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Overview of differences between electronic and mechanical domestic cold water meter

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Abstract

During the last years the share of electronic water meters based on ultrasonic or magnetic-inductive measuring principles installed in households has increased steadily. The question arises to what extent their measuring performance differs from that of classic mechanical water meters. Due to the static measuring principles without moving mechanical components, it is to be expected that electronic water meters are less susceptible to water properties. To gain insights in this regard experiments were conducted with different water qualities (pH, total hardness, particles). In addition, the measurement performance at constant and variable flow rates was evaluated and compared with that of mechanical water meters. The fact that electronic water meters, in contrast to mechanical meters, measure discretely and not continuously was also addressed in the investigations. In particular, it was studied how the sampling interval affects the accuracy with which the total volume is recorded, depending on the time of sampling and the length of the observation period.

1. Introduction

Digitalization is gaining more importance everywhere and every day. Thus, it comes as no surprise that mechanical water meters, which are quite well known, have been gradually replaced by electronic water meters during the last years. Typical types of mechanical water meters are single-, multi-jet or piston meters. All of them have moving mechanical components in the measuring mechanism. In contrast, electronic water meters have no moving parts, but require an external power supply (battery) to measure the volume flowing through the meter. The common types of electronic water meters are either ultrasonic or magnetic inductive water meters.

Electronic water meters comply with the relevant normative documents such as ISO 4064:2014 [1] and OIML R49:2013 [2]. However, these standards were foremost developed for mechanical water meters. Therefore, it cannot be excluded that the requirements in their current form are not sufficient for electronic water meters. Furthermore, it is of interest how electronic water meters perform under real-world conditions compared to the traditional mechanical meters – if the expectations of a reduced sensitivity to water properties are fulfilled. To gain insights here stress tests were performed by using test waters with different pH and total hardness values, and particle sizes and concentrations [3].

Another major difference of electronic water meters to water meters based on mechanical measuring principles is that electronic water meters measure discretely. From single measurements e.g. of the liquid velocity the volume at a certain point in time needs to be derived for which an interpolation between these measurements is required. Only then the total volume that has passed the meter can be calculated. The sampling interval determines how often measurements are carried out. In current standards, there are no restrictions on the sampling interval, which means that in theory very long sampling intervals can be used. The advantage of long sampling intervals is lower energy consumption resulting in a longer lifetime of the meters. From the existing test specifications for determining the meter accuracy [1],[2], which rely on constant flows, the influence of sampling intervals cannot be proven and investigations of the influence of the sampling interval under real consumption conditions are necessary. Additionally, electronic water meters cover a higher ratio R of permanent flow rate (Q_3) to minimum flow rate (Q_1) compared to most mechanical meters. This poses a huge challenge for the laboratories, which perform tests according to ISO 4064:2014 and OIML R49:2013 because the tests rigs must be capable not only to generate a large flow rate range but need also to be suitable to measure of flow rates of some litres per hour in an acceptable time and with an adequate accuracy.

2. Meter response to water properties

As mentioned in the introduction, electronic water meters have no moving parts, which should make them less affected by abrasion and non-affected by friction effects from particles in the pipe. Eventual impact of different pH-values or total hardness is not clear so far. To assess the influence of different water properties a test regime was developed based on typical water consumption and water qualities in Europe [3]. The parameters pH value, total hardness, and particle load were changed accordingly. The guidelines for the preparation of the defined water qualities are available for everyone's use [4].

For the study 187 meters of a size $Q_3 = 2.5$ m³/h were investigated. Each meter used was tested at six predefined test points at the beginning. After each test, the meters were measured again at these test points. The measurement errors before and after the experiment were compared. The test rig on which the measurements were carried out has a measurement uncertainty of 0.1 % ($k=2$).

If the water quality has an impact, it is in the sense that the meter often measures less volume compared to the one in as-new condition [3]. In the case of mechanical meters exposed to different water qualities wear and increased friction may lead to reduced smoothness in the mechanical devices and reduced mobility. However, electronic water meters may also be affected by the quality of the water to which they are exposed. They may also be affected by abrasion or deposits. The effect of meters measuring less volume is exemplified in Figure 1 but can be observed with all types of meters.

Furthermore, it was found that the largest effects do not necessarily occur at the lowest flow rates or the poorer water qualities. For several meters maximum effects occurred at a pH-value of 7.7 and flow rates between 0.8 m³/h and 1.8 m³/h [3]. The impression is that the manufacturing partly has a greater influence on the measurement quality than the measurement principle itself.

It is striking that water meters in mint conditions from the same manufacturer and type can already have large differences in their measurement accuracy (Figures 2, 3). For example, the red meter in Figure 2 from manufacturer H has a range of the measurement error at Q_1 between -0.21 % and - 1.68 %. The x-axis in Figures 2 and 3 show slightly different values, because several measurements are considered, and the mean value is used in the diagram.

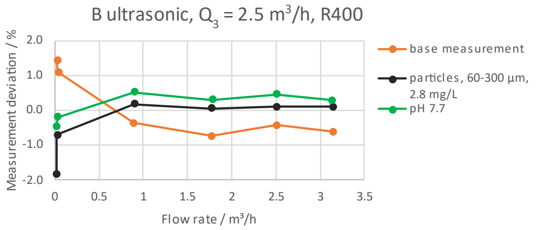

Figure 1: Ultrasonic meter of manufacture B in mint conditions and after testing using different water qualities (pH-value 7.7 and particle load).

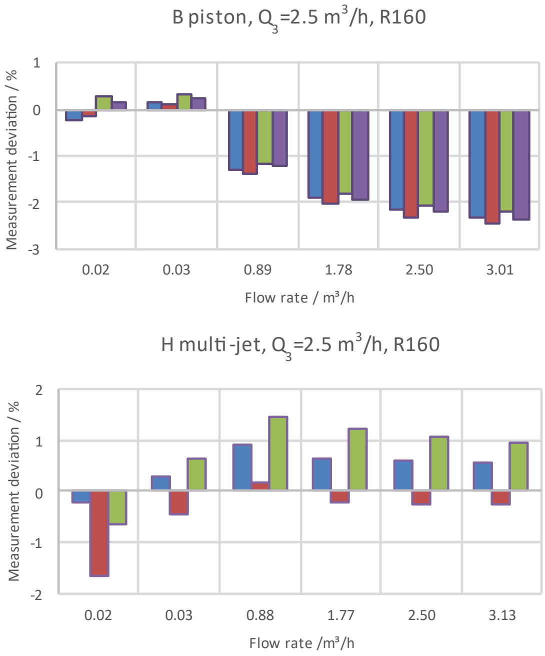

Figure 2: Measurement accuracy of mechanical water meters of the same manufacturer in mint condition; please note the different scaling of the y-axis.

Likewise, the batches themselves might be associated with differences in the measurement accuracy. Apart from some tendencies no generally applicable differences in performance quality between electronic and mechanical water meters were found but the investigations illustrate once more the impact the water quality can have on the measurement accuracy.

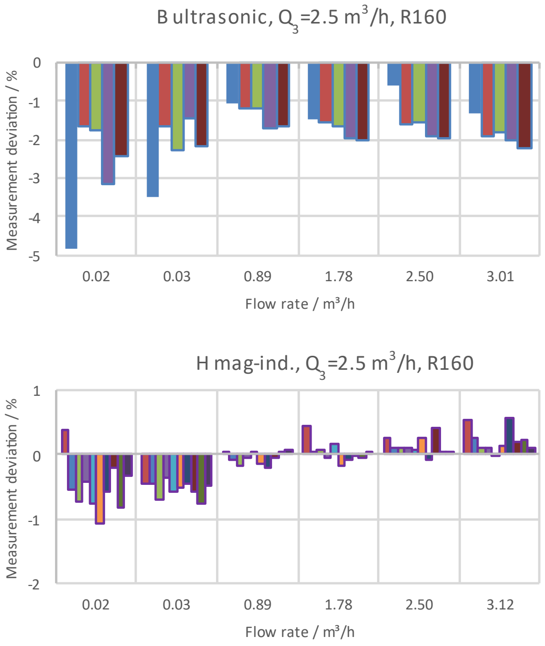

Figure 3: Measurement accuracy of electronic water meters in mint conditions; please note the different scaling of the y-axis.

3. Influence of discrete measurements on the measurement accuracy

Today, the accuracy of water meters has to be demonstrated at at least four constant flow rates (Q_1, Q_2, Q_3 and Q_4) according to ISO 4064:2014 and OIML R49:2013. By measuring a constant flow, the sampling interval, on which the discrete measurement is based, has no influence on the volume registered by the meter. The interpolation of the flow between individual measuring points has no influence since there are no flow changes. The start of the sampling also has no influence since a possible time delay at the beginning leads to a longer measuring time at the end.

A measuring error of up to 2 % ($Q_2 \leq Q \leq Q_4$), respectively 5 % ($Q_1 \leq Q < Q_2$), is permissible at these tests. In addition to the error occurring at constant flow rates, electronic water meters produce errors ε_{t_S} of an unknown magnitude due to the sampling interval. To evaluate the magnitude of this error investigations based on actual consumption data were carried out [5].

The error related to the discrete measurement was calculated by the ratio of the difference between the real volume V_{real} and the volume registered using a sampling interval V_{t_S} to the real volume:

$$\varepsilon_{t_S} = \frac{V_{real} - V_{t_S}}{V_{real}} \, . \tag{1}$$

The influence of the interpolation type was investigated as well as the influence of the observation period and the starting point of the sampling.

For the investigations consumption data from a DVGW (German association of the gas and water industry) study were used [6]. The data was recorded between 2014 and 2016 in different German cities. In the study detached and apartment houses (in total 58) were considered. From the data, recorded with ultrasonic water meters with a recording frequency of 1 Hz, a one-year long profile was derived by merging consumption data from different objects of the same type. This was possible because water consumption in Germany shows no relevant seasonal nor regional effects [7]. In the following the key results are summarized.

3.1 Influence of the interpolation type

The one year-long profile of the detached houses was first used to determine the error resulting from the sampling interval. A linear interpolation between sampling points and the rectangular function, in which a constant flow between the sampling points is assumed, were considered. The area under the curve of the flow rate corresponds to the volume registered by the water meter. The interpolation results in over- and under-recording components that lead to an error ε_{t_S}. First it was determined whether the two types of interpolation lead to comparable results or whether one type results in a smaller measurement error.

For the comparison, the difference between the linear and rectangular interpolation model $\Delta\varepsilon_{t_S}$ was used:

$$\Delta\varepsilon_{t_S} = | \epsilon_{linear\,t_S} - \epsilon_{regtangular\,t_S} | \tag{2}$$

Considering sampling intervals between 2 s and 120 s only negligibly small $\Delta\varepsilon_{t_S}$ below 0.0012 % were found for the one year-long profile as well as for shorter observation periods such as one month. This means both types of interpolation can be used equivalently.

3.2 Influence of the observation period

The length of the observation period might affect the size of the error, since for longer observation periods compensation effects.

To gain insights in this regard, the one year-long profile of the detached house was divided into shorter time periods. Observation times of one month, three months (one quarter), six months and the full one year-long profile were investigated. As a result, more cases were considered for shorter observation periods than for longer periods (e.g., 12 cases for the one month and two cases for six-months observation periods). Because water meters have to work within the legal limits at any time, only the maximum error ϵ_{max} (e.g., of all 12 months) was used for the evaluation of the effect of the sampling on the measurement accuracy:

$$\epsilon_{max} = \max\left\{ \left| \frac{V_{real} - V_{t_S}}{V_{real}} \right| \right\}. \tag{3}$$

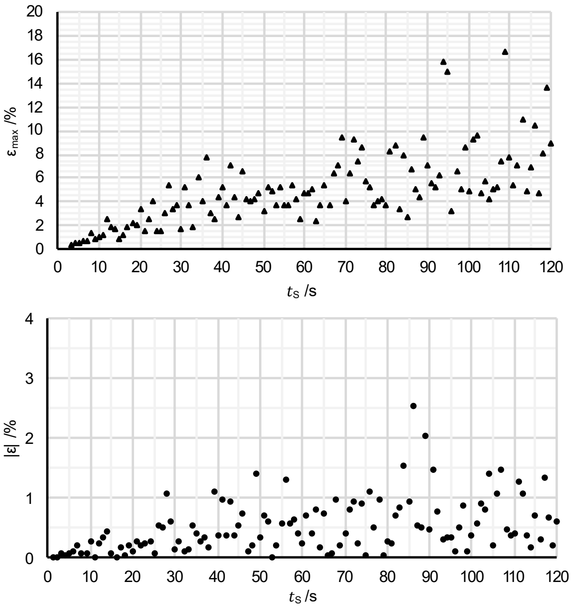

Figure 4: Total error due to the sampling interval for different observation periods; please note the different scaling of the y-axis.

In Figure 4 the results for the one month and one year-long observation periods are shown exemplarily.

As expected, the larger the sampling interval, the greater the error becomes. However, there is also a clear dependence between observation period and the size of the error. With longer observation periods the error due to the sampling interval is getting smaller by a factor of 4 and more. In Table 1 the errors obtained for sampling intervals between 3 s and 10 s and different observation periods are summarized. Because of the long computation time the one year-long profile is only considered for sampling intervals of 5 s and longer. Based on the result of the six months observation period it can be assumed that the error for the one year-long period is negligible in this interval range.

Since in all cases the shorter observation periods lead to higher measurement errors, the sampling interval must be selected as a function of the relevant observation period.

The errors given in Table 1 are based on data from European households. Moreover, for the period of one year, for example, only one case is considered. To check the general validity of the results, the investigations should be extended to other consumption data sets.

Table 1: Error depending on observation period and sampling interval.

sampling interval / **observation period**	**3 s**	**4 s**	**5 s**	**6 s**
one year			0.06 %	0.11 %
six months	0.1 %	0.09 %	0.1 %	0.21 %
three months	0.19 %	0.17 %	0.25 %	0.26 %
one month	0.41 %	0.58 %	0.44 %	0.72 %
sampling interval / **observation period**	**7 s**	**8 s**	**9 s**	**10 s**
one year	0.21 %	0.06 %	0.05 %	0.26 %
six months	0.22 %	0.13 %	0.09 %	0.34 %
three months	0.51 %	0.4 %	0.47 %	0.68 %
one month	0.63 %	1.32 %	0.8 %	1.04 %

3.3 Influence of the sampling starting point

A previous study by Eff [8] showed that, in addition to the length of the observation period, the start of sampling also has an influence on the error which occurs due to the sampling. Therefore, it is necessary to address this issue as well. For this investigation, the start of sampling was shifted between 1 s and 120 s in 1 s steps, so that a total of 121 starting points was considered. In order to have always the same profile length, the part that was cut off at the beginning of the profile was inserted at the end. Since previous studies showed that the error is not unilateral, again the total value of the error was used for simpler analysis.

Figure 5 shows exemplarily how the error is influenced by the start of sampling. Even with small time shifts, the error can change significantly. An ideal starting point does not exist, since no start of sampling leads to the smallest error in all cases. For the one year-long profile the start of the sampling is shifted additionally for three, six and nine months to investigate potential effects due to a start of the sampling at a different season of the year.

In Figure 6 the maximum errors are shown for all time shifts considered. Clearly shorter observation periods lead in all cases to larger errors in the captured volume.

Due to different starting points the errors, which occur at certain sampling intervals become larger compared to the errors given in Table 1. The errors that occur when all cases are considered are listed in Table 2.

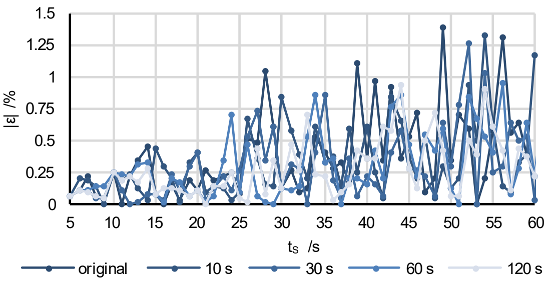

Figure 5: Errors obtained by shifting the start of the sampling by 10 s to 120 s.

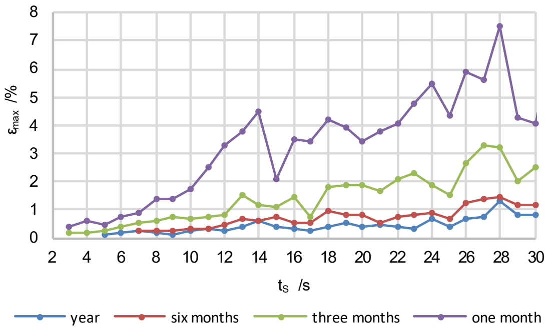

Figure 6: Maximum error considering different observation periods.

Table 2: Maximum errors depending on observation period and sampling interval for 121 different starting points of the sampling.

sampling interval / **observation period**	**3 s**	**4 s**	**5 s**	**6 s**
one year			0.12 %	0.21 %
six months	0.09 %	0.11 %	0.12 %	0.24 %
three months	0.19 %	0.22 %	0.25 %	0.41 %
one month	0.41 %	0.58 %	0.44 %	0.75 %
sampling interval / **observation period**	**7 s**	**8 s**	**9 s**	**10 s**
one year	0.29 %	0.17 %	0.14 %	0.26 %
six months	0.28 %	0.24 %	0.29 %	0.34 %
three months	0.51 %	0.59 %	0.75 %	0.68 %
one month	0.92 %	1.36 %	1.36 %	1.73 %

3.4 Use of stochastic profiles

In addition to the previously discussed directly measured profiles, stochastic profiles were derived using the algorithm of [9] and investigated in the same manner [5]. Similar results were obtained. Since the consumption data is anonymized, this stochastic data can be made available to anyone. The profiles can be used for instance to evaluate the influence of the sampling for new water meters of novel technologies. Profiles are available for downloading from
https://www.ptb.de/empir2018/metrowamet/information-communication/downloads/consumption-test-profiles/

In all cases, however, it should be clear that the consumption data is based on water consumption in Germany. The results can be transferred to countries with comparable water consumption characteristics, but further studies must be conducted for countries with different water consumptions or different orders of magnitude of water consumption.

4. Conclusion

When assessing the measuring accuracy of water meters, the measuring principle must always be taken into account because different aspects may become relevant.

From the tests with different water qualities, it emerged that both mechanical and electronic water meters are affected by the water quality (pH value, total hardness, and particle load). The greatest changes in the measurement error occur at different flow rates, so that it cannot generally be assumed that the measurement error for example changes the most at the highest or lowest measured flow. In general, however, electronic water meters tended to be less affected by water quality than mechanical meters. In addition, it was found that even water meters in mint condition can already have a large difference in their measurement accuracy, likely for manufacturing reasons.

The studies on the effect of the sampling interval show that electronic water meters will lead to new challenges in the future. The sampling interval unique to water meters with electronic measuring principles causes an additional error that can lead to unacceptable measurement accuracies of electronic water meters. The longer the observation periods become, the smaller the maximum occurring error tends to be. That means, that if for example one year is defined as billing period a longer sampling interval seems to be acceptable than one for shorter billing periods. This means for instance if an additional error due the sampling interval of 0.5 % is considered as acceptable a sampling interval of maximum 13 s could be permitted. However, this issue needs to be addressed in the relevant standardization bodies. The study can be seen as starting point for discussions. It must be discussed whether a maximum permissible sampling interval must be defined for discrete measurements, which additional error might be acceptable and whether additional tests, e.g., with changing flow rates, should be required in the future to ensure that electronic water meters operate within the legal limits.

Acknowledgements

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