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MEASUREMENT UNCERTAINTY OF A TEST RIG FOR WATER METERS

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Abstract: The accuracy of test rigs for water and flow sensors of heat meters depends on several parameters of the device and the performance of the calibration. Therefore the expanded uncertainty of a new test rig of the BEV, the Austrian Metrological Service, was determined by investigating the relevant influences. This measuring device allows to control the flow rate in a very wide range from 6 l/h up to 170.000 l/h as well as the temperature from 8 °C up to 90 °C, in the pressurized case up to 130 °C, and the pressure up to 6 bar.

At first a theoretical analysis of uncertainty was performed in line with the „Guide to the expression of Uncertainty in Measurement“ (ISO Guide) followed by experimental tests.The following contribution presents the basic ideas and the results of the investigations.

Keywords: water meters, uncertainty, test rig for water meters

1 INTRODUCTION

A test facility has been installed in the national Metrology-Institute (NMI) of Austria, the Bundesamt für Eich- und Vermessungswesen (BEV), Wien, in the past years which shall fulfill the highest requirements. The calibration range for the water meters comprises flow (*Q*) from

6 L/h to 180 000 L/h and temperatures (*t*) from 30 °C to 90 °C. Furthermore calibration is also possible under pressure conditions in the temperature range from 90 °C to 130 °C if the requirements concerning accuracy are not so strict. The next improvement shall bring an extension even to lower temperatures. A minimum water temperature of 3 °C shall be reached.

This facility shall be described as follows and the estimation of the uncertainty of measurement shall be given for a temperature range for warm water from 30 °C ≤ t ≤ 90 °C. Furthermore the performance under flying conditions only shall be described. For the performance under pressure conditions there are not sufficiently enough test results available.

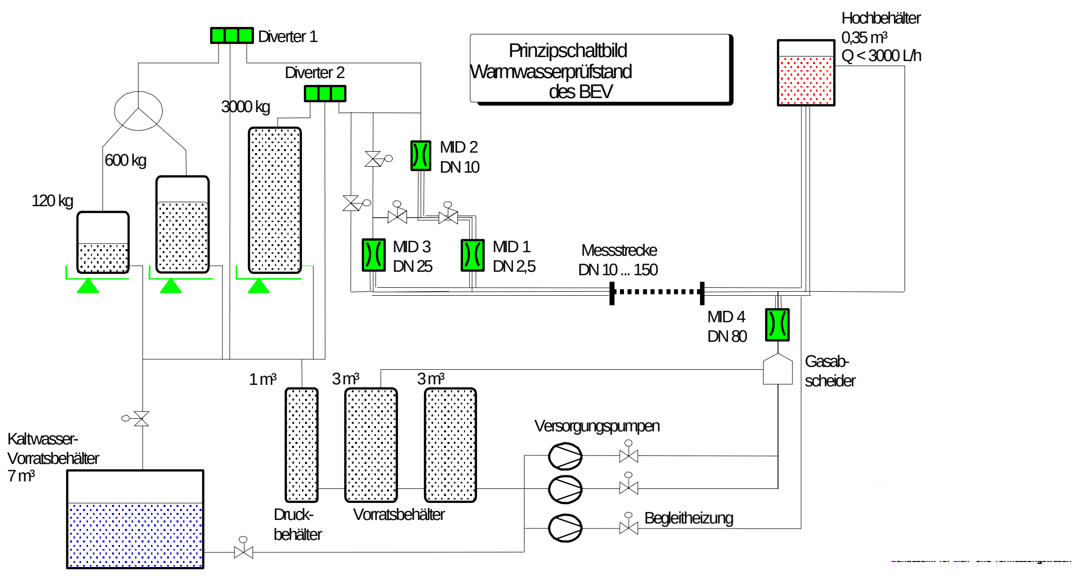


Figure 1: basic curcuit diagram of the test facility for water meters and flow sensors of heat meters

2 SHORT DESCRIPTION OF THE FACILITY

Figure 1 shows the basic curcuit diagram of the calibration facility. Lukewarm water will be taken from storage tanks of a total volume of 7 m^3. In pumping mode the water will flow through the test bench and preselected master meters and diverters in scales which give a value for the mass - after correcting for the buoyancy - and for the nominal volume for the calibration by taking into account the known value of density. According to the flow and the volume preset one of the three scales will be chosen. In order to guarantee constant temperatures the relevant pipes are heated by a double shell system whereas in the outer circuit the "primary water" circulates by high flow. This is espacially important along the test bench in order to prevent a cooling down in the direction of the flow while calibrating simultaneously several test samples.

Calibration is done in most cases at "flying" conditions as described below. First of all the facility has to be vented, then washed by water of the temperature chosen. Then the water has to flow back to the storage tanks. Under stationary conditions with regard to constant flow and constant pressure and temperature the volume flow will be by-passed to the scales selected by means of one of the two diverters according to a signal sent by the test sample. Provided the test volume selected is reached the diverter lets the volume flow return to the storage tanks.

3 TAKING INTO ACCOUNT SYSTEMATIC INFLUENCES

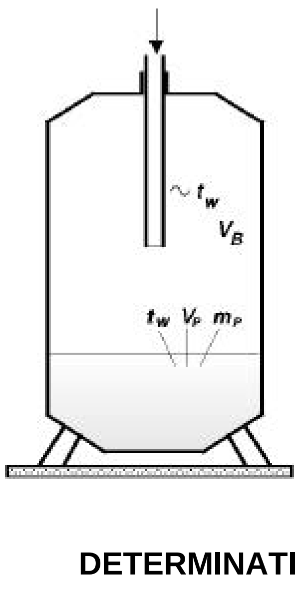
3.1 Systematic deviations of the measurements

At each measurement systematic influences such as corrections of scales and master meters arise and have to be taken into account. In case these systematic influences are well known but can not be corrected they will be treated as random influences are treated according to the GUM [1].

3.2 Buoyancy and density

By weighing the reference volume is determined which has passed the test sample. In order to come from the result of weighing to the reference volume certain calculations are necessary [2]. Furthermore, the fact has to be taken into account that the density of wet air in the container of the scales is obviously lower than that one of dry air. To determine the density of water the formula of *Wagenbreth* and *Blanke* are to be considered [3].

3.3 Evaporation loss



By the flow of warm water into the container of the scales on the one hand a volume of air of the same size is displaced from the container, on the other hand also the state of saturation of the air remaining in the container is changed. By measuring the humidity of air before, during and after a measurement

- the correct density of air is determined which is necessary for the correction of buoyancy (see item 3.2 above)
- the stream of air and its conditions are determined which leaves the container during measurement and therfore has to be taken into consideration as a loss of mass.

Figure 2: For the assessment of the evaporation rate

4 DETERMINATION OF UNCERTAINTY OF MEASUREMENT

4.1 General

Taking into account all systematic influences an assessment of the uncertainty of measurement can be started. As stated above the procedure according to GUM [1] will be applied.

4.2 Assessment of the components of the uncertainty

With regard to the practical problem one can find the following quantities of influence:

4.2.1 Resolution for the indication of the test sample

The indication of the test sample be V_P ; with a resolution of the volume dV_P one gets for the volume indicated therefore: ($V_P \pm dV_P/2$). dV_P can be the scale division or the volume related to a single pulse. Therefore $a_p = dV_P/V_P$ results under the assumption of a rightangle distribution for the relevant variance:

$$u_A^2 = \frac{1}{3}\left(\frac{dV_P}{2V_P}\right)^2 = \frac{dV_P{}^2}{12V_p^2} \tag{1}$$

If the output signals of the test sample are synchronized with the output signal of the volume standard, as it is done here, this contribution of the variance disappears.

4.2.2 Resolution for indication of the reference- or mastermeter

Since the synchronisation is carried out according to the output pulses of the test sample(s) an uncertainty of ± 1 pulse can occur while detecting the pulses of the mastermeter. With a resolution dV_{MZ} of the mastermeter and a test volume V_P the following applies analogously to formula (1) above

$$u_{MZ}^2 = \frac{1}{3}\left(\frac{V_{MZ}}{V_P}\right)^2 \tag{2}$$

Because of the high values of pulses of the mastermeter, e.g. 1000 pulses/l or 1 kHz, his variance is rather small but depends from the test volume and has to be taken into account in any case.

4.3.3 Scales

The systematic deviations of the indication while measuring scales have been determined at selected measuring points. Subsequently, the curve has been approximated by a polynomial. The standard uncertainty as the base of variance has been determined by repeated measurements (contribution to the variance $u_W{}^2$).

4.2.4 Long-duration stability of the scales

The long-duration stability can be determined as a further influence quantity (contribution to the variance $u_{W,LT}{}^2$) by re-calibration measurements.

4.2.5 Determination of the volume by weighing, correction for buoyancy and temperature measurement

The influence of density and buoyancy has been indicated at the systematic effects already. Anyway, not taken into consideration has been the uncertainty of the temperature measurement which leads to a contribution of the variance due to the buoyancy correction and the influence of the density (contribution to the variance $u_{D,A1}{}^2$). Furthermore, the deviation of the density of water in the test facility from that one according to the data given by *Wagenbreth* and *Blanke* has to be taken into consideration (contribution to the variance $u_{D,A2}{}^2$).

4.2.6 Change of temperature of the pipe system

Differences in temperature Dt between the test sample(s) and the mastermeter and/or the volume standard, respectively, arise by small flow. Because of the different expansion coefficients $ß$ of metals and water ($Dß$) an error of the volume arises of the following order of magnitude, whereas V_R is the volume of the pipe between test sample and volume standard (mastermeter) and V_P is the volume of the test sample:

$$\frac{DV_R}{V_P} = Db\ Dt\ \frac{V_R}{V_P} \tag{3}$$

The influence of the cooling down of the pipe can be avoided by determining the temperatures at the location of the test sample and the volume standard (scales or mastermeter, respectively) and by correcting according to formula (3). Finally, in formula (3) only the uncertainty of the temperature determination (as mentioned above) has to be considered.

4.2.7 Air in the pipes

While doing flow measurements air causes special problems since water meters also register air in one or the other way. With regard to the determination of the uncertainty of measurement different effects can be observed which can be traced to air in those parts of the measuring facility being relevant to the measuring process, e.g.:

(1) If there is air in those pipes being relevant for the measuring process e.g. valves, test samples not vented properly, changes in pressure due to the compressibility of air can lead to disturbances. Such changes in pressure arise first of all during the asymmetric “start and stop mode” being not regarded here in more detail.

(2) If the temperature of the air in the relevant part of the piping system changes a missing volume of air results according to the general gas law described by the following variance:

$$u_{L2}^2 = \frac{1}{3}\, 1{,}34 \,.\, 10^{-5}\, Dt^2 \left(\frac{V_L}{V_P}\right)^2 \tag{4}$$

4.2.8 Diverter unit

The relation of the duration of the diverting procedure to the measuring time defines the influence of the diverting unit. It depends strongly on the design chosen. Uncertainties in the diverting time for both procedures (switch-on and switch-off) of about 10 ms can be achieved by state of the art diverting units as they are used in this test facility in which only the direction of the liquid jet is turned round. Under the assumption of a rightangle distribution the related contribution to the variance can be derived (see table 2)

4.2.9 Evaporation in the container of scales

The influence of the evaporation has been discussed already as a systematic effect. Since the evaporation loss is measured by the test facility only the variance due to the uncertainty of measurement of the humidity sensors has to be determined. Surprisingly, a contribution to this variance strongly depending on the relation of the volume of the container (V_0) and of the test sample (V_P), results in and is in the order of magnitude of the following:

$$\frac{u^2(V_P)}{V_P^2} = 2 . 10^{-6} \left[2\left(\frac{V_0}{V_P}\right)^2 + 1 \right] u^2(f) \tag{5}$$

$u^2(f)$ being the contribution of the variance due to the humidity of air. In table 1 this contribution of the variance is shown for different filling heights of the container of the scales. For practical purposes we advise to choose filling quantities for the test procedure comparable to the volume of the container (e.g. $V_0/V_P \approx 1$ would be ideal).

V_P/V_0	$\frac{u^2(V_P)}{V_P^2}$
1	$1{,}3.10^{-10}$
0,5	$3{,}8.10^{-10}$
0,1	$8{,}4.10^{-9}$
0,01	$8{,}4.10^{-7}$

Table 1: Contribution to the variance by the evaporation losses as a function of the filling height of the container (here:as relation of the volume of the test sample(s) and the volume of the container); temperature in the container 90 °C. Assumption: the absolute humidity of the air is measured with an accuracy of 5%.

4.2.10 Stability of the mastermeter

A mastermeter has to fulfill strict requirements which in most cases can be reduced to the short time stability of the deviation of the measurement result in a certain testing point. This requires only the determination of the deviation of the measurement result in each calbration point (Q,t).

5 RESULTS AND CONCLUSION

Table 2 shows an example of a test procedure being analysed with regard to the uncertainty of measurement. The expanded uncertainty U yields different values being extremely small and depending on the working order of the facility. For a rather correct determination of the expansion factor also the determination of the expanded uncertainty by the method of the effective degree of freedom is given besides the standard value k = 2.

So our task was to minimize the different components of the uncertainty of measurements due to asymmetric behaviour of the liquid jet during the change of its direction and the effects caused by changes in density of the air and in bouyancy and evaporation. We think that by the highlights of the test rig described – the new diverter unit, the extra humidity sensors and others – we have been able to reach an order of magnitude of the uncertainty of measurement comparable to the best test facilities operating at this time. E. g., please refer to the expandes uncertainty of the test rig better than 0,03 %, as shown in table 2.

REFERENCES

[1] Guide to the expression of uncertainty in measurement **(GUM),** first edition, 1993, new edition 1995, *International Organization of Standardisation* (Geneva, Switzerland)

[2] R. Balhorn, M. Kochsiek: Der konventionelle Wägewert und seine Anwendung im Eichwesen, *wägen + dosieren 2/1980, S. 44 ff*

[3] H. Wagenbreth, W. Blanke: Die Dichte des Wassers im Internationalen Einheitensystem und in der Internationalen Praktischen Temperaturskala von 1968, *PTB-Mitteilungen Nr. 6/1971, S. 412 ff;* see also: H. Bettin, F. Spieweck: Die Dichte des Wassers als Funktion der Temperatur nach Einführung der Internationalen Temperaturskala von 1990, *PTB-Mitteilungen Nr. 3/1990*, *S. 195 ff*

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Table 2: An example for the expanded uncertainty of the test rig

Q_n in m³/h	**150**	
temperatur of water [°C]	**40**	
environment temperature [°C]	**25**	
air pressure [mbar]:	**1.000**	
flow rate [l/h]	170000	15000
calibration volume V_P [L]	2800	2800
selected scale vessel	3000	3000
calibration time [s]	59	672
pulse rate of the meter to be calibrated [pulses/L]	1,0	1,0
pulse rate of the master meter [pulses/L]	10	100
repeatability of the meter to be calibrated $u(x_i)$ [%]	0,011	0,029
volume of the tube between meter to be calibrated and master meter [L]	56	56
air in water [L]	0,3	0,3
cool down of the air chamber [K]	5	5
temperatur accuracy for density evaluation and buoyancy correction [K]	0,10	0,10
temperature difference between meter to be calibrated and master meter [°C]	0,10	0,18
number of measurements	10	10
absolute humidity [g/m³] at the temperatur of water	51	51
absolute humidity [g/m³] at the temperatur of environment	23	23
evaporation flow [g]	78	78
diverter time [ms]	-6,4	-6,4
last significant bit of the meter to be calibrated: u^2_A	0,00	0,00
last significant bit of the mastermeter: u^2_{MZ}	4,25E-10	4,25E-12
scale u_w^2	3,20E-10	1,86E-12
long term stsbility of the scale $u_{w,LT}^2$	5,00E-09	5,00E-09
buoyancy correction 1: temperature $u_{D,A1}^2$	1,51E-09	1,51E-09
buoyancy correction 2: density $u_{D,A2}^2$	4,10E-10	4,10E-10
temperature drop in the tube between meter to be calibrated and the volume standard $u_{TÄ}^2$	3,23E-13	1,09E-12
air solved in the tubes (1) u_{L1}^2 (only start-stop)	0E+00	0E+00
air solved in the tubes (2) u_{L2}^2	1,28E-12	1,28E-12
diverter u_u^2	3,88E-09	3,02E-11
humidity effects u_f^2	1,68E-11	8,42E-10
repeatability of the meter to be calibrated $u^2(x_i)$	1,21E-08	8,21E-08
combined variance u_c^2	2,37E-08	8,99E-08
expanded uncertainty *U* [%] for *k* = 2	***0,031***	***0,060***
$_{eff}$	18,34	10,66
k_{eff}	2,11	2,27
expanded uncertainty U_{eff} [%]	***0,033***	***0,068***
combined variance u_c^2 without repeatability of the meter	1,16E-08	7,80E-09
expanded uncertainty *U* [%] for *k* = 2	***0,022***	***0,018***
$_{eff}$	9,37	6,65
k_{eff}	2,33	2,57
expanded uncertainty *Ueff [%]* without repeatability of the meter	***0,025***	***0,023***