Installation for the high accuracy flow meter calibration with the weighting method

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Abstract. Installation for precise flow meter calibrations meets demands of the relevant standards: high-quality installation, appropriate calibration methodology, instruments of high accuracy and satisfactory measurement uncertainty. So, it is necessary to calibrate the flow meter on an adequate installation. Designed and assembled installation for flow meters calibration for measurement of liquid flow in closed conduits up to 10 l/min, based on weighing method, is presented in this paper. Modified measurement methodology, which mainly follows standard ISO 4185, is presented in this paper. The geometry of the whole installation is presented and afterwards used for numerical experiments. Two numerical meshes were tested. First approach had a half a million cells and the second mesh was consisted of approximately 1.6 million cells. Both meshes were unstructured. Numerical results were used for installation test before manufacturing and assembling. The test rig was manufactured after the numerical results evaluation. Experimental validation of the calibration procedure followed. Obtained experimental results and measurement uncertainty for three operating regimes were analysed and reported. It was proved, experimentally and numerically, that uniform, i.e. developed turbulent flow, was achieved in the straight measurement section, what is of great importance for flow measurement calibration.

1 Flowmeter calibration

There are many types of flowmeters on the market, and mostly used are: pressure-based (orifice, nozzles, Venturi, Pitot-static tubes, etc.), variable-area (rotameter), turbine, vortex, electromagnetic (for conducting liquids), ultrasonic, Coriolis, thermal, laser Doppler flow measurement, etc.

The flowmeters are very important parts of the fluid systems, so their calibration is important and even necessary. Suitable time periods between calibrations are: six months for ultrasonic, one year for electromagnetic, and etc. If the flowmeter is frequently used, this period may be even shorter. Calibration must be performed in the calibration laboratories accredited by the national accreditation body. One of the most important characteristics of the fluid flowmeter is accuracy, but also repeatability, linearity, hysteresis, range, response time, and etc. In order to determine the highest possible

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accuracy of the flowmeter, it is necessary to calibrate the flowmeter on the adequate installation. It is important that installation for precise flowmeter calibrations meets demands of the relevant standards: high-quality installation, appropriate calibration methodology, instruments of high accuracy and satisfactory measurement uncertainty.

Primary methods for flowmeter calibration for liquids are described in: ISO 4185:1980 - Measurement of liquid flow in closed conduits - Weighing method (method of determining the liquid flow-rate by measuring the mass of liquid delivered into a weighing tank in a known time interval) [1] and ISO 8316:1987 - Measurements of liquid flow in closed conduits - Method by collection of the luquid in a volumetric tank (method of determination of the volume of liquid collected in a volumetric tank in a known time interval) [2]. There is no limit for the application of these methods, but usually, in hydraulic laboratories, maximum achieved volume flow rate is $Q_{max} = 1.5\ m^3/s$.

Weighing method describes an absolute flow measurement calibration method, which, in principle, requires only mass and time measurements. If the installation is carefully designed, constructed, maintained and used, an uncertainty of 0.1% can be achieved. [1]

In the static method liquid has been diverted for a measured time interval into the weighing tank. In the case of the dynamic method, fluid flow is delivered into the weighing tank, without diverter.

2 Installation requirements

The following requirements for the designed installation were: constant volume flow rate, Q_{max} up to 10 l/min, filling time at least 30 s, as well as no leaking and no air or vapor pockets in the measuring section with appropriate straight sections lengths before and following the in-built flow meter. The pipeline is made of PVC, with inner diameter D = 12.7 mm. The effects of the dynamic phenomena is small, although flow distributor is designed and manufactured. Based on the Bernoulli and continuity equations, for version of installation without flow distributor, height of the installation is determined $H_{geo} \approx 1.2$ m.

3D model of installation is made in Solidworks. 3D model of installation with flow distributor is presented in fig. 1, where 1- overflow edge, 2 - flowmeter, 3 - valve, 4 - flow distributor 5- weighing tank 6 - weighing machine and 7 – circulating pump.

a) b)

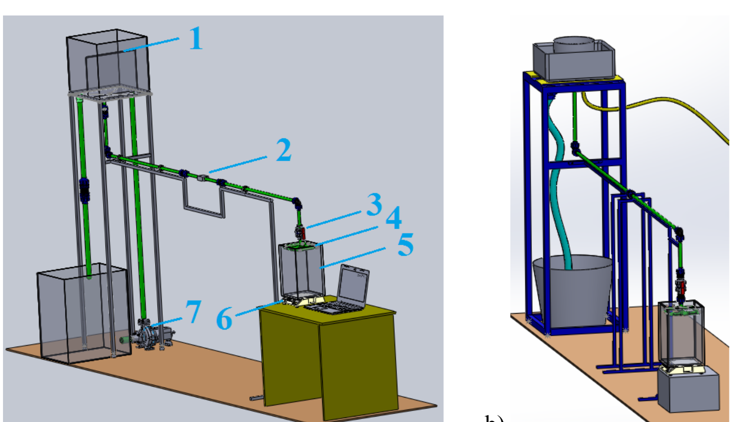

Fig. 1. Two versions of installation with flow distributor: a) with a pump and straight overflow edge and b) with tap water and circle overflow edge.

3 Numerical analysis of the flow in the installation

CFD analysis was performed in Ansys Workbench - Fluent. Geometry for mesh was prepared on the basis of 3D model. Surface used for boundary conditions and mesh details are shown in fig. 2.

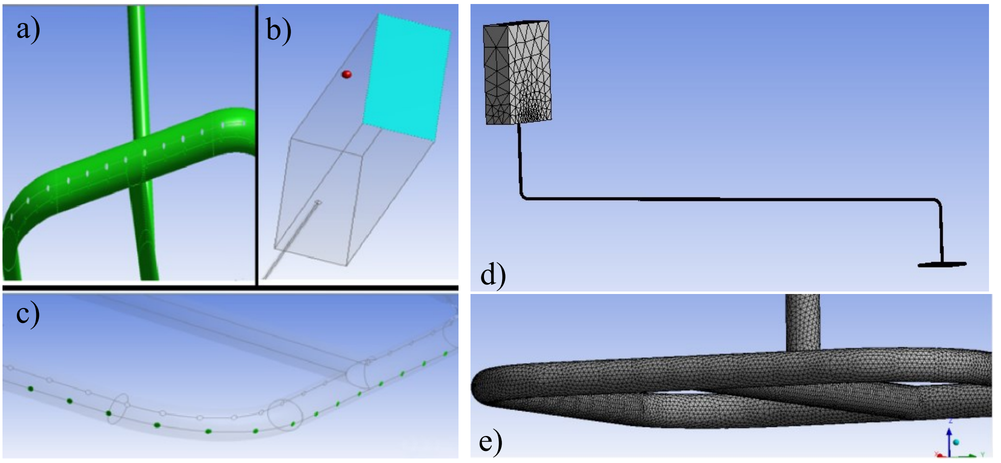

Fig. 2. Geometry: a) wall b) inlet c) outlet and mesh: d) complete and e) flow distributor.

Two numerical meshes were tested. First approach had a half a million cells and the second mesh was consisted of approximately 1.6 million cells.

Table 1. Mesh data.

Statistics	coarse	fine
Nodes	107195	484155
Cells	523101	1594369

Both meshes were unstructured (automatically generated unstructured mesh - tetrahedral elements, fig. 3.). Numerical results were used for installation test before production.

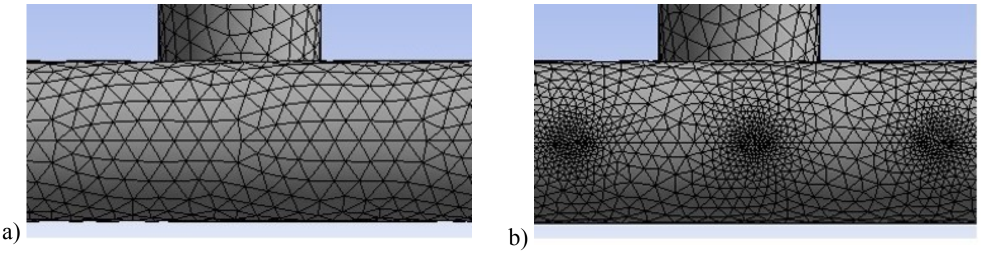

Fig. 3. Meshes of flow distributor – outlet region: a) coarse and b) fine grids.

Numerical problem is observed as a steady state. Turbulence model k – ε is used by double precision solver with convergence criteria 1e-6. All flow regimes are turbulent, where criterion was Reynolds number (Re) significantly higher than 2320. Numerically obtained developed uniform turbulent flow is obvious and presented in fig. 4.a. Equally distribution in the flow distributor is presented in fig. 4.b. This is proved experimentally.

a) b)

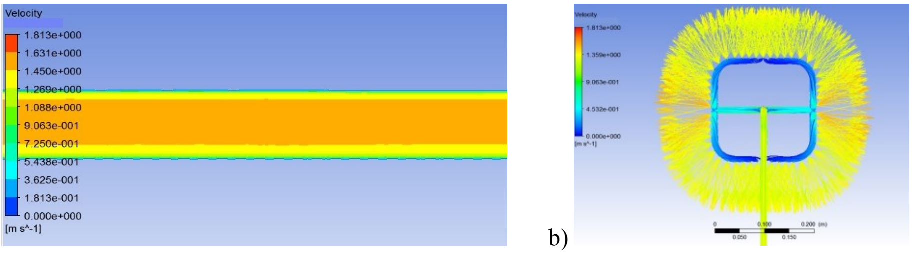

Fig. 4 Velocity distributions: a) through the measuring section and b) outlet from the flow distributor.

4 Experimental installation

The test rig was manufactured after the numerical results evaluation, with small modifications of constant level head tank as shown in fig 1b and fig 5.

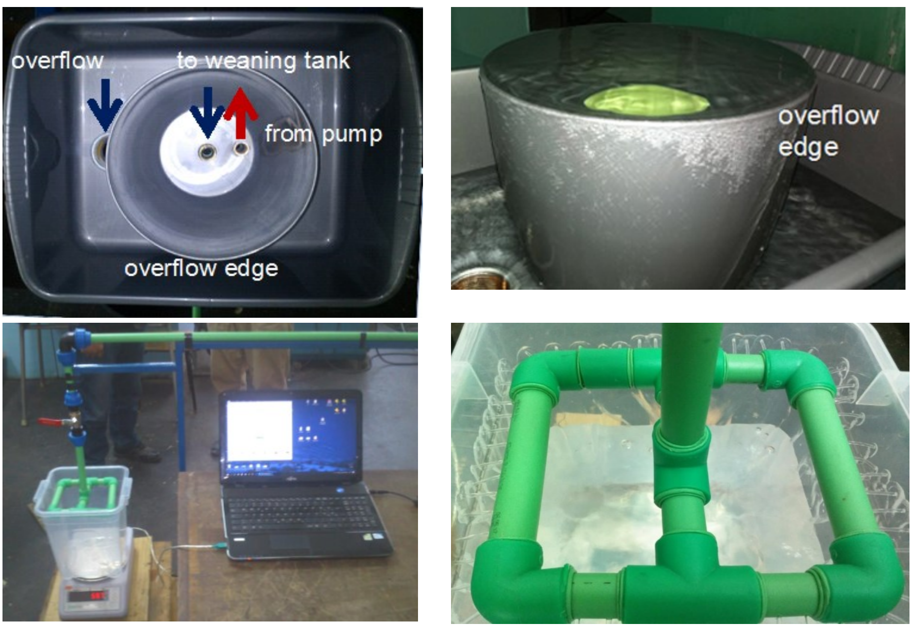

Fig. 5 The experimental test rig

This design of the test rig achieved steady geodesic height and uniform flow in the testing section. Flow distributor enhanced well flow distribution and no additional force is generated on the weighing machine in this way. Weighing machine was calibrated over whole measuring range using standard weights.

5 Experimental results

Density of liquid, of air and of standard weights (cast iron used when calibrating weighing machine) are determined. Experimental results for regime I is given in fig. 6. Reynolds number is determined as Re = QD/Aν, where Q is flow, A is inner pipe cross section and ν is water kinematic viscosity.

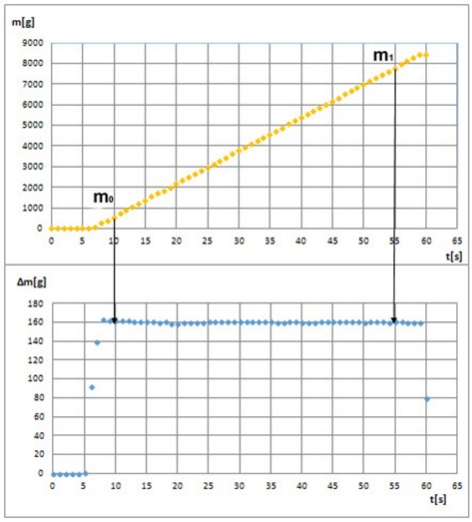

Fig. 6 Regime I: Re = 15473.26

Mass flow rate is calculated as follows:

$$q_m = \frac{m}{t} = \frac{m_1 - m_0}{t} \cdot \frac{1 - \rho_a / \rho_p}{1 - \rho_a / \rho} = 1.00106 \frac{m_1 - m_0}{t} \qquad (1)$$

$$q_m = 1.00106 \frac{7785.7 - 556.5}{55 - 10} = 160.82 \frac{\text{g}}{\text{s}} \qquad (2)$$

Experimentally is obtained volume flow rate q_V = 9.65 l/min, while numerically q_V = 10.1 l/min.

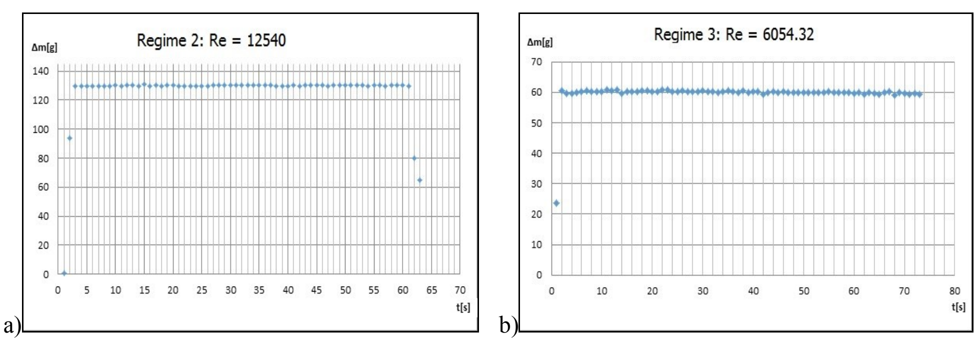

Fig. 7 Regime 2 (Re = 12540) and 3 (Re = 6054.32)

It was shown, both experimentally and numerically, that uniform flow is achieved in the straight measurement section.

According to ISO 5168 uncertainty is calculated as follows:

$$e_q = \sqrt{(e_R)_{95}^2 + (e_s)^2} \qquad (3)$$

Systematic error e_s includes [1]: errors due to weighing machine (calibration curve) $(e_s)_b$ < ±0.05% of the mass, errors due to timing device $(e_s)_t$ < ± 0.01% of the time, what can be generally omitted, and errors due to density measurement $(e_s)_d < \pm 0.05\%$. It is calculated as follows:

$$e_s = \pm 100\sqrt{\left[\frac{(e_s)_b}{m}\right]^2 + \left[\frac{(e_s)_t}{t}\right]^2 + \left[\frac{(e_s)_d}{\rho}\right]^2}\,\% < 0.03\% \qquad (4)$$

The relative random $(e_R)_{95}$ at the 95% confidence level is calculated as follows [1]:

$$(e_R)_{95} = \pm 100\sqrt{\left[\frac{(e_R)_b}{m}\right]^2 + \left[\frac{(e_R)_d}{\rho}\right]^2}\,\%, \qquad (5)$$

where $(e_R)_b$ is error due to weighing machine.

5 Conclusions

- Installation for flow meters calibration (measurement of liquid flow in closed conduits) up to 10 l/min, based on weighing method, is developed and presented in this paper.
- CAD 3D model of the whole installation is created and afterwards used for numerical experiments.
- The test rig was manufactured after the numerical results evaluation.
- Experimental results and measurement uncertainty for three operating regimes are analysed and reported in this paper.
- Developed and presented installation is adequate and should be accredited by the Accreditation body of Serbia. In addition, this is one of three developed installations at the laboratory of the Hydraulic Machinery and Energy Systems Department for volume flow rates up to 50 l/s and 200 l/s. So, this Laboratory should be recognized as the designated institute by the Directorate of Measures and Precious Metals, Ministry of Economy, Republic of Serbia.

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References

1. ISO 4185:1980 - Measurement of liquid flow in closed conduits - Weighing method (method of determining the liquid flow-rate by measuring the mass of liquid delivered into a weighing tank in a known time interval) (1980)
2. ISO 8316:1987 - Measurements of liquid flow in closed conduits - Method by collection of the luquid in a volumetric tank (method of determination of the volume of liquid collected in a volumetric tank in a known time interval) (1987)
3. M. Slijepcevic, MSc thesis, University of Belgrade, Faculty of Mechanical Engineering, Serbia (2017)