New Gravimetric National Standard for Water Flow Measurements in Finland

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Centre for Metrology MIKES has accomplished a state-of-the-art gravimetric device for water flow calibrations in Finland. This new calibration rig will serve also as a national standard for water flow. Flow rate in the rig is possible up to 720 m³/h and the largest accommodated pipe size is up to DN200. Lowest measurement uncertainty achieved is 0.03 % (k = 2). This presentation will show in detail the construction and the performance of the national standard. Comparison measurements are agreed between PTB and will be conducted in near future. These comparison results will give a solid base for the CMC-submission. Part of the CMC process is also the detailed academic presentation of the measurement capabilities.

1 Introduction

VTT MIKES Metrology acts as national standard laboratory in Finland. The water flow laboratory (Figure 1) is located in Kajaani, where a new calibration rig D200 with gravimetric standards has been built for calibrations of water flow meters. The device is also a national standard for water flow in Finland.

Figure *1. MIKES-Kajaani office.*

2 Design

2.1 Overall

The D200 calibration device is located in one of the former paper mill buildings. The surroundings of the building give some limitations for the design work. Nevertheless, all the desired properties have been achieved to install for the D200 device. The national standard is shown in Figure 2. There were three main aspects to take into consideration in the design. Firstly, the maximum diameter for the meter under test should be DN200. Secondly, the maximum water flow achieved should be at least 720 m^3/h. Thirdly, the lowest measurement uncertainty achieved for the calibrations should be as low as 0.03 % (k = 2).

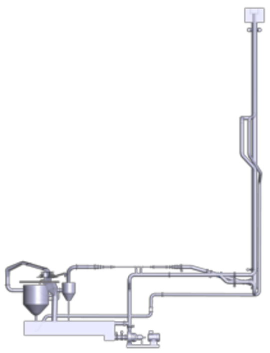

Figure 2. D200 national standard.

The water reservoir for the device is 14 m^3. The upper tank is 1 m^3 and the height difference between the water level in the tank and the meter under test is 20 m giving the stable 2 bar pressure to the measurement line. It is also possible to bypass the tower and operate the flow directly by pumps.

2.2 Piping

Material used in piping is ANSI 304 stainless steel. Pipe diameters range from DN15 up to DN400 in the device. Measurement section is designed from DN10 up to DN200 pipe sizes.

2.3 Scales

D200 device has two scales as a normal. The bigger one can weigh up to 6000 kg and the smaller one up to 800 kg. The scales are made of stainless steel. Load cells used are made by Lahti Precision, model RC2 for the smaller scale and HBM, model RTN for the bigger scale. Both scales have three load cells positioned in triangle form.

2.4 Pumping

Water circulation is arranged with two inverter controlled pumps.

3 Measurements and data collection

Gravimetric national standard includes several measurements to guarantee the uncertainty of the measurements. All the measurement sensors are selected to keep the quality of the measurements at a high level. Measurements include temperature and pressure of water and air, air humidity, air pressure, density of water and several electrical measurements.

All of the measurement instrument are calibrated and the traceability to SI-system is via Finland’s national standards. Laboratory also follows the ISO17025 standard [1].

A custom made LabView® program together with a real-time controller handles the operations of the D200 device. The heart of the data collection is National Instruments CompactRIO controller. Its I/O modules handle the electrical signals from the operating devices to the computer.

Figure 3. Pt100 temperature sensor

3.1 Water temperature sensors

There are ten temperature sensors around the D200 device: SKS Pt100 resistance sensors with accuracy of ±0.15 °C (Figure 3).

3.2 Water pressure sensors

Water pressure inside the pipeline is monitored in five different locations. The sensors are Rosemount M2088 pressure sensors (Figure 4).

Figure 4. Pressure sensor.

3.3 Measurement of ambient conditions

A custom made measurement system has been made to record the ambient conditions (air temperature, air pressure and air humidity) inside the VTT MIKES-Kajaani building. One of the sensor boxes is inside the water flow laboratory, next to the gravimetric standards. Data is stored in a database, from where it can be extracted by programs or manually.

The air humidity and air pressure sensor is located in to the atmospheric conditions inside the water flow laboratory near the scales of the

D200 device. Other electronics for ambient conditions are located inside measurement box, which is also close to the scales of the D200 device.

3.4 Density of water

Water density is measured with Anton-Paar DMA5000M density meter. Water density is measured for each calibration. The accuracy of the measured density is 0.000 005 g/cm^3. Picture of the density meter is shown in Figure 5.

Figure 5. Water density meter.

3.5 Electrical measurements

Data collection system includes the measurement of electrical signals from several measurement devices as well as from the meter under test. Water meter calibrated from frequency output is the most accurate way of calibration, but customers also need current output calibrations. Both of them are operated.

3.5.1 Frequency measurements

Frequency is measured up to 10000 Hz. In the D200 calibration rig there are two frequency data inputs for customer devices.

3.5.2 Current measurements

Current output is measured up to 22 mA.

3.5.3 Voltage measurements

Voltage measurements are needed in controlling the operations of the D200 devices. Speed of the motor for example is adjusted with the voltage signal.

All the measurement instruments of the D200 device are regularly calibrated against the national standards.

4 Diverter

4.1 Diverter design

The diverter is essential part of the gravimetric measurement standard. Other designs were studied and learned advantages of them [2], [3]. Previous studies also describe the theory of the diverter very well, so it is not necessary to represent in this study. D200 device has two scales and thus two diverters. The work started with getting familiar with different diverter types around the other calibration facilities.
The model used in this device is kind of traditional one. The unit has a nozzle and below it a reversible divert edge. Very precise design and workmanship was used during the manufacture of the diverter. CFD-code was used to simulate the performance of the selected diverter design. The simulations were performed with COMSOL Multiphysics software and k-ε turbulence model was used. Figure 6 shows the simulation grid of the diverter inlet. Symmetrical flow was assumed so symmetry plane was used in the cross section of the diverter. The grid is composed of 750 476 elements.

Figure 6. The grid used in simulations.

Few different combination angles in inlet section were studied with simulation program together with the boundary conditions set by the laboratory geometry. The one shown in Figure 7 was the best combination.

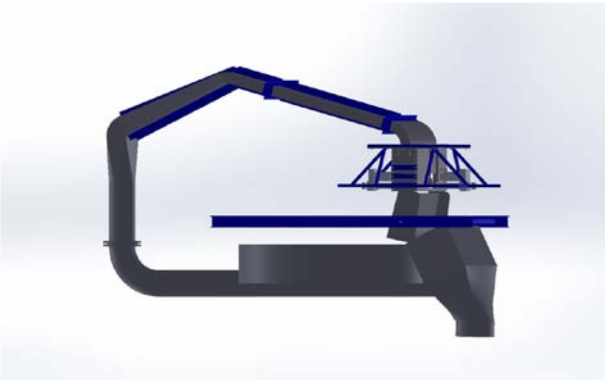

Figure 7. Design of the diverter.

In Figure 8 can be seen the simulated velocity profile of the diverter with k-ε turbulence model used in simulation.

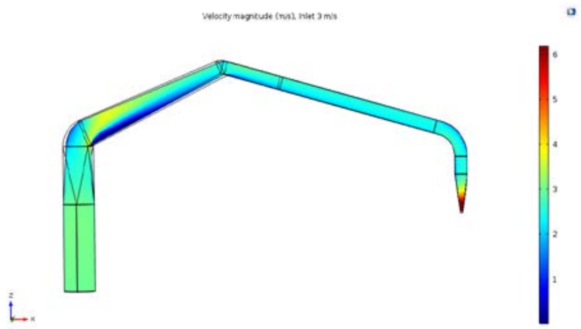

Figure 8. Velocity profile at 3 m/s inlet velocity.

According to literature [3], the diverter should have a movable nozzle which observes the cross-sectional area of the calibrated meter. The movable nozzle was made from polypropylene side plates. The aperture of the nozzle is fully adjustable from totally wide open, (100 mm) to totally closed. Plates are moved by the ball screw actuators which are operated by servo motors. Comsol Multiphysics simulation software was used for estimating the right values of the force for moving the plates and also for the geometry of the hinge of the side plates (Figure 9 and Figure 10). In both figures the acting force of 1700 N is on y-axel to negative direction and it moves the tip of the plate 50.9 mm (Figure 9). Von Mises stress shows that movement remains in linear elasticity region of the polypropylene plate (Figure 10).

The movements of the side plates are done with servo motors. The distance of the adjustment is controlled by the laser distance meters with measurement accuracy of 50 µm.

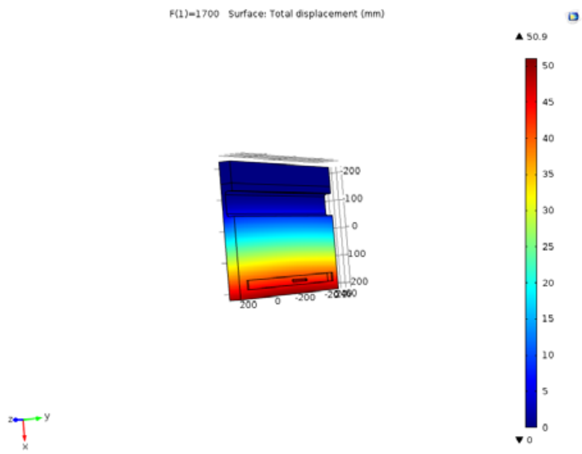

Figure 9. Movement of the side plate with 1700 N force.

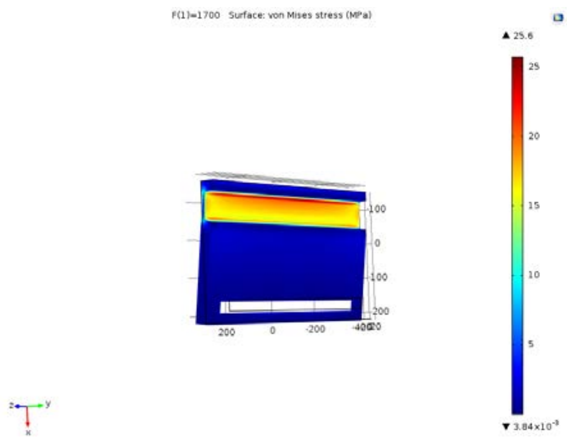

Figure 10. Von Mises stress of the side plate at 1700 N force.

5 Uncertainty

Measurement uncertainty of the gravimetric device is an essential aspect. Uncertainty budget is calculated with Equation 1 and Equation 2 [4]. Extra values due to air buoyance and meter under test were added to the combined uncertainty.

$$K_{Meter} = \frac{f_{Output}}{\dot{V}_{REF}} \qquad (1), \text{ where}$$

$$\dot{V}_{REF} = \frac{\frac{m}{\rho_{Water}} - \Delta V_{IP}(\vartheta,p) - \Delta V(\Delta T_{Error})}{T_{Meas}} \quad (2)$$

Table 2. Uncertainty budget.

Source	Symbol	Uncertainty value %
Frequency	W_f	0.001155
Mass	W_m	0.003464
Density of water	W_w	0.002891
Connecting pipe	$W_{\Delta V}$	0.000173
Diverter error	W_{div}	0.013333
Measurement time error	W_T	0.000192
Meter under test	W_{MUT}	0.0035
Air buoyance	W_b	0.000015
Expanded uncertainty	W (k = 2)	0.03 %

6 Test measurements

Two kind of test measurements (Figure 11) were made and shown in Table 2 and Table 3. The flowrate was constant during the measurement period. Test 1 shows the repeatability of the scale and stability of the flow rate. In each measurement, the scale was filled at once and emptied after measurement. The test was repeated three times. Mean and deviation is reported in Table 2.

In test 2 the scale was filled in 10 measurement sections without emptying the scale between the measurements. At the end of the measurements the final scale reading was compared to the result of the single fill. Results are reported in Table 3.

Table 3. Results from single fills (Test 1).

	Measurement time (s)	Flow rate (t/h)	Balance (kg)
Long run 1	302.039	63.178	5300.609
Long run 2	301.984	63.151	5297.393
Long run 3	301.976	63.183	5299.943
mean	302.000	63.170	5299.315
deviation	0.034	0.017	1.697

Figure 11. Water flow through D200 large diverter.

Table 1. Results from ten different fills (Test 2).

	Measurement time (s)	Flow rate (t/h)	Balance (kg)
Short run 1	30.293	63.356	533.119
Short run 2	30.287	63.385	533.257
Short run 3	30.294	63.283	532.524
Short run 4	30.300	63.299	532.769
Short run 5	30.292	63.341	532.984
Short run 6	30.303	63.317	532.973
Short run 7	30.284	63.208	531.723
Short run 8	30.271	63.150	531.003
Short run 9	30.297	63.082	530.886
Short run 10	30.300	63.267	532.499
Sum	302.921		5323.736
mean	30.292	63.269	532.374
deviation	0.009	0.096	0.868

Supplementary comparison measurements are agreed with PTB to support the CMC-claim.

7 Conclusion

New gravimetric national standard is built in VTT MIKES Metrology water flow laboratory. CFD-simulations helped the design work. Reported test measurements show the steady operation of the diverter and scale. Comparison measurements are agreed with PTB to verify the CMC claim.

References

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[2] Iosif I. Shinder, Iryna V. Marfenko. NIST Calibration Services for Water Flowmeters, *Water Flow Calibration Facility*. NIST Special publication 250; 2006

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