

# **The Water Test rig at SMU**

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## **INTRODUCTION**

Water and energy measurement in the Slovak Republic is getting more and more important according to the rising prices of water and energy. On the other hand the number of water meters is rising from year to year and at present time there are about 2 million water meters in use in the Slovak Republic. Measuring water and energy for custody transfer is always closely tied to procedures of verification and calibration. In the traceability chain of water flow and delivered volume the calibration rigs for water meters and flowmeters have the position of secondary standards.

In traditional understanding the traceability in water meters and flowmeter calibration means traceability of volume, mass, density, temperature and time to the corresponding national standards in connection with an error analysis. But often the conventional error analysis, i. e. carrying out static tests of the main elements and assessing some additional error influences, does not lead to a realistic evaluation of the measurement uncertainty of water and flowmeter calibration devices, in particular when automatic controlled calibration systems are used.

Reasonable solution is to build the traceability chain for flowmeters calibration from the National standard of flow and delivered volume. For realisation of this conception of the traceability the Primary Standard and portable transit standards are needed.

Water test rig at SMU has the position of the National Standard for flow and delivered volume and delivered mass of liquids.

Calibration assembly is static gravimetric system installed in specialised buildings. Main parts of the assembly are situated in the laboratory room and flow generator in the room of the flow centre building. Constant head tank is installed in the water tower as a separate building situated about 46 m from the flow centre building.

Most important purposes of the test rig are:

- primary standard for water calibration - calibration of the water meter test rigs - indirect calibration
- primary standard for flowmeters used as flow sensor for heat meters calibration- calibration of the flowmeter test rigs - indirect calibration
- calibration of secondary standards – reference flowmeters direct calibration
- international traceability – international comparison,
- calibration of high accuracy flow and volume meter,
- volume meters calibration,
- mass flow meters calibration,
- determination of the error - tests for type approval procedures.

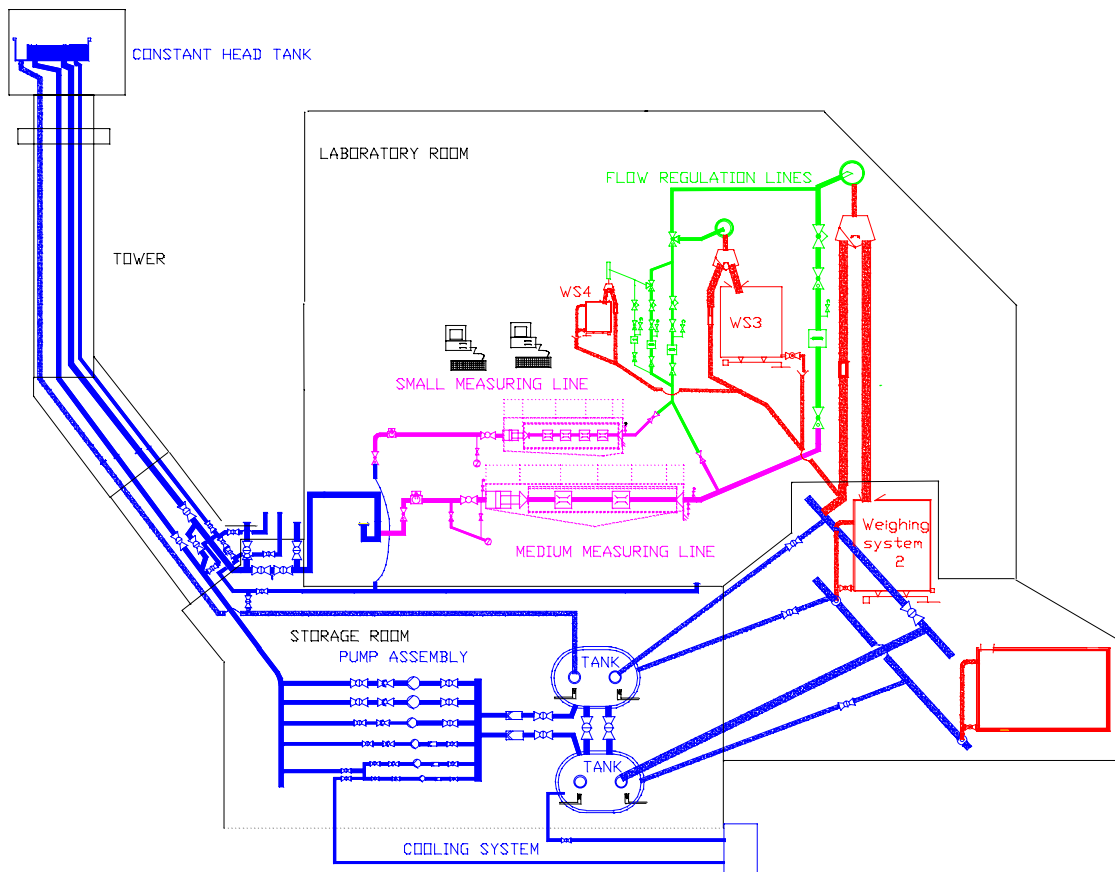
## **Description of the test assembly**

Test assembly at SMU is based on weighing principle of operation with two test benches, three weighing assemblies and four flow adjusting branches. Constant flow of the system is reached with constant head tank assembly.

Basic specifications of the system are in the table 1.

Table 1

Measuring range:	(0,020 – 280) m <sup>3</sup> /h
Available size of the meter on test (DN) :	DN 15 až DN 150
Maximum working pressure:	0.7 Mpa
Test liquid:	water
Temperature range of the water:	(10 – 85) °C
Minimum test volume:	3 dm <sup>3</sup>
Maximum test volume:	5 000 dm <sup>3</sup>
Methods of testing:	weighing method, flying start and stop weighing method, Standing start and stop volumetric with master meter, flying start and stop



Picture 1:

Constant metrological characteristics and good uncertainty in the described flow-rate range is reached with three weighing assemblies in different size, connected in parallel. Four flow regulation lines, each in different size are designed not only to tune the required flow-rate precisely but also to minimise the water volume between test meter and weighing tank. Design of the system fulfils criteria for leakage detection. Conduits and important hydraulic component of the hydraulic system is made from stainless steel.

Test assembly can be divided into following parts:

1. Flow generator,
2. Small test line
3. Medium test line
4. Flow regulation lines
5. Weighing assemblies
6. Control systems

### **Flow Generator**

Flow generator consist of 2 sumps each with capacity 20 m<sup>3</sup>, 6 pumps with filters and valves, constant head tank and connection pipes with valves. Water in storage tanks can be heated up with heating system and can be also cooled with cooling generator.

Nominal power of heating elements per one storage tank is 30 kW.

The nominal power and size of five pups are gradually rising from nominal flow-rate 3 m<sup>3</sup>/h up to 400 m<sup>3</sup>/h. Two most powerful pumps have the same size and nominal flow-rate 400 m<sup>3</sup>/h. Flow-rate of two most powerful pumps together with the third pump with nominal flow-rate 200 m<sup>3</sup>/h have summary flow-rate reaching 1000 m<sup>3</sup>/h.

Storage tanks and pumps are situated in the laboratory building in the tank storage room.

Constant head tank is situated in the tower. Level of the hydraulic head in the constant head tank is 46 m related to the level of the testing meter. Size of the main pipe, connecting pump assembly to the constant head tank is DN 200. Largest pipe size diameter connecting constant head tank and laboratory room is DN 250. Smaller main connecting pipe conduit is DN 80.

Maximum flow-rate of 1000 m<sup>3</sup>/h has been prepared for the big test line, which is not ready yet.

Stainless pipes are insulated with plastic insulation. Pipes connecting constant head tank with pump room and laboratory room are double insulated.

Storage tanks have extraction pipes.

### **Small test line**

Small test line assembly is connected to the smaller main conduit from tower with conduit DN50.

Test line assembly consist of input valve, stainless steel bench, axial pneumatic fixing assembly, reduction and expanding pipes, fixtures for tested meters, various inter changeable pipes for meters with thread and flange connections, start and stop valve, outlet valve, short cut valve and drain valves. Measuring section – the place where tested meters are connected to the system is designed for easy and precise assembling, fixing and re-assembling the meters on test.

Small test line is designed for meters from DN 10 up to DN 40. Depends on the meter size but also test requirements there can be connected from 1 to 12 meters at ones. Stainless steel channel is situated under the installed meters to drain out the water after opening the measuring



Picture 2

section. The space of the measuring section can be closed by doors for safety reasons and temperature stability as well.

Temperature and pressure sensors are located at the inlet and outlet pipes of the test line. Connectors and optical sensors for 12 meters are available for test meters connection. System is compatible with pulse output, frequency output and analogue output as well. For the best temperature stability at low flow measurement there is a shortcut pipe with valve situated at the input pipe of the test bench.

### **Medium test line**

Medium test line assembly is connected to the main DN 250 pipe with pipe conduit of DN150.

Test line assembly consist of input valve DN 150, stainless steel bench, axial hydraulic fixing assembly, reduction and expanding changeable pipes, fixtures for meters on test, various inter changeable pipes for meters with flange connections, start and stop valve, outlet valve short cut connections with valve and drain valves.

Medium test line is designed for meters from DN 50 to DN 150. This test line is fitted for maximum 4 meters. Similar stainless steel channel is situated under the installed meters to drain out the water after opening the measuring section. Similar cover is also placed for the same reasons as for the small line. This cover is closing the space of the measuring section.

Temperature and pressure sensors are also located at the inlet and outlet pipes of the test bench. Connectors and optical sensors for 4 meters are available for connecting meters to the system. Connections and construction design is very similar to the small test line assembly.



Picture 3

### **Flow regulation lines**

Flow regulation lines are used for precise flow adjustment in the defined flow-rate range. Each flow adjusting branch consist of input valve, flowmeter, output valve, regulation valve, leakage valve. There are two three-way valves installed in the system. One is situated at the outlet of line 3 and line 4 and the other one is between outlet from line 2 to outlet from 3-way valve one.

Flow regulation lines are connected to the weighing systems.

Flow-rate range of the each line is described in the following table.

Description of line	Size of the flowmeter	Liner	Minimum flow	Maximum flow
V4	DN6	Al <sub>2</sub> O <sub>3</sub>	0,015 m <sup>3</sup> /h	0,4 m <sup>3</sup> /h
V3	DN15	Al <sub>2</sub> O <sub>3</sub>	0,2 m <sup>3</sup> /h	2 m <sup>3</sup> /h
V2	DN40	Al <sub>2</sub> O <sub>3</sub>	1,25 m <sup>3</sup> /h	25 m <sup>3</sup> /h
V1	DN100	Al <sub>2</sub> O <sub>3</sub>	15 m <sup>3</sup> /h	270 m <sup>3</sup> /h

Picture. 4: lines V2,V3,V4



Picture 5: line V1



### Weighing systems

Weighing systems are realising the conventional true value of the delivered flow and flow. For appropriate realisation of the delivered volume with good uncertainty in described flow-rate range are required 3 independent weighing systems. Basic specifications of the weighing systems are in the table.

	Maximum load	Readability	Nominal volume	Nominal size of the diverter
	kg	g	m <sup>3</sup>	mm
Weighing system 2 / D2	5 000	10	5 000	DN100
Weighing system 3 /D3	600	10	600	DN40
Weighing system 4/ D4	25	1	25	DN15

Each weighing system consist of dividing point, diverter, conduit to the weighing tank and conduit to storage tank, weighing tank and output valve.

Three open type diverters one per weighing system are changing the position for less the 0,15 s in the whole flowrate range. Gain switch sensor is situated in the middle position of the change over device for each diverter. The diverter D2 has also the sensor for the end positions. Important is that the time difference between the changing over from the way to weighing tank and way to storage tank is less then 0,03s in the whole flowrate range.

Dividing point of each weighing system is equipped with visually controlled construction situated at the maximum height of appropriate weighing system.



Picture 6: Weighing system 3



Picture 7: Weighing system 4

### **Control systems**

Control system of the test rig has been designed for getting an appropriate data from the measurement and also to fulfil the requirements of uncertainty. System has been designed as an compromise between the price and possibilities. Valves of the flow generator are manually operated. Also many valves from adjusting branches are hand operated. Start stop valve, regulation valves, diverters are remote controlled and also readings from balances, flowmeters, temperature and pressure sensors are stored by computer. Small and medium test lines are controlled by program. Measuring procedures can be defined by program menu. Up to 3 measurement could be defined in one procedure. System warns operator when there is any need of open or close the defined valve (only for valves not controlled by computer). In the case when is no need to change the regulation line and weighing system during three defined measurements the system can run automatically for 3 measurement.

Number of pulses from meter on test can be carried out by direct reading or by broken pulse method. Appropriate method is calculated by the system from the number of pulses per measurement.

The system can also be manually operated. Manual operation is carried out by the computer mouse (clicking on appropriate component on the screen).

Calculation of the results from measurements are carried out automatically by the computer program. These calculations fulfils requirements only for standard measurements. For more accurate purposes an additional computations have to be done by excel sheet.

Important readings from the measurement is stored in the memory during the measurement. Data from the measurement are systematically stored and they can be converted to excel spread sheet file. There is also possibility of logging additional data from measurement.

## Realisation of units

Test rig is realising units of mass flow, volume flow (integrated in the time delay), and delivered mass and delivered volume.

- mass flow :

$$Q_m = \frac{1}{\tau} \int_0^{\tau} Q_m(\tau) \cdot d\tau \quad (1)$$

- volume flow :

$$Q_v = \frac{1}{\tau} \int_0^{\tau} \frac{Q_m(\tau)}{\rho(\tau)} \cdot d\tau \quad (2)$$

- delivered mass :

$$m = \int_0^{\tau} Q_m(\tau) \cdot d\tau \quad (3)$$

- delivered volume :

$$V = \int_0^{\tau} \frac{Q_m(\tau)}{\rho(\tau)} \cdot d\tau \quad (4)$$

where  $Q_m(\tau)$  is actual mass flow and  $\rho(\tau)$  actual density of the water in the measuring line. Delivered volume (delivered mass) is quantity of liquid in volumetric or gravimetric units, flows at defined diameter at defined time interval  $\tau$ . Volume flow or mass flow is relation of this quantity and time  $\tau$ .

## Uncertainty calculation

Mathematical model of the process is given by Formula (5)

$$\begin{aligned} \Delta V_v = & \frac{I}{I_c} - c_v \cdot \frac{M_k - M_z}{\rho(t_i)} - c_v \cdot \frac{M_k - M_z}{\rho(t_i) \cdot \tau} \cdot \Delta \tau_p - c_v \cdot \frac{o}{\rho_s} \cdot \tau - 2 \cdot c_v \cdot \frac{r}{\rho_s} \cdot \tau_p - V_{pt} (3\alpha - \beta) \cdot \Delta t_2 - \\ & - c_v \cdot \frac{M_k - M_z}{\rho_s} \cdot \beta \cdot \Delta t_1 - \Delta V_{pvz} \end{aligned} \quad (5)$$

Where  $\Delta V_v$  represent difference between volume given from rig and tested meter,  $I$  represent number of pulses during measurement,  $I_c$  represent K-factor of tested meter,  $c_v$  represent buoyancy correction,  $M_k$  and  $M_z$  are readings of the weighing scale,  $\rho(T)$  denotes density of water at temperature  $t_i$ ,  $\tau$  represent duration of the measurement,  $\Delta \tau_p$  represent average time difference between diverter changing over times,  $o$  represent factor of the evaporation during measurement,  $r$  represent factor of sprayed water during diverter is changing over,  $V_{pt}$  is volume of the water from tested meter to dividing point,  $\alpha$  represent specific temperature factor of the pipe material,  $\beta$  is specific temperature factor for water at given temperature,  $\Delta t_2$  is average difference of the temperature of water at given flowrate between the temperature at the beginning and at the end of measurement,  $\Delta t_1$  is an average temperature difference of water at given flowrate between place at tested meter and place at dividing point and finely  $V_{pvz}$  volume difference at given flowrate between volume of water (volume is given from tested meter to dividing point) at the beginning and the end of the measurement.

Influences taken to account .

$$1. A_1 = \frac{1}{I_c} \quad (6)$$

Represents sensitivity on reading of the tested meter during the measurement.

$$2. A_2 = -\frac{I}{I_c^2} \quad (7)$$

Represents sensitivity on given K-factor of tested meter.

$$3. A_3 = \frac{M_k - M_z}{\rho(t_i)} \cdot \left( 1 - \frac{\Delta\tau_p}{\tau} - \beta \cdot \Delta t_1 \right) \quad (8)$$

Represents sensitivity on buoyancy correction.

$$4. A_4 = -c_v \cdot \frac{1 - M_z}{\rho(t_i)} \cdot \left( 1 - \frac{\Delta\tau_p}{\tau} - \beta \cdot \Delta t_1 \right) \quad (9)$$

Represents sensitivity on readings after the measurement of the weighing scale.

$$5. A_5 = -c_v \cdot \frac{M_k - 1}{\rho(t_i)} \cdot \left( 1 - \frac{\Delta\tau_p}{\tau} - \beta \cdot \Delta t_1 \right) \quad (10)$$

Represents sensitivity on readings at the beginning of the measurement of the weighing scale.

$$6. A_6 = -c_v \cdot \frac{M_k - M_z}{\rho(t_i)^2} \cdot \left( 1 - \frac{\Delta\tau_p}{\tau} - \beta \cdot \Delta t_1 \right) \cdot \rho'(t_i) + c_v \cdot \frac{o}{\rho_s^2} \cdot \tau - 2 \cdot c_v \cdot \frac{r}{\rho_s^2} \cdot \tau_p \quad (11)$$

Represents sensitivity on density caused by temperature measurement.

$$7. A_7 = c_v \frac{M_k - M_z}{\rho(t_i) \cdot \tau} \quad (12)$$

Represents sensitivity on diverters characteristics.

$$8. A_8 = c_v \frac{M_k - M_z}{\rho(t_i)} \cdot \frac{\Delta\tau}{\tau^2} - c_v \cdot \frac{o}{\rho_s} \quad (13)$$

Represents sensitivity on measurement of the time.

$$9. A_9 = -\frac{c_v \cdot \tau}{\rho_s} \quad (14)$$

Represents sensitivity on evaporation during measurement.

$$10. A_{10} = -2 \cdot c_v \frac{\tau_p}{\rho_s} \quad (15)$$

Represents sensitivity on sprayed water during diverter changing over.

$$11. A_{11} = -2 \cdot c_v \frac{r}{\rho_s} \quad (16)$$

Represents sensitivity on changing over time properties of the diverter.

$$12. A_{12} = -c_v \frac{M_k - M_z}{\rho(t_i)} \cdot \beta \quad (17)$$

Represents sensitivity on temperature difference of water between meter and dividing point.

$$13. A_{13} = V_{pt} (3\alpha - \beta) \cdot \Delta t_2 \quad (18)$$

Represents sensitivity on volume of the water from tested meter to dividing point.

$$14. A_{14} = V_{pt} (3\alpha - \beta) \quad (19)$$

Represents sensitivity on temperature difference of water between the temperature at the beginning and the end of the measurement.

$$15. A_{15} = 1 \quad (20)$$

Represent sensitivity caused by wetted space in the conduit between tested meter and weighing tank.

### Calculated expand uncertainty U ( with coverage factor 2 in %)

Weighing system	Flow range		Cold water		Hot water	
			Flow	Delivered	Flow	Delivered
2	10 m <sup>3</sup> /h-270 m <sup>3</sup> /h	Volume	0,046	0,041	0,121	0,115
	10t-270t	Mass	0,039	0,034	0,085	0,076
3	1 m <sup>3</sup> /h-10m <sup>3</sup> /h	Volume	0,045	0,044	0,122	0,120
	1t-10t	Mass	0,039	0,037	0,087	0,085
4	0.02 m <sup>3</sup> /h-1 m <sup>3</sup> /h	Volume	0,040	0,038	0,134	0,130
	0,02t-1t	Mass	0,032	0,030	0,095	0,093

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