Evaluation of Measurement Uncertainty in Calibration Standard Gravimetric Installationfor Water Flowmeters Verification

Gabriel Constantin Sârbu

Gheorghe Asachi Technical University of Iasi
Faculty of Hydrotechnics, Geodesy and Environmental Engineering Iasi, Romania
gabrielsarbu26@yahoo.ro
0756 010008

***Abstract* – The paper refers to evaluation of measurement uncertainty in calibration standard gravimetric installation for water meter verification/calibration. For design and construction of a standard gravimetric installation for water meters verification/calibration, is taken account of all metrological, constructive and functional requirements and uncertainty.All the individual uncertainty components of the gravimetric installation for water meters verification should have predefined values and provide for the total extended measurement uncertainty of the installation a smaller value.**

For the calibration of gravimetric installations, weighing instruments, measuring instruments for environmental conditions (thermometer, hygrometer, barometer), thermometers for measuring water temperature are required.Measurement uncertainty evaluation involves determining the influence factors of the calibration. The main factors of influence are: the linearity correction of balance, the uncertainty of the calibration of the balance (taken from the calibration certificate), derive the balance indication with the temperature and the resolution of the balance, correction for archimedical force, correction due to liquid evaporation; correction due to leakage.

***Keywords* – Uncertainty of measurement, gravimetric installation, weighing scale, water flowmeter, mass.**

I. INTRODUCTION

A flowmeter can be calibrated gravimetrically by weighingthe quantity of liquid collected in a collection tank. As the quantity of fluid has to be expressed as mass, the weight has to be corrected for the effect of air buoyancy.To determine the volume, the mass is divided by the density determined at the flowmeter. Density can be calculated from a knowledge of the fluid properties and measurements of temperature and pressure at the test meter. In start-and-finish method called the diverter method, the flow through the flowmeter is not stopped but the flow is diverted between a return to the supply and the collection tank (Figure 1). A switch on the diverter mechanism starts and stops a timer to measure time the filling of the collection measure and counter tototalize pulses from the test device. In this method, the key to accurate measurement is a clean separation between fluid entering the Weighing tank and fluid returning to the supply tank.

Diverter methods are used primarily for flowmeters with slow response times and where flow rate is the primary measurement rather than quantity passed.

The main source of uncertainty for gravimetric calibration methods lies in the timing error, in the case ofthe standing start and stop method, this is caused by the response time of the flowmeter and the changing flow at each end of the test,for the diverter methods, this is introduced by not triggering at the hydraulic center of the liquid jet.

Calibration of water meter installations consists of:

a. Examination of the external appearance and construction, where it is established whether the assembly of the installation and its components meet the requirements specified in the relevant metrological normative;

b. The assessment of the volume of the supply tank shall be by geometric measurement and shall be 1,5 times the sum of the volumes of vessels (standard measures or vessels mounted on water balances) and the volume of water contained in the hydraulic circuit of the installation;

c. Checking the tightness, where it is determined whether the entire hydraulic circuit of the installation is sealed, when it is under pressurefor 10 minutes, successively in the resting state and then at maximum load;

d. Determining the mass measurement errors and their associated uncertainty;

e. Determination of the measurement errors of the flow indicators can be done directly on the calibrated installation if it can measure the flow in dynamic mode, making determinations at the flows specified in the metrological normative applicable to the flow indicator (rotameter, flowmeter);

f. The determination of the flow instability consists in determining the difference between the maximum and minimum values of the flow rate indicated by the flowmeter, for a minimum period of 5 minutes, for the flow rates at which the flowmeter measurement error was determined;

g. Checking the operation of the installation with the maximum number of meters for each nominal diameter in order to determine if the installation permits all the samples provided in the applicable metrological norm.

II. RELATED RESULTS IN THE LITERATURE

International Standards ISO, provides the methods for determining flow in closed pipes and the requirements for the gravimetric standard installations for water flowmeters verification.

If these installations are used forverification the water flowmeters subject to legal metrological regulations, they must be periodically calibrated by a laboratory of a national body with regard to basic physical measures(mass and time) and an analysis of influence factors for assessing measurement uncertainty of mass and mass flow-rate.[1-2]

Also, in several of ISO documents, are references to evaluation of uncertainty of measurement, documents which provide guidance on calibration methods, the principle and the requirements on the evaluation of the uncertainty measurement in calibration.[3-5]

In the document, NIST' Water flowmeter Calibration Facility, we have a description of standard installation for water flowmeter calibration with a uncertainty of 0.033% for liquid mass collections of 3000 Kg. The document explains the method of operation, the functions of varios component and gives a detailed analysis of the uncertainty of its mass flow measurement rezults.[6]

The study conducted in the PTB laboratory Hidrodinamic Test Field, it led to obtaining an expanded measurement uncertainty o as low as 0.02% of total volumetric flow-rate measurement. [7]

III. DESCRIPTION OF THE METHOD

Evaluation of measurement uncertainty involves determining the influence factors of the calibration. To determine factors of influence we start from the general equationof measurement, given in equation no. (1):

$$V = \left(\overline{M}+\Delta M+\delta M_{lin}+\delta M_{res}+\delta M_T+\delta M_{drift}+\delta M_{evap}\right)x$$
$$x\cdot\left(\frac{1}{\rho-\rho_{aer}}\right)\left(1-\frac{\rho_{aer}}{\rho_G}\right)+\delta V_m \quad (1)$$

Where:

V Is the volume of liquid;

ΔM is the difference in mass;

δM_{lin} isthecorrectionduetothenonlinearity of the balance;

δM_{res} isthecorrectionduetobalanceresolution;

δM_T isthecorrectiondue to time derivationofthe balance;

δM_{drift} isthecorrectiondue to drift with the temperature of the weighing scale;

δM_{evap} isthecorrectiondue to liquidevaporation;

$\left(\frac{1}{\rho-\rho_{aer}}\right)\left(1-\frac{\rho_{aer}}{\rho_G}\right)$ isthecorrectioncoefficient for thearchimedical force;

ρ_{aer} isairdensity;

ρ_G isthedensityofthe material fromwhichtheweights aremade (steel: 8 g / cm3)

ρ isthedensity of the calibration fluid;

δV_m isthecorrectiondue to leakageandjetdeviation.

Water density is determined with the relationship (2):

$$\rho = \sum_{i=1}^{4} a_i t^i \quad (2)$$

Where:

t is the water temperature in^{0}C and the coefficients a_i,have the following values:

a_0= - 85308 kg/m^3;

a_1= 6.32693·10^{-2} kg/(m^3·^{0}C);

a_2= - 8.523693·10^{-3} kg/(m^3·^{0}C^2);

a_3= 6.943248·10^{-5} kg/(m^3·^{0}C^3);

a_4= - 3.821216·10^{-7} kg/(m^3·^{0}C^{-7}).

Air density is determined with the relationship (3):

$$\rho = \frac{k_1 p_{aer} + h\cdot\left(k_2 t_{aer} + k_3\right)}{t_{aer}+t_0} \quad (3)$$

Where:

p_{aer} is the air pressure in kPa;

h is the relative humidity in%;

t_{aer} air temperature in ^{0}C;

t_0=273.15^{0}C.

The coefficients k_i, have the following values:

k_1= 0.34844(kg/m^3)·^{0}C/kPa;

k_2= - 0.00252(kg/m^3);

k_3= 0.020582(kg/m^3)·^{0}C.

The density of the weights used for calibration is considered to be 8000 kg / m^3.

The main factors of influence are:

a.Balance(weighing machine) of the installation:

The main characteristics of the balance that contribute to the measurement uncertainty budget are: linearity correction, balance calibration uncertainty (taken from the calibration certificate), balance reading with temperature and balance resolution.

The uncertainty due to the balance is determined with the equation no. (4):

$$u_{Bal} = \sqrt{u_{lin}^2 + \left(U/_k\right)^2 + 2 \cdot u_{res}^2 + u_T^2 + u_d^2} \quad (4)$$

Where:

$u_{lin} = \delta M_{max}/\sqrt{3}$

δM_{max}, isthe maximum linearitydeviation of thebalance (tobetakenintoaccountifthelinearitycorrection of thebalanceisnotusedwhencheckingthewatermeters);

U is the expanded uncertainty of the balance measurement, taken from the calibration certificate of the balance;

$u_{res} = d/\left(2 \cdot \sqrt{3}\right)$,istheinfluence due to the resolution of the weighing scale (d=balance division). It is taken twice because in the measurement process both zero error (at the beginning of the measurements is carried out the balance division) as well as error reading the measured value.

$u_T = c(t-20)/2 \cdot \sqrt{3}$,istheinfluence of the temperature drift (c is the coefficient ofdrift with the balance temperature, taken from the balance manual)

u_d is the uncertainty due to the deviation of the balance in time

b. Correction for archimedical force

The correction for archimedical force is determined from the maximum variation of environmental parameters in the laboratory and the working fluid temperature.

The value of the correction factor for the archimed force is determined with the relation (5):

$$\left(\frac{1}{\rho - \rho_{aer}}\right)\left(1 - \frac{\rho_{aer}}{\rho_G}\right) \quad (5)$$

Starting from this equation, and taking intoaccountthat $\left(1 - \frac{\rho_{aer}}{\rho_G}\right) \cong 1$,and $\rho >> \rho_{aer}$, the uncertainty associated with this factor is considered to be equal to the uncertainty to determine the density of water.

c. Correction due to liquid evaporation δV_{evap}

This parameter is taken into account only for installations that work with hot water.

If the technical conditions of the installation tank are met, no correction is required, but it is assumed to induce an uncertainty of 0.03% of the measured water volume, respecting a rectangular probability distribution.

d. correction due to leakage δV_m

If the technical conditions of operation of the installations are observed, no correction is necessary, but it is assumed to induce an uncertainty of 0.03% of the measured water volume, respecting a rectangular probability distribution.

Applying the law of uncertainty propagation resultsin the following equation no. (6):

$$u^2(V) = c_M^2 u_{Bal}^2 + c_{Mevap}^2 u^2(\delta M_{evap}) + c_{Farh}^2 u^2(\delta F_{arh}) + c_m^2 u^2(\delta V_m) \quad (6)$$

Where:

$c_M = c_{Mevap} = c_m = \left(\frac{1}{\rho - \rho_{aer}}\right)\left(1 - \frac{\rho_{aer}}{\rho_G}\right)$

and $c_{Farh} = M$

The uncertainty of determining the correction for the archimedical force is given in equation no. (7):

$$u^2(F_{arh}) \approx u_c^2(\rho) = \left(\partial\rho/_{\partial t}\right)^2 \cdot u^2(t) \quad (7)$$

Where:

$\partial\rho/_{\partial t} = a_1 + 2 \cdot a_2 \cdot t + 3 \cdot a_3 \cdot t^2 + 4 \cdot a_4 \cdot t^3$

$u^2(t) = \left(U/_2\right)^2 + u_{res}^2$

Table 1.Budget of uncertainties:

Uncertainty source	The value of the standard uncertainty	Sensitivity coefficient
u_{Bal} balance	$u_{Bal} = \sqrt{u_{lin}^2 + \left(U/_k\right)^2 + 2 \cdot u_{res}^2 + u_T^2 + u_d^2}$	$\left(\frac{1}{\rho - \rho_{aer}}\right)\left(1 - \frac{\rho_{aer}}{\rho_G}\right)$
u_{evap} liquid evap	$3 \cdot 10^{-4}$ M	$\left(\frac{1}{\rho - \rho_{aer}}\right)\left(1 - \frac{\rho_{aer}}{\rho_G}\right)$
δV_m leakage	$3 \cdot 10^{-4}$ M	$\left(\frac{1}{\rho - \rho_{aer}}\right)\left(1 - \frac{\rho_{aer}}{\rho_G}\right)$
u_{Farh} buoyancy force	$u(\rho)$	M

IV. RESULTS AND DISCUSSIONS

The schematic diagram of a gravimetric calibration facility used for meter calibration / verification is shown in Figure 1.

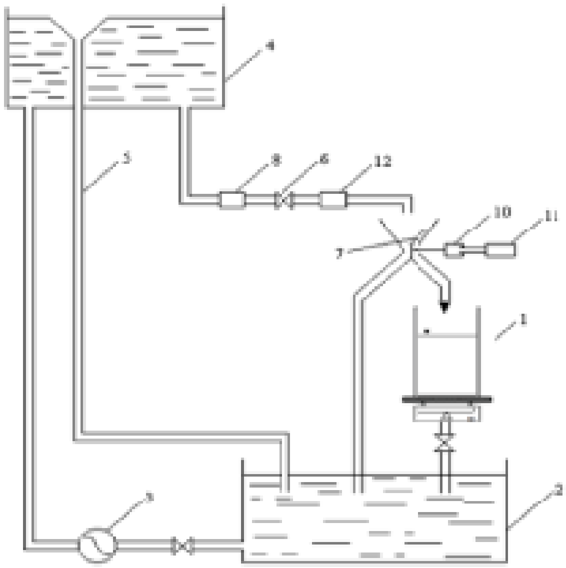

Fig.1. Gravimetric installation

1. weighingscale ; 2. Storage/supply tank; 3.Pump; 4.constant level tank; 5. overflow pipeline; 6. adjusting valve; 7. jet diverter; 8. flow meter / water flowmeter under verification; 9. evacuation valve; 10. contacts; 11. timer; 12. flow indicator.

Using the pump (3) the constant level tank (4) is fed until the liquid flows through the overflow pipe (5).The test flow rate is adjusted by means of the valve (6), which is indicated by the flow indicator (12) (electromagnetic flowmeter, rotameter, etc.).The installation is provided with a pneumatically operated jet deflector which allows the flow of water submitted to cross flow meter calibration/verification vessel or directly to the storage tank.In order to ensure constant flow in place of the constant level tank, pumps equipped with frequency converters can be used.

The verification of water flowmeter involves the determination of the relative error of indication within the applicable flow range of the meter. The measurement is made using a gravimetric standard installation, which ensures the required water flow with a constant level tank. The water is collected in an open collecting tank, which is placed on an electronic weighing scale, that has been calibrated and determines the reference mass of the water which passed through the flowmeter under verification. After collection of a sufficient quantity of water, the divertermanages in the sense of directing the jet of the liquid in storage tank, stopping the timer, allowing determining the time of weighingthe mass of water collected.

The measurement is done for values of flow-rate, from the metering range of the meter under verification. The indication of the flowmeter under verification is recorded at the start and the stop of the measurement, synchronized with start/stop time to measure the mas of water collected.

The temperature and the pressure of the water at the flowmeter under verification, and the temperature of the water in collecting tank, are recorded as well.

For calibration of gravimetric installations, standard weights used for calibration weighing machine are required for secondary calibrations with appropriate nominal values, thermometer, chronometer if the plant has rotameter flow indicators.The weighing machine may be of any electronic type, provided it ocures the proper sensitivity, accuracy and fidelity.

Determining the mass measurement errors and their associated uncertainty require:

-calibration of the weighing scale must be made over its entire measuring range by means of standard weights. If the weights are insufficient to cover the entire measuring range, we can proceed by steps, alternately replacing the weights with liquid and using the standard weights to control exactly the intervals.

-correction of the mass read must be made, due to the difference in aerostatic thrust between calibration of the weighing scale with weight, on the one hand and the weighing of an equivalent mass of liquid, on the other hand.

An example for calculating the uncertainty of mass measurement refers to a gravimetric plant equipped with an electronic weighing scale with a maximum capacity of 3000 Kg. In Table 2, I will give the results of the measurement uncertainty calculation for mass.

Table 2. Massuncertainty calculation

Uncertainty source	Value (±Kg)	Probab Distrib. Divisor	Standard Uncertainty (±Kg)
Scale uncertainty (by calibration certificate)	0.11080	Normal 2	0.05540
Uncertainty for buoyancy at max. mass collected 2000.00 Kg	0.07000	Rectangular 1.73	0.04046
Uncertainty for evaporation	0.00013	Rectangular 1.73	0.00008
Uncertainty for Scale drift over time	0	Rectangular 1.73	0
Uncertainty for leak test criteria	0.06666	Normal 2	0.03333
Uncertainty of Scale temp. drift	0.10666	Rectangular 1.73	0.06165

Combined Scale uncertainty			0.09807
Extended Scale Uncertainty P=95%, K=2		Normal	0.19614
Minimum mass collected (Kg)	1000.00		
Mass Uncertainty Calibration (%)			± 0.01961 %

Given the uncertainties of the sub-components such as those for collected mass, the collection time and the density of the water flowing through the meter under verification during the collection which must be combined to obtain the mass and volume flow rate uncertainties.

Calculation of mass flow measurements uncertainty is based by combining the mass uncertainty and collection time uncertainty using the root-sum-squared technique, given in Table 3.

Table 3.Mass and volume flow uncertainty calculation

Uncertainty source	Uncertainty(%)	
Mass collected (kg)	1000.00	2000.00
Mass uncertainty	0.009807	0.004904
Collected time uncertainty	0.01	0.01
Water density uncertainty	0.005	0.005
Mass flow Uncertainty	0.014	0.011
Expanded mass flow Uncertainty P= 95% K =2	0.028	0.022
Volume flow Uncertainty	0.015	0.012
Expanded volume flow UncertaintyP= 95% K =2	0.030	0.024

V. CONCLUSIONS

For evaluation of measurement uncertainty in calibration standard gravimetric installation for water meter verification/calibration, is necessary in thedesign and construction of a standard installation, to be taken into account of all metrological,constructive and functional requirements and uncertainty.

All the individual uncertainty components of the gravimetric installation for water meters verification should have predefined values and provide for the total extended measurement uncertainty of the installation a smaller value.

Measurement uncertainty evaluation involves determining the influence factors of the calibration. The main factors of influence are:characteristics of the weighing scale that contribute to the measurement uncertainty budget: linearity correction, balance calibration uncertainty (taken from the calibration certificate), balance reading with temperature and balance resolution;correction for archimedical force;correction due to liquid evaporation; correction due to leakage.

With a well-built, maintained and careful installation, an extended uncertainty (for confidence probability of 95%) can be achieved in the order of±0.03%.

REFERENCES

[1] *ISO 4185 – Measurement of liquid flow in closed conduits. Weighing method.*

[2] *ISO 5168 – Fluids flow measurement – Accuracy calculus*

[3] ISO-GUM−*Guide to the Expression of Uncertainty in Measurement.*

[4] SR13434−*Guide for evaluating and expressing uncertainty in measurement*.

[5] EA-4/02−*Expression of the Uncertainty of Measurement in Calibration*

[6] Shinder I,Marfenko I, −*NIST'-Waterflowmeter Calibration Facility,* NIST Special Publication 250

[7] Engel R,Baade H.J,Rubel A,- *Performance improvement of liquid flow calibration by applying special measurement and control strategies,* The 11th International Conference on Flow Measurement FLOMENKO 2003

[8] Costea O, Donciu C, *Labview based analog and digital instrument's automated calibration,* Management of Technological Changes, vol. 1, pp. 473-476, 2009

[9] Popescu Șt, Marcoie N, Toma D, *Modelling of a hydrophore pumping facility in slow variable operational regimes,* Buletinul Institutului Politehnic din Iași, Tomul LIV (LVIII), Fasc. 2, pag. 57-66, 2008

[10] Toma D, *Issues related to the adapting of variable operating regime pumping plants by the use of variable speed drives,* “Ovidius” University Annals - Constantza, Year XIV, Issue 14, Series: Civil Engineering, ISSN 1584-5990, pp. 111-119, 2012

[11] Beniugă O, Neacsu O,*Virtual instrumentation system for remote reading of digital and analogical equipment display*, AWERProcedia Information Technology & Computer Science. [Online]. 2013,3, pp.1087-1092. Proceedings of 3rd World Conference on Information Technology (WCIT 2012), 14-16 November, University of Barcelon, Barcelona, Spain