635. Liquid flow rate measurement using the weighing method

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Abstract. One of the methods of measurement of liquid flow rate is based on the measurement of the mass change over the unit of time. It allows to achieve high measurement precision of the moderate flow rate since the mass and the time can be evaluated with high precision. The problem arises when it is required to measure the instantaneous flow rate. It is caused mainly by the varying component of the force generated by the moving liquid. In this paper the approaches for solution of the mentioned problem are analyzed. The damper and the flow nozzle are proposed, which reduce the impact of the varying force component. Simultaneous application of signal processing resulted in relative uncertainty of the flow measurement that is less than 0,5 % under the flow rate of 1000 l/h.

Keywords: liquid flow, weighing method, dynamic force measurement, disturbances.

Introduction

Recently in flow measurements the main attention is focused on measurement accuracy and acceleration. High-accuracy liquid flow measurement facilities are generally based upon static weighing gravimetric systems with flying start and finish [1]. It is stated that dynamic measurement of liquid flow is less accurate with respect to static measurement and is quite complex.

In general, liquid flow is estimated by ratio of volume to time. The liquid flow can be replaced by the ratio of mass to time if liquid density is known. High measurement accuracy of time and mass allows achieving a high accuracy of moderate flow measurement. We need to accomplish differentiation while measuring the flow. This operation increases the influence of disturbances. The noise of measurement system and the flow pulsation (varying impact forces or mass inertia) [1] determine disturbances.

Standard weighing method [1-4] of liquid flow rate measurement is based on liquid mass measurement by collection tank in a defined time interval. Usually a reference equipment [2, 3, 5] consists of these parts: equipment producing and ensuring constant water flow, water temperature control system, instantaneous flow deflector, water content and timing equipment, and computerized control system (reservoir, pump(s), constant head tank, balance). This equipment is a stationary one. Water flow creation is the most significant element in it. The important condition is flow stability as it influences the level of pressure, pulse rate, hydrodynamic and temperature stability of the flow [6].

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Usability, metrological characteristics of mobile reference flow rate equipment that shall perform measurements in a dynamic mode in the case, when water system delivers water of particular density, are objects of our interest.

Dynamic liquid flow measurement systems require specific experiments that will enable establishment of all possible uncertainty sources. Qualification of systematic or random character of errors is of high importance. Repeatability of measurements and environmental conditions will allow introduction of corrections into the values of measurement quantity and evaluate measurement uncertainties. It is important to evaluate and to minimize the influence of disturbances and all factors which relate to the dynamic accuracy and acceleration.

General description of the test system (liquid flow-weighing system)

Real-time measurement of liquid flow rate is possible using electronic weighing scales (force transducer) and the proper signal processing. Liquid flow-weighing system consists of flow control valve, diverter (pipe and nozzle), collection tank, damper and force transducer. Figure 1 shows the principled setup of the dynamic liquid-weighing system. Figure 2 presents the program window for system control and visualization.

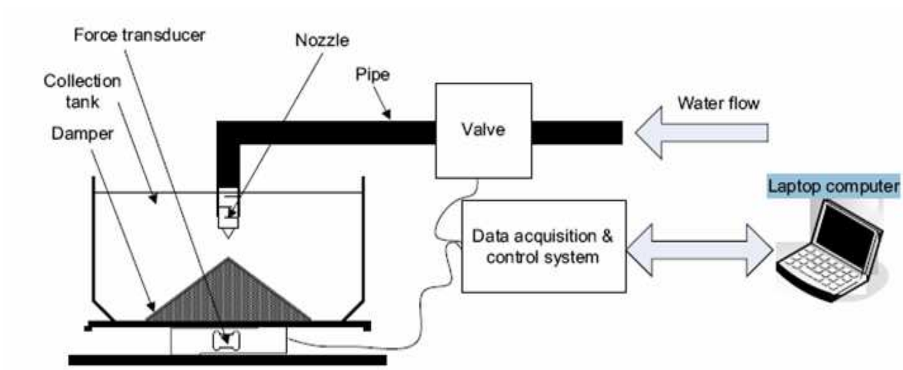


Fig. 1. Schematic diagram of the proposed techniques for water flow rate measurement

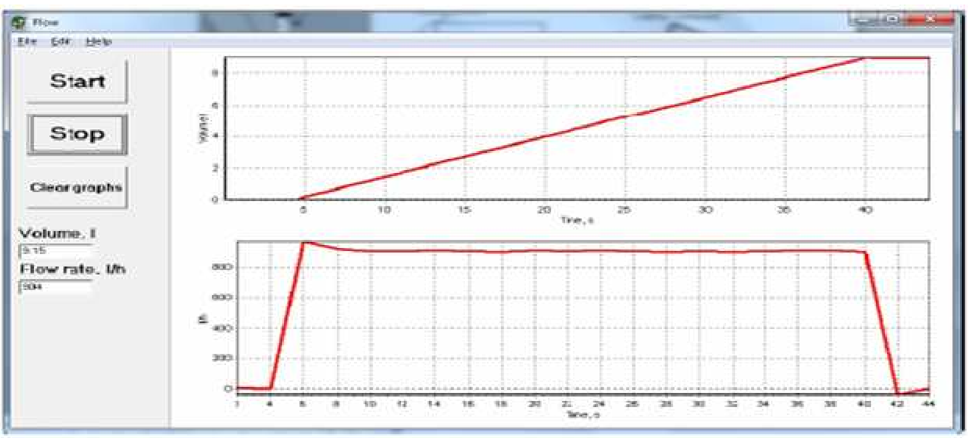


Fig. 2. The program window for system control and visualization

The impact force can be calculated as follows:

$$F(t) = g\int Q(t)dt + aQ(t) + bP(t), \tag{1}$$

where: g- gravitational acceleration, Q(t)- slowly varying mass flow, P(t)- varying component caused by flow pulsation, a,b- coefficients describing the functional influence of constant flow rate.

Differentiating with respect to time and considering that Q(t) is varied slowly we have:

$$\frac{dF(t)}{dt} = gQ(t) + b\frac{dP(t)}{dt} \tag{2}$$

or

$$Q(t) = \left(\frac{dF(t)}{dt} - b\frac{dP(t)}{dt}\right)\frac{1}{g}. \tag{3}$$

When the density of the liquid in the weight tank is known, it is easy to calculate the volume flow. The second term inside the parenthesis of formula 3 is determined by the measurement error of flow pulsation in the tank. We assume a condition that during the filling time of the weighing tank the water temperature and density are stable.

Measurement procedure by using water flow-weighing system commences by diverting the flow into the weighing tank and starting the registration of the output of the meter under the test and the time measurement. Under a condition of steady flow, the flow control valve is closed. The flow is measured by weighing the quantity of water during a certain measuring time. This procedure requires acceleration of the weighing scale just prior to both the start and stop actuations of the timer.

The water is collected in the weighing tank, whereby the mass increment is measured by calibrated load transducer. Weighing range can be expanded when the load transducer is changed. The system error does not depend on tank dimensions. Data collection and calculation are processed by the computer.

The variation of the impact force, created by the falling water, between the initial and final weigh points, is important for this system. Any turbulences or disturbances of the scale (force transducer) readings are meaningful when the flow rate is calculated in real time. Flow pulsation effect in the collection tank influences the flow measurement error.

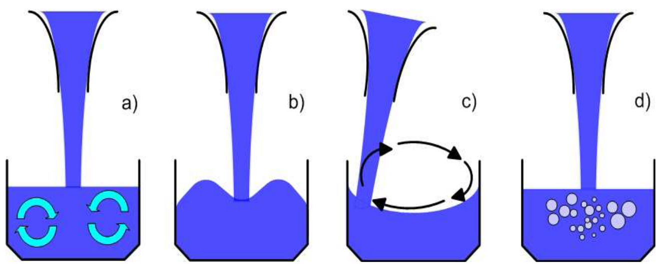


Fig. 3. Possible disturbances [7]: a) internal circulations, b) symmetric wave, c) rotation, d) rising bubbles accompanied by falling water

Main goal of the experiments is to avoid impact forces of the water stream directed to the weighing tank. To minimize these possible sources of errors for dynamic weighing, the proper damping structure was installed in the collection tank.

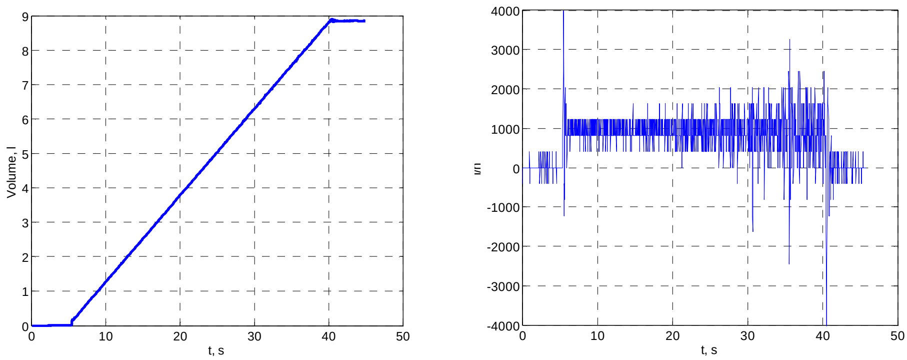
We need essential information about the system response when the test water is directed into the weighing tank. It is necessary to investigate the influence of varying impact forces or mass inertia that is specific to the dynamic weighing method [1].

Pulsation research

As it has already been mentioned before, the falling water flow causes the variable component of pulsed force to the tank. Based on publications [7-10] and our initial research, the interaction between the flow and water, influence of nozzle and damper on the pulsations and flow measurement will be analyzed.

The research was accomplished according to the structural diagram given in Figure 1. It should be noted that during the first stage of investigation the flow dispersing pipe nozzle and the tank damper located in the tank were not used. The first tests were performed by injecting the water flow from the nozzle perpendicularly to the bottom of the measured tank. Firstly, when the test was initiated, the magnetic valve was opened. With the magnetic valve open the water flows to the collection chamber the mass of which is continuously weighed and the time between the measurements is recorded. The time interval between the measurements was 0.02 s. The obtained weighing result is provided in Figure 3 (a). When the tank was filled the water feed was turned off using the same magnetic valve; the measurement was also stopped.

By differentiating the collected weighing results we determined the water flow, which is illustrated in Figure 3 (b). It can be observed that the calculated water flow has a pulsating character and not informative, and the pulsations increase in magnitude over the time. It can be explained by the fact that when the water volume increases in the tank and its surface approaches the nozzle, the increasingly stronger water pulsations emerge. Therefore the weighing process loses accuracy and the flow rate calculated from it becomes non-informative.



a) b)

Fig. 4. Weighing result (a) and calculated flow of water (the water stream is fed perpendicular into the tank) (b)

The next test was performed using several modifications. Water flow was not perpendicular to the bottom of the tank but was directed at an angle towards the wall of the tank, and averaging of the results of weighing data was used. The resulting water flow measurement was obtained by averaging of 50 weighing readings (Fig. 4). Appearance of cyclic flow pulsations was observed. Periodic flow pulsations could be explained by the fact that during the test the water flow was directed at an angle towards the wall of the tank. This led to the rotational motion of water. Since the water motion in the tank was rotational, non-stochastic, harmonic periodic pulsations were induced. It can be observed from the calculated flow. During the research it has been established that the angle at which the water flow was directed towards the wall of the tank did not make a considerable influence on the result. Pulsations emerged each time when the water in the tank started to spin. By averaging the signal shown in Fig. 3 (b), when the water fell perpendicularly to the tank bottom, it was possible to obtain a better result (Fig. 5). Nevertheless the averaging of results is not enough to get a reliable flow.

Initial tests have demonstrated that in order to increase the measurement accuracy it is necessary to fulfill such conditions: no intense water turbulence in the water tank, no water rotation, flow of water from the nozzle would have the least possible impact on the surface of water in the tank. All this can be achieved by inserting a flow resolve nozzle into the pipe and fitting a cone-shaped damper in the tank. After the aforementioned modifications have been implemented, the measuring system (Fig. 1), that was used for the tests shown in Fig. 6, demonstrated that the flow can be measured reliably using the weighing method. The average standard deviation was 12 l/h, when taking the average of 25 measuring points, and 3-4 l/h, when taking the average of 50 points. It can be stated that averaging of 50 weighing readings is optimal when the measured water flow delivered to the tank is relatively large (900 l/h).

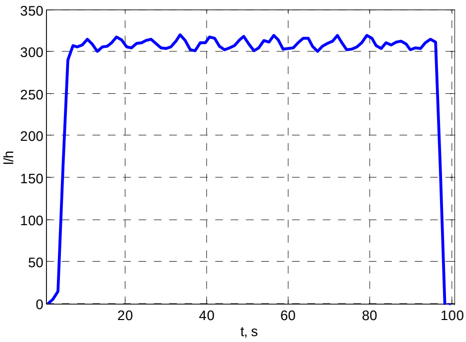


Fig. 5. Flow pulsation with water rotation in tank

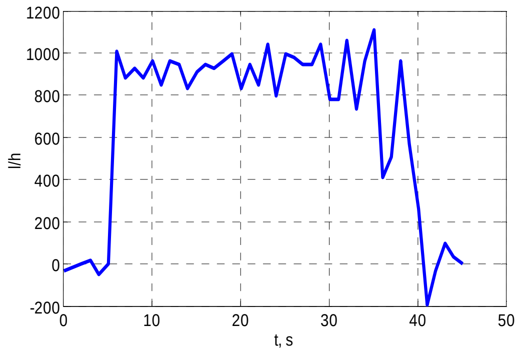
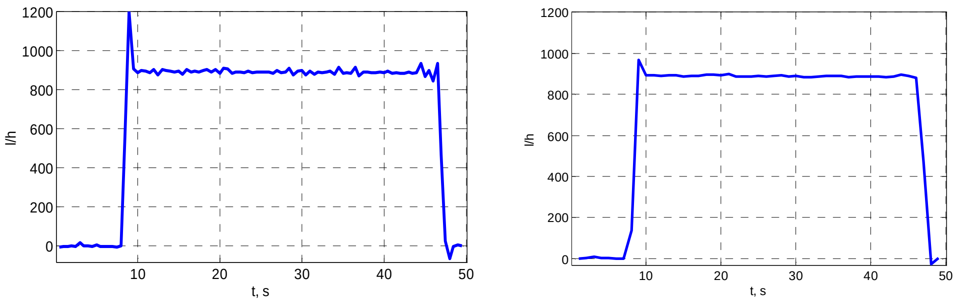


Fig. 6. Calculated flow of water (falling to bottom of tank) obtained by averaging



a) b)

Fig. 7. Calculated flow of water with selected damper and diverter (pipe and nozzle), a) obtained by averaging of 25 measuring points, b) obtained by averaging of 50 measuring points

Conclusions

1. Flow-weighing system allows measurement of water flow with improved uncertainty of 0.5 % and measurement duration of about 2 seconds.

2. The flow rate depends on the turbulence inside the tank. The flow pulsation is the main source of uncertainty. It can be significantly reduced by using the damper and water diverter (pipe and nozzle), that are placed in the collection tank.

3. It is evident that further study of the dynamic flow system for small and large flows is necessary and recommended.

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