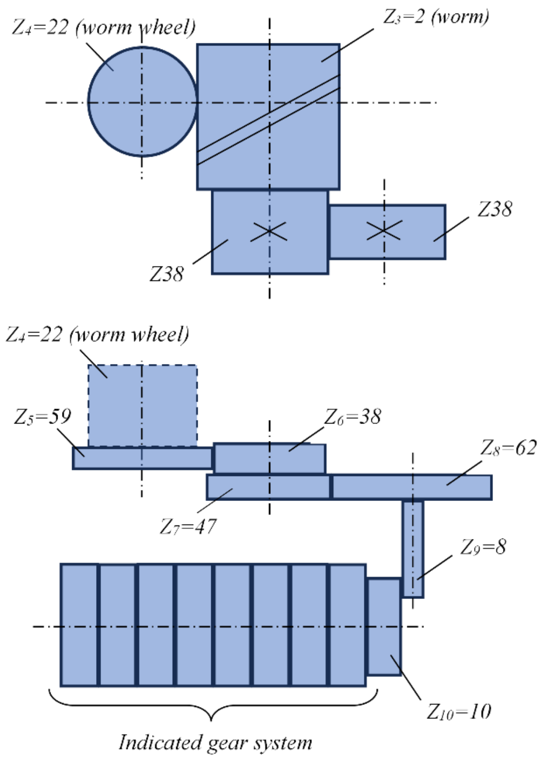

Figure 3: Diagram of the mechanical transmission

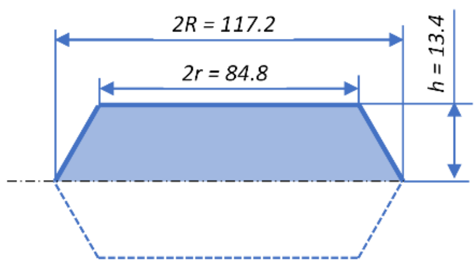

Figure 4: Dimension of a diaphragm chamber

As shown in Figure 5, when the gear ① rotates one round which is equivalent to 10 dm3, the volume that needs to be measured of the two diaphragms is:

$$V_{cal} = \frac{10}{i} \quad (3)$$

Figure 5: Indicator of the meter

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Thus, compared to the theoretical calculation, the deviation of the measured gas volume of the diaphragm between the theoretical and the actual is:

$$\Delta = \frac{V_{real} - V_{cal}}{V_{cal}} \tag{4}$$

Substitute the value of all parameters in Figure 3 and Figure 4, the calculated error of the meter is approximately +1%.

2.2 Evaluate the accuracy of the gas meter

As calculated, the error of the meter is about +1%. How come the error? In principle, transmission mechanisms (including four-bar linkage mechanisms and gear systems) do not cause measurement errors. Thus, the error here is due to gas leaking through the gap between the valve and its contact surface (Figure 6). The greater the amount of leakage, the greater the measurement error.

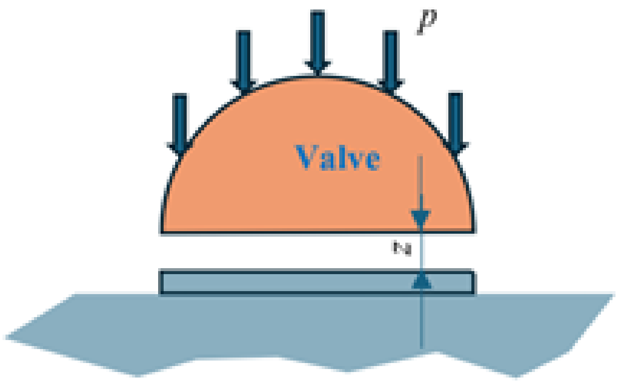

Figure 6: The gap between the valve and the contact surface

In gas meters, the cause of movement of the membrane and internal mechanisms is gas pressure p. Pressure p not only makes the valve rotate, but it also puts pressure on the upper surface and lower surface of the valve. When the pressure p increases, the pressure on the top surface of the valve increases, which has the effect of pressing the valve down. Meanwhile, the pressure on the lower surface also increases, tending to push the valve up, causing the amount of air leakage to also increase. Therefore, we must control the gas pressure at a certain value so that the gap between the valve and the contact surface is zero.

Suppose the gap between the valve and the contact surface is z. In theory, we can completely find the optimal pressure for the gap z=0. Unfortunately, due to manufacturing, the contact surface of the valve always has surface roughness and flatness, so even if the gas pressure is optimal, there is still a gap z. The problem here is to find the valve manufacturing precision (flatness and surface roughness) to satisfy the smallest leakage flow through that gap. The leak gas flow is determined by [4]:

$$Q = v.S \tag{5}$$

Where:

Q is the gas flow
v is the gas flow velocity through the gap z
S is the equivalent flow area

The equivalent flow area is calculated by [4]:

$$S = \pi.D.z \tag{6}$$

Where D is the diameter of the valve.

The gas flow velocity is determined based on pressure as follows. Suppose there is a stream of pressurized gas p0 flowing through a narrow gap with an area of F. The gas pressure after passing through the narrow gap is p1 (gas pressures are calculated in absolute values). The gas flow through the narrow gap is [5]:

$$G = \mu F \rho_0 \sqrt{\frac{2gk}{RT(k-1)}\left[\left(\frac{p_1}{p_0}\right)^{\frac{2}{k}} - \left(\frac{p_1}{p_0}\right)^{\frac{k+1}{k}}\right]} \tag{7}$$

Where:

p_0 and p_1 are the absolute gas pressures before and after the gap
F is the gap area
μ is a coefficient that depends on the nature of the flow
ρ_0 is the density of the liquid
g is the gravitational acceleration
k is the coefficient: k=Cp/Cv (Cp and Cv are specific heat of the gas at constant pressure and constant volume, respectively)
R is the gas constant

Setting $p=p_0-p_1$, we get the formula to determine the gas flow velocity through the narrow gap (approximately calculated with the gas being air) as follows:

$$v = 320\sqrt{p} \tag{8}$$

So, the leak gas flow is:

$$Q = 320\sqrt{p}.\pi Dz \tag{9}$$

As calculated above, the gas meter has an error of +1%, corresponding to a leak gas flow of 0.01 m^3. Hence:

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$$320\sqrt{p}.\pi.D.z = 0,01 \Rightarrow z = \frac{0,01}{320\sqrt{p}.\pi D} \quad (10)$$

Corresponding to the valve parameters, we can calculate:

$$z \approx 2.10^{-6}m = 2\mu m \quad (11)$$

Thus, the clearance between the valve and the contact surface z ≈ 2µm determines the allowable flatness and roughness of the valve surface as:

$$z < [flatness] + [Ra] \; or \; z < [flatness] + [Rz] \quad (12)$$

III. VERIFICATION OF THE DIAPHRAGM GAS METER G1.6

The main requirements for membrane gas meters are external checks, technical inspections, and measurement checks [6]. For the G1.6 gas meter, the main characteristics of the supplier are:

- Maximum working pressure: P_{max}=20 kPa
- Maximum flow: Q_{max}=2.5 m^3/h
- Minimum flow: Q_{max}=2.5 m^3/h

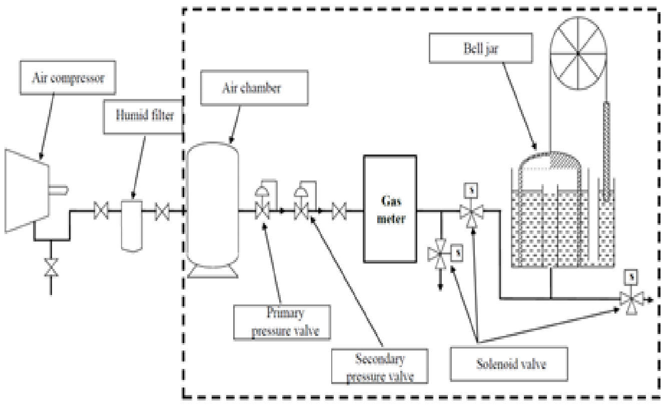

Figure 7: Diagram for verifying a gas meter using a bell jar [6]

A diaphragm gas meter verification process can be performed in different ways such as: checking with the bell-jar method, verifying by nozzle type gas flow standard, checking with standard meter, and checking by nozzle and suction type. In this research, the G1.6 membrane gas meter has been tested by the Volume and Flow Measurement Department of the State Metrology Center, using the bell-jar method. The verification scheme is shown in Figure 7. The verification process takes place as follows [7]:

The gas source must be passed through the opening and closing valve before entering the meter, then through thepressure regulator and flow, regulator to accurately control the pressure and flow of gas into the meter, ensuring no damage to the rubber diaphragm in the clock. The gas is then introduced into the meter at the inlet pipe. The amount of gas leaving the meter is fed into the standard bell. This is an accurate flow-measuring device that has been previously tested. By comparing the gas flow in the standard bell with the flow indicated on the meter, we can determine the accuracy of the gas meter.

The process of testing gas meters is carried out at different pressures and flows, specifically at 7 points: Q_{max}, 0.7Q_{max}, 0.4Q_{max}, 0.2Q_{max}, 0.1Q_{max}, 3Q_{min}, and Q_{min}. To increase reliability, the gas flow was measured six times at each point. Environmental conditions of the verification process are:

- Temperature: 21°C+1°C
- Humidity: 75% ~ 80%
- Air pressure: 1,013 bar
- Type of testing gas: air
- Standard bell: 50-liter type

IV. RESULTS AND DISCUSSIONS

The verification results are shown in Table 1 and Figure 8. According to the experimental error curve, the error of the G1.6 gas meter almost reached a positive value, with a small fluctuation amplitude, in the +1% region. The best working area for the gas meter is in the flow range from 0.2Qmax to 0.7Q_{max}. With a small flow (Q_{min}) the error is positive and larger than 1%. Otherwise, with a large flow (Q_{max}), the error is negative but very small, approximately -0.01%.

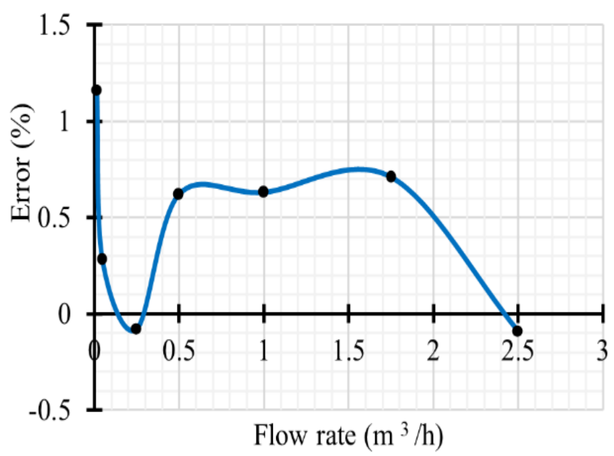

Figure 8: Experimental error curve

The conclusion of the State Metrology Center for the G1.6 gas meter is that the error test is "PASS". Compared with the above-calculated error result of the gas meter of +1%, the G1.6 gas meter has high accuracy and stability. That means it could be applied to practical use.

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Table 1: Experimental results

Flow rate (m^3/h)	Volume (dm^3)	Experimental error (%)						Max. Deviation (%)
		1st test	2nd test	3rd test	4th test	5th test	6th test	
Q_{max}	70	-0.58	-0.09	-0.39	-0.21	0.40	0.34	0.40
$0,7Q_{max}$		1.12	0.15	1.14	0.40	0.71	0.71	1.14
$0,4Q_{max}$		-0.07	0.76	0.26	0.70	1.07	1.07	1.07
$0,2Q_{max}$		0.63	0.66	0.90	0.77	0.37	0.37	0.90
$0,1Q_{max}$		0.03	-0.18	-0.35	-0.04	0.03	0.03	0.03
$3Q_{max}$		0.25	0.31					0.31
Q_{min}		1.20	1.12					1.20

V. CONCLUSIONS

Researching and understanding the design of diaphragm gas meters, based on the G1.6 model, has practical significance. From the quantitative calculations of the gas meter, it is possible to evaluate the accuracy of the gas meter. These calculation results allow for determining the manufacturing error of the valve, an important part of the gas meter, which determines the accuracy of the measuring instrument.

Gas meter inspection is mandatory before putting the meter into actual use. Gas meter verification helps ensure that the measurement data used for decision-making and evaluation is reliable. This article tested the G1.6 diaphragm gas meter using the bell-jar method. Verification results show that the experimental error of the G1.6 diaphragm gas meter is approximately +1%, consistent with the theoretical calculation results. This means that the G1.6 diaphragm gas meters can be widely used in practice.

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