Research on Measurement Performance Change of Water Meter in Use Based on Multi-stage Sampling Inspection

Liu Yajie[1], Tian Peng[2],
Liu Yizai[3], Zhang Yuanming[4]

[1]Guangzhou Institute of Energy Testing, 1-2 Zhujiang Road, Shilou Town, Panyu District, Guangzhou city, Guangdong Province, GuangZhou, China
[2]Guangzhou Institute of Energy Testing, GuangZhou, China
[3]Guangzhou Institute of Energy Testing, GuangZhou, China
[4]Guangzhou Institute of Energy Testing, GuangZhou, China
E-mail (corresponding author): 526810676@qq.com

Abstract

Water meter measurement data is the basis for users to pay water bills, sewage charges and some enterprises to pay water collection fees, the national administrative departments of measurement of water meters to implement the cycle of calibration, the use of the deadline, the expiration of the rotation of management. Because of the high cost of replacing a large number of water meters, and disassembly will affect the normal production and life of water, so there are still a large number of water meters have exceeded the rotation cycle but still in use. The lack of measurement and testing data for water meters in long-term use in the industry is likely to cause cost disputes between users and water companies, and is not conducive to the water authorities' accurate measurement of the quotas for water users in their jurisdictions, or to the enterprises' accurate accounting of water costs and revenues. At present, most of the domestic residential water meters in use are rotary-wing water meters and screw-wing water meters, and through sorting out the two types of water meters in use in a city, researching the sampling plan, implementing multi-stage sampling and testing, and obtaining statistics on the metering performance of 1920 water meters of various years of use, various specifications and various frequencies of use with a sample capacity of 1920 units. The positive offset and negative offset ratio were compared horizontally. Combined with the characteristics of water meter structure, working principle and error generation mechanism, the analysis was carried out to determine the specific stage of the life cycle of each type of water meter. Water companies, water end-users, and water extraction enterprises can grasp the qualification rate and indicated value error of their water meters based on the research results, which can facilitate the development of disassembly and calibration or rotation plans. The administrative department in charge of metering can refer to the research results and revise the cycle inspection or rotation time in the relevant metering technical regulations with the current economic development. Therefore, the research results have high application value.

1. Introduction

Water meter measurement data is the basis for customers to pay water and sewage charges and some enterprises to pay sewage charges, so it is of great concern to the society. According to JJG 162-2019 "drinking cold water meter calibration procedures[1]": "for nominal caliber of 50mm and below, and the common flow Q3 is not greater than 16m3/h water meter only for the first mandatory calibration before installation, the use of a limited period of time, the expiration of the rotation. The use period is as follows: the nominal diameter of the water meter does not exceed DN25 use period of no more than 6 years; nominal diameter of more than DN25 but not more than DN50 water meter use period of no more than 4 years; nominal diameter of more than DN50 or commonly used flow Q3 more than 16m³ / h water meter calibration cycle is generally 2 years". At present, it is common in China that domestic water meters over 6 years are still in use, and there is a lack of metrological testing data of water meters in long-term use in the industry (the durability test is only done for 100 hours during routine special sampling). Zhou Zhenxing put forward some of the reasons for the deviation of the water indication value error over time, and summarized the factors that can cause the indication error in the operation of the water meter[2]. However, the analysis was not verified by real measurements. Therefore, an in-depth metrological performance study of water meters in use using sampling tests can effectively verify the actual situation of water meter error shifts and provide an important reference basis for the correct use of water meters by users.

2. Sampling program

2.1 Develop a sampling plan

The overall number of units sampled in a city is about 7 million, and the distribution is very wide, so multi-stage sampling method is used to avoid the dilemma of not only a large workload, but also difficult to grasp in terms of accuracy, so as to achieve the desired sampling effect. The specific operation process of multi-stage sampling is as follows[3-4].

In the first stage, the overall population is divided into a number of first-level sampling units, from which a number of first-level sampling units are selected into the sample.

In the second stage, each first-level unit is divided into a number of second-level sampling units, and a number of second-level sampling units are selected from each first-level unit in the sample, and so on, until the final sample is obtained.

Each level in multi-stage sampling introduces some error. It seems that adding one level of sampling will increase the error, but this is not necessarily the case. Therefore, although adding one level of sampling will add a layer of error, but if the group is properly divided, then adding one level of sampling can play a certain role in classification, so that the intra-group variation is greatly reduced, not only to offset the increase in error due to the addition of one level of sampling, but also to reduce the total error. As can be seen, although multilevel sampling increases the source of error, it does not necessarily increase the value of the error. Increasing the level of sampling makes the sampling error increase or decrease, depending on the relationship between intra-group variance and inter-group variance after binning[5-6]. Under the condition of the established test cost, multi-stage sampling can achieve the minimum level of estimation error by adjusting the number of samples in each stage and selecting the optimal sample size at each level.

Therefore, a reasonable sampling plan should be determined in conjunction with the actual situation, and the sample size to be drawn at each stage should be initially determined after the sampling plan is developed.

2.2 Analysis of sampling error sources and calculation

If the number of secondary units contained in the primary unit is M, so the number of secondary units drawn in the primary unit in the sampling is also equal, recorded as m; and the sampling method of both stages is simple random sampling; and the second-stage sampling in a number of primary units drawn is carried out independently of each other[7-9].

Y_{ij} represents the jth secondary unit in the i-th primary unit, $i=1, 2, 3\ldots N$, $j=1, 2, 3\ldots M$.

y_{ij} represents the observed value of the j-th secondary unit in the i-th primary unit in the sample, $i=1, 2, 3\ldots n$, $j=1, 2, 3\ldots m$.

The sum of the i-th primary unit is:

$$Y_{i\text{-sum}}=\sum_{j=1}^{M}Y_{ij} \tag{1}$$

The average value of the i-th primary unit is:

$$\overline{Y}_i=\frac{Y_{i\text{-sum}}}{M} \tag{2}$$

The overall average is:

$$\overline{\overline{Y}}=\frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}Y_{ij}=\frac{1}{N}\sum_{i=1}^{N}\overline{Y}_i \tag{3}$$

Overall inter-primary unit group variance is:

$$s_1^2=\frac{1}{N-1}\sum_{i=1}^{N}\left(\overline{Y}_i-\overline{\overline{Y}}\right)^2 \tag{4}$$

Variance within primary unit clusters in the overall is:

$$S_2^2=\frac{1}{N(M-1)}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(Y_{ij}-\overline{Y}_i\right)^2 \tag{5}$$

Change M to m, N to n, and Y_{ij} to y_{ij} to be the index value of the sample. The variance between sub-units in the i-th group is recorded as:

$$s_{2i}^2=\frac{1}{M-1}\sum_{j=1}^{M}\left(Y_{ij}-\overline{Y}_i\right)^2 \tag{6}$$

The estimate is:

$$\overline{\overline{y}}=\frac{1}{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}Y_{ij}=\frac{1}{n}\sum_{i=1}^{N}\overline{Y}_i \tag{7}$$

This is an unbiased estimator, and the variance is:

$$\mathrm{Var}\left(\overline{\overline{y}}\right)=\frac{1-f_1}{n}S_1^2+\frac{1-f_2}{nm}S_2^2 \tag{8}$$

Where: $f_1=\frac{n}{N}, f_2=\frac{m}{M}$

The unbiased estimate of variance is:

$$\mathrm{V}\left(\overline{\overline{\mathrm{y}}}\right)=\frac{1-f_1}{n}s_1^2+\frac{f_1(1-f_2)}{nm}s_2^2 \tag{9}$$

In summary, the sampling error caused by the first level of sampling is:

$$s_1=\sqrt{\frac{1-f_1}{n}s_1^2} \tag{10}$$

The second level of sampling error for each group is:

$$s_{2i}=\sqrt{\frac{1}{M-1}\sum_{j=1}^{M}\left(Y_{ij}-\overline{Y}_1\right)^2} \tag{11}$$

But as a whole, the second-level sampling error is not only related to the sampling error within each group, but also varies with the different groups selected. Sampling theory has proved that if these two factors are considered together, the error caused by the second-level sampling is:

$$s_2=\sqrt{\frac{1-f_2}{nm}s_2^2} \tag{12}$$

The total error of two-level sampling has the following relationship with these two-level sampling:

$$s=\sqrt{\frac{1-f_1}{n}s_1^2+\frac{1-f_2}{nm}s_2^2} \tag{13}$$

For each additional level of sampling, one item is added to the total sampling error.

In multi-level sampling, the sampling must determine a reasonable ratio to ensure the convenience of work and the necessary representativeness. It can be seen that how to allocate the number of samples reasonably among all levels is an important issue[13].

2.3 *Determine the sample size*
Sample size is related to the test budget, but also related to the sampling error. In actual work, the inspection budget is limited, and there are certain requirements for survey errors. Therefore, the total inspection cost budget and sampling error to determine the sample size based on both. The present idea is to study how to configure the sample size to minimize the estimated variance given the cost[11-12].

First, divide the whole into R first-level groups, set i_1 ($1\le i_1\le R$) first-level groups to include R_{i1} second-level groups, and i_2-th ($1\le i_2\le R_{i1}$) second-level groups in the i_1 first-level group Contains $R(i_2)$ three-level groups, until the first (n-2) groups are i_1, i_2, i_3 ... i_{n-2} (n-2)-level groups contain $R(i_{n-2})$ (n -1) group, the i_{n-1} ($1\le i_{n-1}\le R(i_{n-2})$) (n-1) level group contains $R(i_{n-1})$ overall units.

Let c_i be the average cost of surveying each i level group unit at stage i , then the total survey cost is:

$$C=\sum c_i\cdot r_{i-1} \tag{14}$$

Under the conditions given by the total testing cost C, the optimal sample size at each stage is as follows:

$$r_{(n-1)}^{(n-1)}=\frac{S_n}{\sqrt{S_{n-1}^2-\frac{S_n^2}{R_{(n-1)}^{(n-1)}}}}\cdot\sqrt{\frac{C_{n-1}}{C_n}} \tag{15}$$

$$r_{(l)}^{(l)}=\frac{\sqrt{S_{l-1}^2-\frac{S_{l+1}^2}{R_{(l+1)}^{(l+1)}}}}{\sqrt{S_l^2-\frac{S_n^2}{R_l^l}}}\cdot\sqrt{\frac{C_l}{C_{l+1}}} \tag{16}$$

After analysis, according to the inspection cost budget and survey error requirements, the water meter sampled in this project is a city in use (use period of 1 to 10 years), there are seven different caliber specifications water meter, a total of 1920 units, the classification scheme is detailed in Table 1.

Table 1: Classification of cold water meter sampling

object	types of average annual water consumption	caliber type
Within 6 years of use DN≤25mm, common flow rate not exceeding 16m³ /h, class 2	3	3
More than 6 years of use DN≤25mm, common flow rate not exceeding 16m³ /h, class 2	3	3
Within 4 years of use DN=40/50mm, common flow rate not exceeding 16m³ /h, class 2	3	2
More than 4 years of use DN=40/50mm, common flow rate not exceeding 16m³ /h, class 2	3	2
Within 2 years of use DN>50mm or common flow rate more than 16m³ /h, class 2	3	2
More than 2 years of use DN>50mm or common flow rate more than 16m³ /h, class 2	3	2

The 1920 tested water meters cover most of the well-known manufacturers in China; the average annual water consumption of water meters contains three types: moderate (50m³~ 200m³), low (50m³ below), and high (200m³ above); the water meter caliber covers (15~100) mm range. In summary, the sampled cold water meters have a certain degree of representativeness.

The caliber of the water meter is different, and its prescribed service life is different. The water meters produced by several cold water meter factories in the market were sampled for this study. According to 7.3.4.7 of JJG 162-2019 "Regulations for Verification of Cold Water Meters for Drinking Water", the indication error E of the water meter is calculated as follows:

$$E=\frac{V_{i-V_a}}{V_a}\times100\% \tag{17}$$

Where: V_i represents the increased (or decreased) volume of the water meter indicating device, V_a represents the actual volume flowing through the water meter, and the unit is m³ or L.

3. Indication error pass rate change

3.1 Annual average water consumption moderate water meter value error analysis

3.1.1 The average annual water consumption is moderate, DN ≤ 25mm caliber water meter
For moderate average annual water consumption (50m3 ~ 200m3), DN ≤ 25mm caliber water meter, there are three cases: 15mm, 20mm and 25mm. Each caliber water meter were sampled 160 units. The service life is divided into two categories: below 6 years and above 6 years. For better data analysis, the years below 6 years were divided into two cases of 0 to 3 years and 3 to 6 years, and the years above 6 years were divided into two cases of 6 to 8 years and 8 to 10 years. According to the test data statistics, the change trend chart of the qualified rate of the water meter is shown in Figure 1.

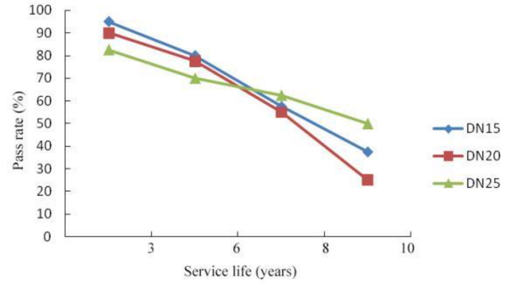

Figure 1: Statistic chart of the qualified rate of DN ≤ 25mm water meter error (average annual water consumption: 50m³~200m³)

It is clearly reflected from Figure 1 that the qualified rate of the three types of water meters is getting lower and lower with the increase of using years, especially the qualified rate of DN15 and DN20 water meters drops sharply after exceeding 6 years of using years, while the qualified rate of DN25 water meters decreases more steadily, but the qualified rate of water meters with more than 8 years of using years is lower than 60%, and the qualified rate of water meters with 6 to 8 years of using years is Only 62.50%. It can also be seen from the figure, although the qualified rate of water meters within 6 years of use has decreased, but the qualified rate of all three types of water meters remained at more than 70%. This indicates that the water meters used beyond the period of time have a tendency of serious decline in metering performance or a great risk of inaccuracy in the measurement of the indicated value.

3.1.2 Moderate average annual water consumption, 25mm < DN ≤ 50mm caliber water meters

For water meters with moderate annual water consumption (50 m^3 ～ 200 m^3), 25 mm < DN ≤ 50 mm caliber, there are two situations: 40 mm caliber and 50mm caliber. 120 sets of water meters of each caliber are randomly inspected, and the service life is divided into three situations: less than 4 years, 4 years to 6 years, and more than 6 years. According to the test data statistics, the change trend chart of the qualified rate of the water meter is shown in Figure2.

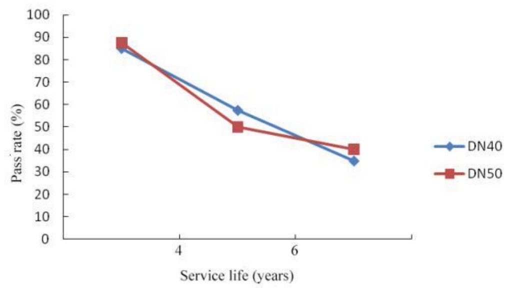

Figure 2: Statistic chart of the qualified rate of indication value error of 25mm＜DN≤ 50mm water meter (average annual water consumption is moderate: 50m³～200m³)

Figure 2 shows that the qualified rate of metering performance of these two types of water meters decreases almost linearly with the increase of water meters' usage years, and it is obvious that the qualified rate of overdue water meters are below 60%, which means that the metering performance of overdue water meters is very serious.

3.1.3Moderate average annual water consumption, DN ＞ 50mm caliber water meter

For the average annual water consumption is moderate (50 m^3 ~ 200 m^3) and DN ＞ 50 mm caliber water meter, there are 2 cases: 80mm caliber and 100mm caliber. Each caliber water meter were 120 units of sampling inspection. The service life is divided into two categories: below 2 years, 2 years to 4 years, and above 4 years. According to the test data statistics, the water meter pass rate change trend chart is shown in Figure 3 below.

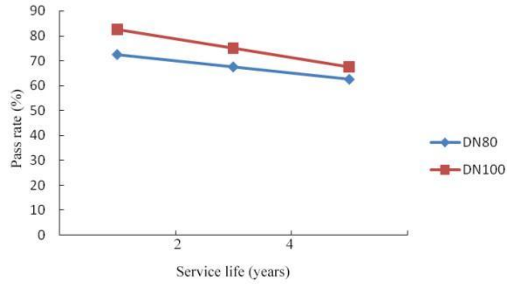

Figure 3: Statistic chart of the qualified rate of DN ＞ 50mm water meter error (average annual water consumption: 50 m3 ~ 200 m3)

Figure 3 shows that for large-diameter water meters, even if they exceed one calibration cycle, their performance only decreases, and the qualified rate of the sampled water meters does not differ much, so the water meters can be replaced in the process of use as long as they are calibrated according to the cycle and the meters with excessive indication value error are found.

3.2 Analysis of low and high water meter value errors for average annual water consumption

In order to better and more generally analyze the water value error, we took water meters of different calibers with different years of use and carried out testing data statistics for low (50m^3 below) and high (200m^3 above) average annual water consumption, combined with the previous data statistics of water meters with moderate average annual water consumption, and put various water meters of different calibers in different years of use. In combination with the data statistics of the previous moderate annual average water consumption meters, the statistics of the passing rate of various caliber water meters in different years of use and different annual average water consumption are synthesized into line graphs using excel and analyzed for horizontal comparison, as shown in Figure 4 to 10.

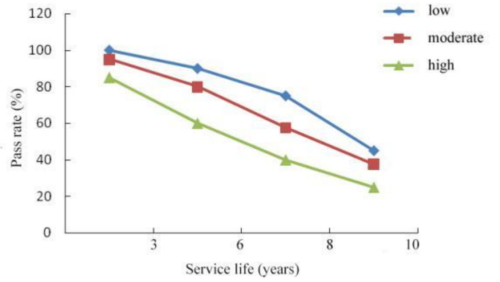

Figure 4: Statistic chart of the qualified rate of DN15 water meter value error

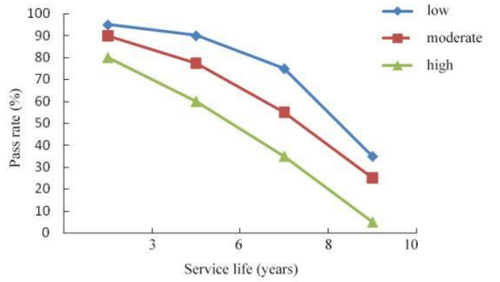

Figure 5: Statistic chart of the qualified rate of indication value error of DN20 water meter

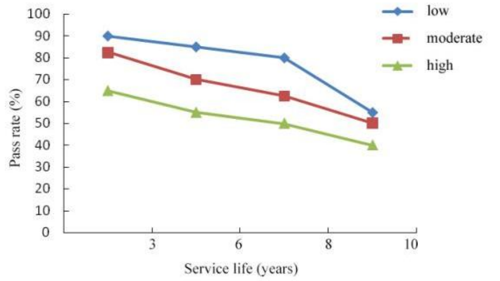

Figure 6: Statistic chart of the qualified rate of indication value error of DN25 water meter

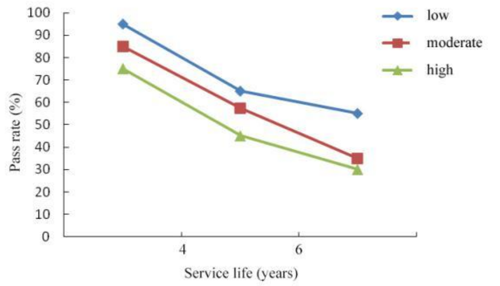

Figure 7: Statistic chart of the qualified rate of indication value error of DN40 water meter

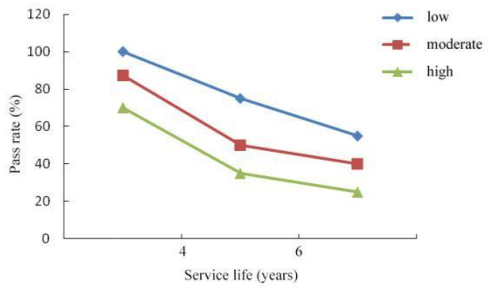

Figure 8: Statistic chart of the qualified rate of indication value error of DN50 water meter

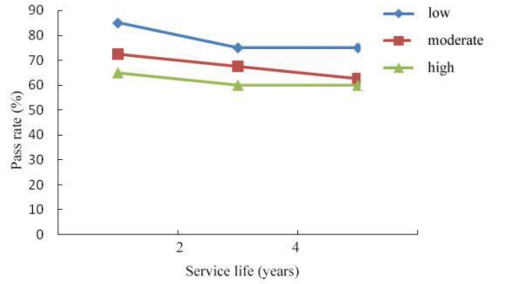

Figure 9: Statistic chart of the qualified rate of indication value error of DN80 water meter

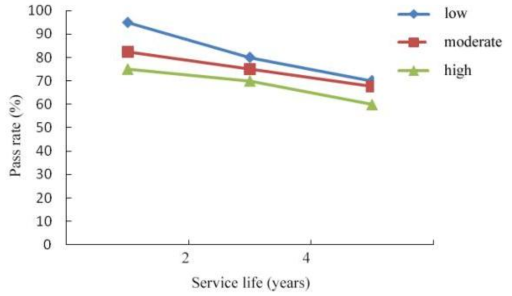

Figure 10: Statistic chart of the qualified rate of indication value error of DN100 water meter

From Figure 4 to 10, it can be clearly seen that the qualified rate of the same caliber water meter decreases with the increase of the average annual water consumption under the same service life.

Comparing water meters of different calibers, it is found that for water meters with DN ≤ 50mm, with the growth of the use life, the qualification rate of water meter error decreases faster for various average annual water consumptions. Compared with large-diameter water meters of DN80 and DN100, the qualified rate of water meter error for various average annual water consumption decreases more slowly with the growth of usage years, such as DN80 water meter, whose qualified rate decreases shows a slight decrease. For large-caliber water meters, regardless of their length of use and average annual water consumption, the error qualification rate of the sampled water meters is almost always above 60%, while the error qualification rate of small-caliber water meters with DN ≤ 50 mm is seriously reduced when they exceed the corresponding use life, and they are all lower than 60%, and the qualification rate of water meters with serious overuse is almost always lower than 40%, which seriously affects the measurement performance of water meters, and only the average annual water consumption is low. Only the different caliber water meters with low average annual water consumption can continue to maintain certain measurement accuracy when they are used for 6 to 8 years or 4 to 6 years, and the qualification rate of sampled water meters is above 60%, but they continue to be seriously overused, and even if the average annual water consumption is low, the qualification rate also drops sharply, which cannot guarantee the measurement performance of water meters.

3.3 Analysis of the change trend of metering performance

Table 2-1 and Table 2-2 is a summary of the passing rate of all the water meter value error verification results in use in this sampling.

In summary, the conclusion of this cold water indication value error statistics is: 15 mm < DN ≤ 50 mm of 1440 water meters, more than the use of water meters for 800 units, 640 units of water meters within the specified use life; After verification, 800 units have exceeded the service life limit of water indication value error qualification rate of 47.13%, 640 units used within the specified years of water indication value error qualification rate is 82.19%, and the total qualification rate is 62.71%. The metering characteristics of water meters over their service life are extremely poor, and their indicated value error seriously deviates from the metering performance requirements of billing water meters; the data in Table 2-1 show that, especially for most residents using small diameter water meters (DN ≤ 25mm), the qualified rate of "over-aged" water meters is obviously lower than that of water meters used within the specified service life, of which The qualified rate of DN20 "over-aged" water meters is only 38.75%, which is only nearly 1/2 of the qualified rate (82.50%) of the water meters used in their specified years. Among the 480 water meters with DN > 50mm, the qualification rate of two kinds of meters is 68.75% and 75.00% respectively, and the total qualification rate is 71.87%.

In summary, in order not to affect the normal measurement performance of the water meter, for DN≤50mm small-diameter water meter, in the case of moderate and high average annual water consumption, it must be rotated at the end of the use life, and in the case of low average annual water consumption, the use life of 1 to 2 years can be extended appropriately; for DN > 50mm large-diameter water meter, regardless of the average annual water consumption, it is only necessary to carry out water meter For DN > 50mm large-diameter water meters, regardless of the average annual water consumption, it is only necessary to carry out water meter calibration according to the cycle, and to replace the water meters that are not qualified for the cycle calibration value error.

In order to analyze the change trend of water meter value error, the average annual water consumption is moderate (50 m^3~ 200 m^3), and all the water meters (960 units) are checked according to different calibers and different years of use, and the average value error of common flow is calculated and a curve is fitted, as shown in Figure 11 to 13.

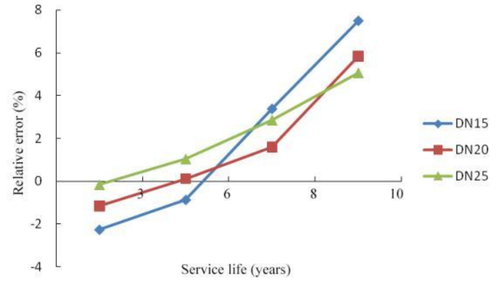

Figure 11: Variation chart of average indication error of DN ≤ 25 mm water meter

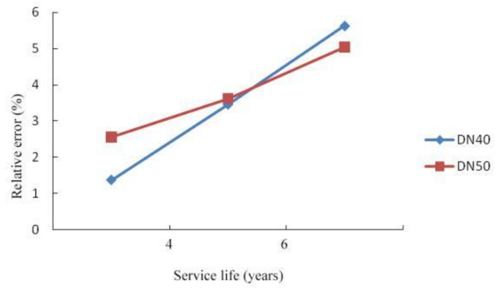

Figure 12: Variation chart of average indication error of 25 mm < DN ≤ 50mm water meter

Table 2-1: Statistics of the qualified rate of the error of 15mm <DN≤50mm water meter

Caliber (mm)	*Total number of sampled water meters*	*The number of water meters with a prescribed life limit*		*Number of overage water meters*		*Qualified rate of water meter used for specified years*	*Qualified rate of over-age water meter*	*Total pass rate*
		Qualified	*Unqualified*	*Qualified*	*Unqualified*			
15	320	137	23	75	85	85.63	46.88	66.25
20	320	132	28	62	98	82.50	38.75	60.63
25	320	120	40	90	70	75.00	56.25	65.63
40	240	68	12	76	84	85.00	47.50	60.00
50	240	69	11	74	86	86.25	46.25	59.58
Total	1440	526	114	377	423	82.19	47.13	62.71

Table 2-2: Statistics of Qualified Rate of Error of DN>50mm water meter

Caliber(mm)	*Total number of sampled water meters*	*Number of qualified water meters*	*Number of unqualified water meters*	*Qualified rate(%)*
80	240	165	75	68.75
100	240	180	60	75.00
Total	480	345	135	71.87

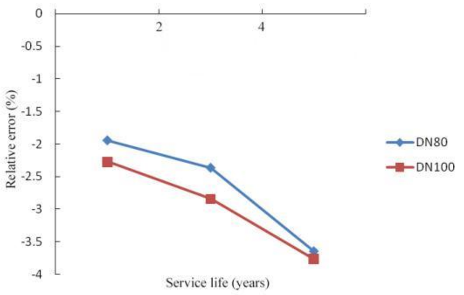

Figure 13: Variation chart of average indication error of DN > 50mm water meter

From Figure 11 to 13, the variation chart of average indication error of water meter can be seen that the average indication error of water meter tends to become larger with the growth of service life, and the average indication error of small-diameter (DN≤50mm) water meter is positive, and the average indication error of large-diameter (DN > 50mm) water meter is negative. That is, with the increase in the use of water meters, small-diameter water meters show a trend of turning faster and faster, while large-diameter water meters show a trend of turning slower and slower.

Figure 14 shows the statistical chart of the positive and negative errors of the different calibers of the unqualified water meters in all the sampled water meters (1920 units).

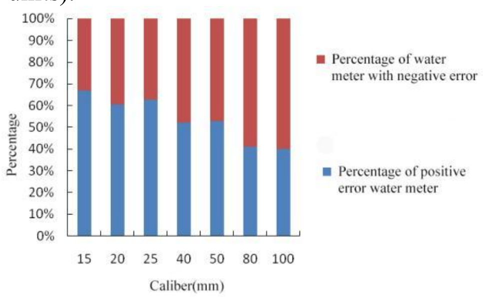

Figure 14: Statistics of positive and negative errors of unqualified water meters

From Figure 14, we can know that as the caliber of water meters increases, the percentage of positive errors of water meters gradually decreases, and the percentage of positive errors of small caliber water meters is basically around 60%, with positive errors overall; the percentage of negative errors of large caliber water meters is around 60%, with negative errors overall.
This is consistent with the above-mentioned statistical law of the average value error of water meters of different calibers with different service life for moderate average annual water consumption. It shows that with the increase of water meter usage years, the small diameter water meter shows the trend of turning faster and faster, while the large diameter water meter shows the trend of turning slower and slower.

4. Theoretical analysis and experimental data comparison of the trend of change in the value of the error

4.1 Rotor water meter

Rotor water meter is a kind of velocity water meter, which is the most used water meter variety in the world. In the national standard, the definition of velocity water meter is "a water meter installed in a closed pipe, consisting of a power element, and directly caused by the water flow velocity to obtain movement". When the water flows through the meter, the impeller (rotor or screw) is driven to rotate, and the flow rate of the water is proportional to the rotational speed of the impeller, because the cross-sectional area of the spout at the impeller driven by the water is constant, so the rotational speed of the impeller is also proportional to the flow rate. Through the impeller shaft linkage parts connected to the counting mechanism, so that the counting mechanism to accumulate the number of impeller (rotor or screw wing) revolutions, so as to record the amount of water through the water meter.

Rotor multi-flow beam type water meter consists of case, middle cover, table glass, sealing gasket, measuring mechanism, counting mechanism and water filter, etc[14]. The impeller starts to rotate after the water flow strikes the impeller, and the number of revolutions is accumulated by the counting mechanism to record the amount of water passing through the meter. As shown in Figure 15-1 and Figure 15-2.

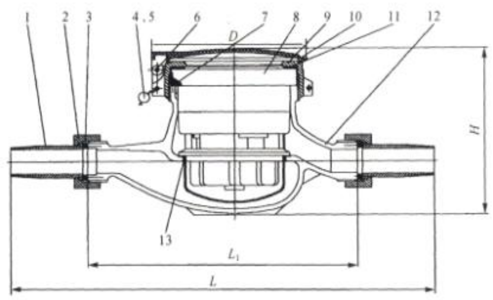

Figure 15-l: Structure diagram of rotary water meter
1-Takeover; 2-Connection nut; 3-Takeover sealing gasket; 4-Lead seal; 5-Copper wire; 6-Pin; 7-0-shaped sealing gasket; 8-Impeller metering mechanism;9-cover; 10-cover; 11-cover liner; 12-case; 13-Bowl filter screen;

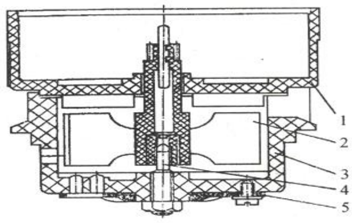

Figure 15-2: Measuring mechanism diagram of rotor type water meter
1-gear box; 2-integral impeller; 3-impeller box;
4-top; 5-Adjustment plate

The main reason for the high error of water meter is due to the site conditions of water meter use. First of all, the water quality of the pipe network factors, when the water entrained solid impurities (such as sand, sisal, rust scale, etc.) deposited in the water meter filter network and the bottom of the flow adjustment hole, will cause the water should be diverted not fully diverted and act on the impeller, resulting in the impeller speed to accelerate the measurement of bias. Because the solid particles in the water are easy to form scale, the aperture of the water filter net and the water inlet hole of the impeller box becomes smaller, the speed of the flow speed increases, the speed of the impeller increases, and the water meter measures the deviation. The second is the mechanical wear factor of the water meter thimble. The thimble is a key component in the water meter to support the rotation of the impeller, in the process of continuous operation, it is very easy to cause wear on the tip of the thimble, which increases the friction coefficient between the top and the impeller, and the water meter measurement is negative. In addition, the top and impeller position down, will also make the impeller and the gear box between the gap increases, the damping of the water flow is reduced, the measurement of large flow is biased. The result of the combined occurrence of these two states will lead to negative measurement of the water meter at small flow rates and positive measurement at large flow rates[15-16].

After the above analysis, due to impurities in the pipe blockage and other reasons, the water meter measurement is positive trend, and with the increase in the degree of mechanical wear, the friction coefficient between the thimble and impeller and other components increase, so that the water meter measurement and negative trend change, and then offset the factors that lead to the water meter bias, so that the total measurement error has rebounded phenomenon[17]. But with the extension of the water meter operation time, mechanical wear factors enhance, will lead to the total measurement of negative. Water meter service life and common flow measurement error relationship is shown in Figure 16.

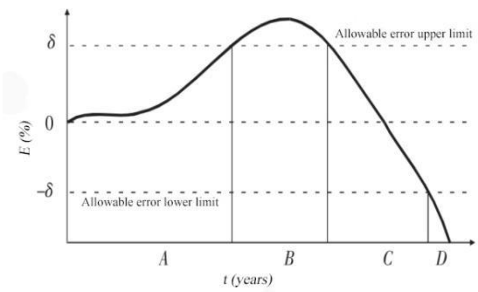

Figure 16: Trend chart of water meter error and service life

By comparing with the experimental data, it is found that the DN15～DN25 rotor water meters with a service life of 3-8 years are in the A section of the trend graph; the DN15～DN25 rotor water meters with a service life of 8-10 years are in the B section of the trend graph ; DN40～DN50 rotor water meters with a service life of 6 years are in the A section of the trend graph; DN40～DN50 rotor water meters with a service life of more than 6 years are in the B section of the trend graph.

A town water supply station of a water company in a city has long-standing severe production and sales gaps. After investigation and visits, there are thousands of rotary-wing water meters in the town and street that have been in service for more than 20 years. According to the above analysis, this batch of water meters may be in the latter half of the C interval or even the D interval of the trend chart, and the overall indication error is negative. Under the promotion of the administrative department of measurement, the water department completely replaced the batch of water meters. After more than 20 years of water meter replacement work was completed, the production and sales gap of the water supply was reduced by 2.7%, which improved operating efficiency. It can be seen that the research results can be effectively applied to guide the replacement of water meters.

4.2 Screw-wing water meter

Screw-wing water meter, also known as *Woltmann* water meter, is a kind of velocity water meter, suitable for use in large diameter pipeline, which is characterized by large circulation capacity and small pressure loss.

Like the rotary water meter, the screw-wing water meter also belongs to a kind of speed water meter. When the water flows into the water meter, the impeller in the direction of the axis of the water meter screw wing shape rotates and then flows out, the speed of the impeller is proportional to the speed of water flow, and after the reduction gear drive, the total amount of water through the water meter is displayed on the indicating device.

The screw-wing water meter is divided into two categories: horizontal screw-wing water meter and vertical screw-wing water meter. Most of the industrial meters used in China are horizontal screw type water meters. In addition, the detachable horizontal screw-wing water meter, because of its wide range of measuring flow, strong versatility of parts, installation and maintenance can be carried out without stopping the water without dismantling the meter and other characteristics, has also become one of the series of products, welcomed by users.

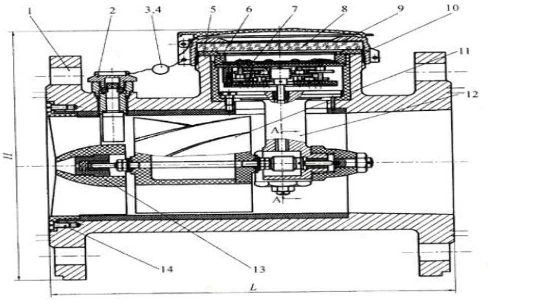

Figure 17-1: Schematic diagram of horizontal screw type water meter
1-Case; 2-Adjuster; 3-Copper wire; 4-Lead seal; 5-Sealing gasket; 6-Lining ring; 7-Indicating mechanism; 8-Gauge glass; 9-Hood assembly;10-meter cover; 11-wing wheel assembly; 12-bracket assembly; 13-rectifier assembly; 14-slotted cylindrical head screws

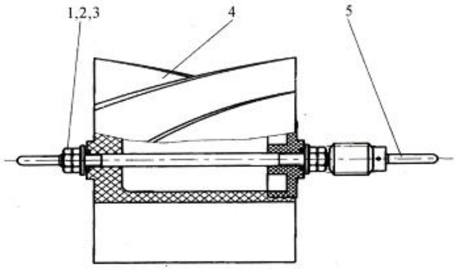

Figure 17-2: Spiral wing structure diagram
1-Nut; 2-Washer; 3-O-seal; 4-Wing wheel; 5-Other components

The main reason for the error of the spiral wing water meter is the mechanical wear of the rotor and the increase of the friction coefficient of the transmission parts, both factors will cause the negative value error.

5. Conclusion

The research results show that the overdue use of DN50 and below water meters will lead to a low qualification rate, and the qualification rate of water meters with a service life of more than 8 years is less than 50%. In addition, the qualification rate of water meters with higher water consumption in the same age is lower, and the indicated value error is larger, and the average indicated value error increases positively with the growth of usage time. Therefore, in order to ensure accurate and reliable measurement data, it is recommended that users give priority to eliminating water meters that have been used for more than 8 years and those that have been used for more than 6 years and have a high average annual water consumption, and to eliminate water meters that have been used for 6 to 8 years and have a moderate or low average annual water consumption in the second phase. The qualified rate of water meters with DN50 or above used for more than 4 years and with higher average water consumption decreases very obviously, and the indicated value error is greater, and the average indicated value error increases negatively with the growth of use time, so it is recommended that the users should regularly check them.

References

[1] JJG162-2019, Drinking cold water watermeter calibration procedures [S]
[2] Zhou Zhenxing. Study on the change of metering performance and accuracy analysis during the operation of water meters[J].
[3] Zhu Jianming,Liu Zhuojun,Sun Junhong. Research on multi-stage sampling method of product quality and safety based on a priori information[J]. China Science and Technology of Safety Production,2016,12(02):159-163.
[4] Cui Ying'an,Li Xue,Wang Zhixiao,Zhang Deyun.A multi-stage whole group sampling method for social media big data[J].Journal of Software,2014,25(04):781-796.
[5] Szabolcs Szilveszter, Raul Beltran,Arturo Fuentes. Performance analysis of the domestic water meter park in water supply network of Ibarra, Ecuador [j]. Urban Water Journal,2017(01):85-96.
[6] F.J. Arregui, M. Balaguer, J. Soriano, J. García-Serra. Quantifying measurement errors of new residential water meters considering different customer consumption patterns [j]. Urban Water Journal,2016(05):463-475.
[7] Sun Lixin. Random sampling design of multi-stage whole group sampling in overall network analysis [J].Statistics and Decision Making,2013(06):24-26.
[8] He Jianfeng. Design of double sampling frame estimators based on two-stage sampling[J].Statistics and Decision, 2011(15):12-14.
[9] Ye Ezhong. Multi-stage sampling regression estimation and its sample size selection[J].
[10] Zhang M.S., Li Q. Practical aspects of the equal probability principle in multistage random sampling[J].Journal of Shenyang Normal University(Social Science Edition), 2002(03):8-10.
[11] Na Xianyi. A preliminary investigation of the first-stage sample-content problem in multi-stage sampling[J].China Statistics, 1994(08):33-34.
[12] Zhang Zhong, Lv Shujuan, Xu Zhijie. Optimal configuration of sample content in multi-stage sampling and its application[J].Journal of Mathematical Medicine, 1993(02):19-21.
[13] Wu Guofen. Flow equation and characteristic curve equation of rotor type water meter[J]. Journal of Shanghai Institute of Mechanical Engineering,1987(03):9-18.
[14] GB/T 778.1-2007, Measurement of water flow in closed full pipes drinking cold water meters and hot water meters Part 1: Specification [S].

[15] Li Yanrong, Hu Peimin, Shen Zhenlie. Use of water meter and measurement error analysis[J]. China Metrology,2009(04):115-117.

[16] Ding Qingtian,Liu Jinliang. Analysis and improvement measures for the use of water meter errors[J]. Water Supply and Drainage,2008(12):104-105.

[17] Chen Lingfeng. Sampling-induced measurement uncertainty assessment[J]. Journal of Metrology, 2020,41(07):891-896.