Metrology and standardization in pressureless flows

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Abstract. In modern technological processes, a large role is played by measurements of technical parameters. The total number of industrial enterprises is constantly monitored by regulatory authorities for the use of water resources. Mostly it was not possible to measure most of the existing pressure-free flows recently, but with the advent of equipment on the metrology market that could measure the speed and level at the same time, the situation changed radically. It makes sense to consider in detail two measurement methods that are currently used in more than 90 % of cases – the acoustic (non-contact) method and the two-channel Doppler method which metrological standards of these methods were compared.

1. Introduction
In modern technological processes, a large role is played by measurements of technical parameters. The total number of industrial enterprises is constantly monitored by regulatory authorities for the use of water resources. Payment is made to the water object owner by such monitoring reports. It has been established that state district power plants discharge thousands of water cubic meters per day. A small measurement error can lead to inaccurate in the report and, as a consequence, excessive or insufficient payment for discharging water. Therefore, there are special metrological standards for commercial calculation, which allow us to evaluate the accuracy of measurements of the metering devices and to prevent measurement errors, both of the parameters of technological processes and of parameters that affect commercial relations between water users [1-3].

2. Terms and definitions
Accounting node – is a complex of instruments and devices that provide accounting for the amount of flowing fluid.

Measurement tool (flow meter) – a technical tool intended for measurements with normalized metrological characteristics can reproduce the measured physical values within the established error. In this paper, the volume of the flowing fluid is measured.

Primary flow transducer – an integral part of the measuring instrument, providing a primary measurement of the parameters of the flowing fluid and transmitting them to the secondary transducer.

Secondary flow transducer – an integral part of a measuring instrument that receives information about the parameters of a flowing fluid from primary transducers and calculates the flow. The secondary converter saves information about the volume of the flowing liquid [4].
3. Experimental method

Mostly it was not possible to measure most of the existing pressure-free flows recently, but with the advent of equipment on the metrology market that could measure the speed and level at the same time, the situation changed radically. It makes sense to consider in detail two measurement methods that are currently used in more than 90% of cases.

The acoustic (non-contact) method is the most common due to its relatively low cost. Measuring equipment of this kind has long been manufactured in Russia and is widely known (figure 1).

The flow rate is determined by measuring the water level and recalculating the obtained value of the “level-flow” function using calibration tables. The level has calculated by measuring the transit time of the ultrasonic signal from the transducer located above the stream to the surface of the stream and the reflected echo signal to the sensor. It should be noted that the speed with this method of determining the flow rate is not measured explicitly, which leads to unreliable results in the case of deposits on the bottom of the water main and the occurrence of backwater. This method has several advantages and disadvantages.

![Figure 1. Installation diagram of the primary transducer of the acoustic measurement method.](image)

Advantages:

- non-contact method allows the use of flows with aggressive environment;
- the measurement ability of the small volumes.

Disadvantages:

- high requirements for the lengths of straight-line sections - 20 maximum levels of liquid filling to the primary transducer and 10 afterwards;
- high requirements for the gaseous environment between the primary transducer and the environment surface to be measured (vaporization impact on signal transmission quality) and to the environment surface to be measured (foaming makes a great contribution to the measurement error);
- requirement for constant deviation of the entire measurement section (the flow stops or moves in the opposite direction), the equipment always considers the flow rate “plus”
- installation of equipment involves the organization of an additional measuring cell [5-8].

The accuracy is ±3% – up to complete misrepresentation.

The two-channel Doppler method is a method the level and flow rate are measured simultaneously. Primary speed and level transducers are mounted in the flow itself (figure 2).

The velocity is measured by Doppler method. The ultrasonic signal emits into the flow and reflects from the suspended particles. The velocity sensor takes back that signal and calculates the particle velocity by frequency offset. There are two ways to measure the level. First is hydrostatic by level pressure on the sensor. Second is ultrasonic by acoustic or ultrasonic level gage. If we know the geometry parameters of water channel and flow level, we can calculate the flow area. The flow rate calculates by multiplying of flow velocity and flow area.
The cross-correlation method is a more progressive method based on the Doppler. The point is similar but velocity measurement goes in several plates. The results are averaged and the measurement accuracy makes higher because of it.

![Diagram](image)

**Figure 2.** The installation diagram of the primary converter of a two-channel Doppler measurement method.

**Advantages:**
- direct and reverse flow measurements;
- it’s easy to mount and tune;
- mounting in any kinds of water channels from 100mm to 9000mm.

**Disadvantages:**
- it’s necessary to clean the sensor sometimes in dirty types of water.

**Accuracy:**
±1% — ±5% [9-12].

Passed on all of the above, we can say that two-channel Doppler method is the best way to measure flow rate in unprepared water channels.

4. Discussion
Technical report on comparative tests of the accuracy of the MainFLO flow meter fulfilled at the Vodokanal water draw system.

For making tests, we applied water draw system with the following parameters:

- Pipe length – 12 m.
- Diameter – 630 mm.
- Pipe grade – 0.0012 %.

The test method was the comparison of MainFLO flow meter data and the simultaneous data of a reference KROHNE flow meter. The measurement of the flow carried out by calculating method, which is described in the “Results” chapter.

The calculation of the level-determination error based on the comparing the MainFLO level sensor meanings with the data of reference Siemens level gauge.

The process of measurement consisted of the following steps:
1) Assembling of the MainFLO flow meter in the pipe.
2) Starting the pump.
3) Recording the data from the flow meter.
Assembling of the flow meter in the pipe.
Installing the sensor on the rim in the place showed in Fig. 3. The distance from the pipe’s beginning to the sensor was 11.9 pipe diameters (7500 mm), and there were 7.14 pipe diameters (4500 mm) after sensor to the pipe’s end. The rim was opened as tight as possible for eliminating gaps.

Calibrating of MainFLO flow meter by two level values - on 0 and 50 mm of water.

![Figure 3. The location of sensor installation.](image)

**Starting the pump.**
The pump was started through the control panel. The setting of the pump frequency was on the control panel by turning the knob on control cabinet. For the first experiment the frequency was 38 Hz, and values for subsequent experiments are showed in the Table 1.

**Recording of flow values.**
1) Turn the KROHNE display from the mapping of current flow (Fig. 4) to the total water volume display (Fig. 4).
2) The data was listed in Table 1 (the time for KROHNE and MainFLO was checked simultaneously):

- KROHNE. Volume at the beginning (figure 4).
- KROHNE. Volume at the end, with an 30-minute-interval (figure 4).
- KROHNE. Direct flow (figure 4).
- Pump frequency.
- Level of water (from the level sensor of MainFLO).
- Level of water (from the level sensor of Siemens).
- MainFLO. Current flow.
- MainFLO. Volume at the beginning.
- MainFLO. Volume at the end.

![Figure 4. KROHNE display. Current flow and water volume.](image)
5. Result
There were six measurements with different pump frequencies; parallel measuring of water flow we got with a MainFLO flow meter and reference KROHNE flowmeter. The obtained results are summarized in Table 1.

The calculation of the level-determination error was based on the readings of the Siemens level gauge and the MainFLO level sensor. The formula for calculating is as follows:

\[
\delta_h = \frac{(h_{Siemens} - h_{MainFLO})}{h_{Siemens}} \times 100\% = \frac{(156 - 152.22)}{156} \times 100\% = 2.42\%
\]

The calculation of the flow-measurement error was based on the readings of KROHNE and MainFLO flowmeters. The formula for calculating is as follows:

\[
\delta_{MainFLO} = \frac{(Q_{KROHNE} - Q_{MainFLO})}{Q_{KROHNE}} \times 100\% = \frac{(158 - 168.12)}{158} \times 100\% = -6.41\%
\]

The results for the other experiments are shown in Table 1.

| № | Pump frequency, Hz | Flow, m³/h | flow-measurement error | Level, mm | level-determination error |
|---|-------------------|------------|------------------------|------------|--------------------------|
| 1 | 38                | 158        | 168.12                 | -6.41%     | 156                      | 152.22                  | 2.42%                   |
| 2 | 22                | 88.2       | 97.82                  | -10.91%    | 127                      | 118.58                  | 6.63%                   |
| 3 | 15                | 57.2       | 66.22                  | -15.77%    | 98                       | 102.99                  | -5.09%                  |
| 4 | 9                 | 28.8       | 33.18                  | -15.21%    | 77                       | 76.6                    | 0.52%                   |
| 5 | 7                 | 18.6       | 21.44                  | -15.27%    | 61                       | 67.1                    | -10.00%                 |
| 6 | 6                 | 11.6       | 13.68                  | -17.93%    | 50                       | 54.04                   | -8.08%                  |

6. Conclusion
We can draw conclusions, building on the results of the measurements and errors:

- The flow meter does not meet requirements to allow a relative measurement error of level. It is necessary to be in range ±5%, but MainFLO has since -8.08% to +10%.
- Flow meter does not meet requirements to allow a relative measurement error of volumetric flow rate. It is necessary to be in range ±5%, but MainFLO has -17.93%.

Overall findings:

- In analyzing archive data of level during the experiments we have found crude errors in the level data until 12.6 mm upper real level and 7.6 mm lower.
- Unfortunately, in archive data we have no total flow parameter. It makes the analysis process a bit complicated.

Flow rate measurements in non-pressure flows are complicated things from the technical side. For obtaining the best accuracy, you should follow all of meteorological standards and rules. Examples of measurement methods for non-pressure flow were given in this clause. Also, the metrological standards of these methods were compared.

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