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DESIGN OF A FLOW DEFLECTOR FOR AN ACCURATE FLOW METER CALIBRATION FACILITY

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ABSTRACT

The design and test of a flow deflector gate used for controlling the flow deviation toward the primary tank in a flow-meter calibration facility is presented. The deflector gate is pneumatically controlled and permits the flow conduction to either the suction tank or to the primary tank. The deflector is designed to approximately compensate the flow deficit towards the primary tank during the opening, with the flow excess while in the shutting process. Numerical simulations are performed to study the flow hydrodynamics during the deflector operation. Results are compared to experimental data, and used to improve the gate design. The enhanced design proved to guarantee the uniformity of the flow through the calibration section and the dramatic reduction of the error in volume measurement during calibration.

INTRODUCTION

The degree of precision, using a primary tank, to determine the flow rate discharge out of a pipeline, is directly related to the measurement of the volume and period of time taken to download the volume into the tank. This paper presents the design and evaluation of a derivation gate, which diverts the flow to a primary tank, volumetrically calibrated to measure the volume stored during the discharge interval of time. During the gate operation, a fraction of the diverted volume is accounted at opening, while another fraction is taken at closing. These two fractions, ideally speaking, though included in the period of time of the measurement, do not correspond to volume through the pipeline in steady regime. Nevertheless, while opening the gate, the deficit in volume accounted for, tends to be compensated by the excess obtained when closing it. Therefore, in order to accurately compute the flow discharge through the diverting gate, it is very important to perform a thorough analysis of the hydrodynamic behavior of the gate during its opening and closing cycles.

The error in flow-rate measurement through the whole process, related to the gate operation, is presented as a function of the diverted volume and time.

Results from a preliminary numerical analysis of the flow through the gate at different positions permitted to foresee the gate behavior and to develop a close to optimal design of it. A comparison between numerical predictions and experimental results is also presented.

DESCRIPTION OF THE SYSTEM

The derivation gate consists in a 0.5m x 0.6 m steel plate pivoting along one side, while activated by a pneumatic actuator that allows it to carry out an angular motion between 0 and 14° (Fig. 1). The gate is part of a reception manifold to which four pipelines (8”, 10”, 12” and 14”) of the Universidad Simón Bolívar Flowmeter Calibration Facility (USB-FCF) are connected.

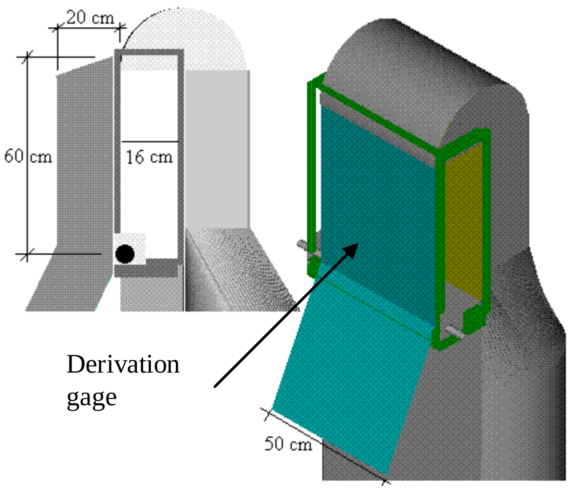

Fig. 1. Diverting Gate (coupled to manifold head)

The manifold receives the flow coming from one of the pipelines and conducts the water through its body, made of a 20” pipe, towards the convergence section just upstream the gate. At the gate, the flow is discharged either to a return channel that takes the water back to the main tank, or to the calibrated open tank (Fig. 2). Once the gate is set to open towards the calibrated tank, the calibration time starts. Part of the flow, at the beginning of time-counting, is not effectively going to the calibrated tank since the gate takes a few miliseconds to get totally open. On the other hand, the opposite occurs while closing, since time-counting ends at the precise moment the gate is set to close, thus a fraction of the water volume coming through the manifold, while the gate closes, will go to the calibrated tank.

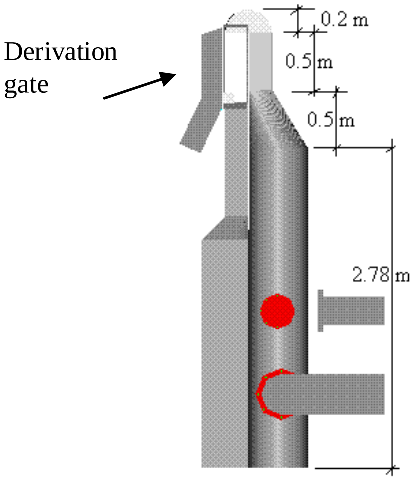

Fig. 2. Outline of the Manifold

The time during the diverting process is measured by using a potentiometer, coupled to a secondary disk (d2) which is connected to a primary disk fixed to the gate axle, as shown in Fig. 3.

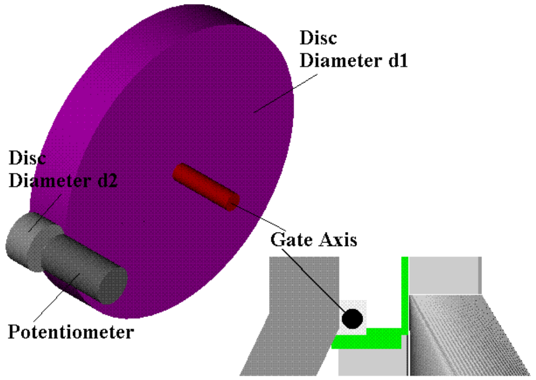

Fig. 3. Schematics of Potentiometer Connection

The potentiometer is wire-connected to a data acquisition system (DAS) that receives the 1-5 Volts signal and converts it to the potentiometer 0-180° angular position. The plot of voltage vs. angular position, shown in Fig. 4, depicts the linear nature of the potentiometer.

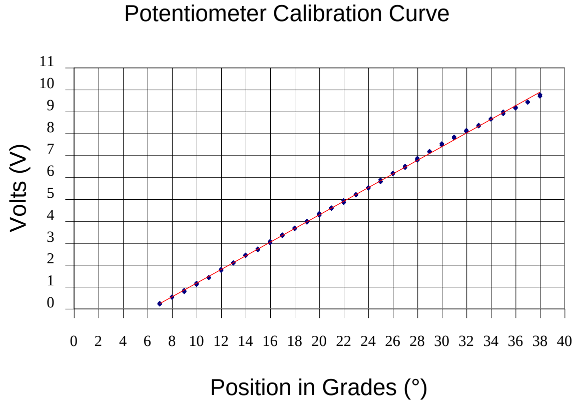

Fig. 4. Calibration Curve of Potentiometer

The signal out of the potentiometer, via the calibration curve, is then translated through the DAS to time (see Fig. 5). Thus, each critical position of the gate (i.e., opening start-end and closing start-end) is associated to certain time.

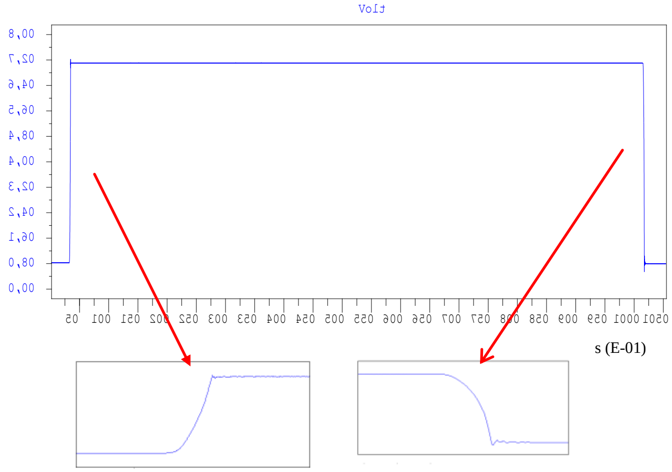

Fig. 5. Potentiometer Voltage vs. Time

DESIGN AND TESTING OF THE GATE

As part of the gate design, preliminary numerical simulations of the flow field were performed on the proposed geometry prior to the construction of the actual prototype. The real problem was modeled as a two-phase incompressible flow, where air and water were the working fluids.

The water coming out of the gate had to impinge an atmospheric environment. This type of situation is recognized as very complicated, but with the help of a finite volume-based numerical code, the simulation was successfully performed.

The numerical study, though is not the central part of this work, represented an important effort in understanding the flow behavior and its interaction with the gate while in operation. The geometry of the gate and surroundings was modeled as close as possible to the actual set up, and a highly refined mesh was chosen to perform the final simulations. Momentum, continuity and k-ε (for turbulence modeling) equations were simultaneously solved for using a semi-implicit temporal scheme.

For the boundary conditions, it was assumed an uniform velocity profile coming into the gate and a constant pressure (atmospheric) outflow.

Results from simulations, though shortly referred later in this paper, permitted to understand better the gate behavior and to foresee mechanisms to improve its design.

DESCRIPTION OF THE TEST

The first phase of the experimental assembly was based on running the facility with the gate at several intermediate positions from fully-open to fully-closed position (2, 4, 5, 7, 10, 12 and 14 degrees), as shown in Fig. 6. The intermediate positions were guaranteed by using a especial subjection pin to brake the gate at the desired position.

The USB-FCF allowed flow rates of up to 280 l/s

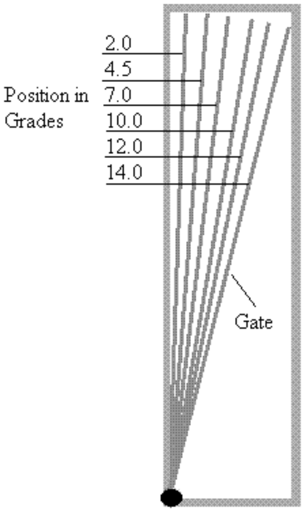

Fig. 6. Outline of Gate Positions in Experiments

For each of the experiments, it was registered the time it took the gate to open to every preset position, with the purpose of being able to define the influence on the discharge in relation to the opening and closing motion of the gate.

EXPERIMENTAL RESULTS

The influence of the gate operation (opening and shut-off) onto the measured discharge volume and time is presented in dimensionless plots, as a function of the following parameters:

- **Flo (Qi/Qt)**
  Flo represents the ratio between the partial flow (obtained at partially open gate) and the total flow (generated when the floodgate is positioned at 14°).

- **Pos (Gi/Gt)**
  Pos is the ratio between the angular position of the gate and the maximum angle when the gate is fully open. The positions are measured in degrees, beginning in 0° until arriving to the final position in 14°.

- **Tim (Tci/Tct)**
  Tim represents the ratio between a partial time during the gate opening-closing and the time it takes the gate to arrive to its final position. In the opening process it will be at 14°, while in the closing process it will be when the gate returns to position 0°.

- **Tot (Ti/Tt)**
  Tot is the ratio between the total time it takes to the gate to complete a open-close cycle.

  Since time to complete a test is quite longer than the time it takes to the gate to completely open or close, it is difficult to figure these intervals of time in Fig. 7. Figures 7a and 7b, present a zooming of those critical moments.

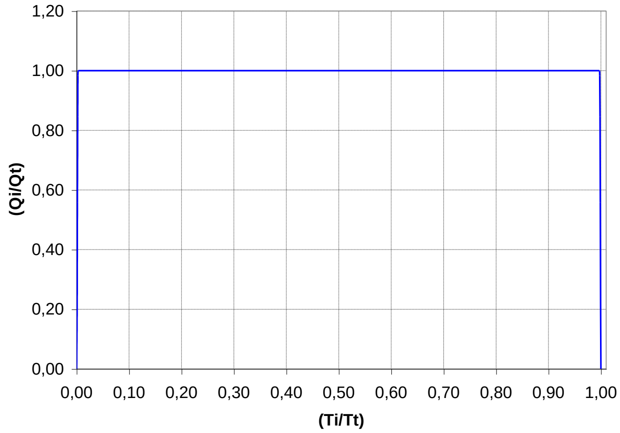

Fig. 7 (Qi/Qt) vs. (Ti/Tt)

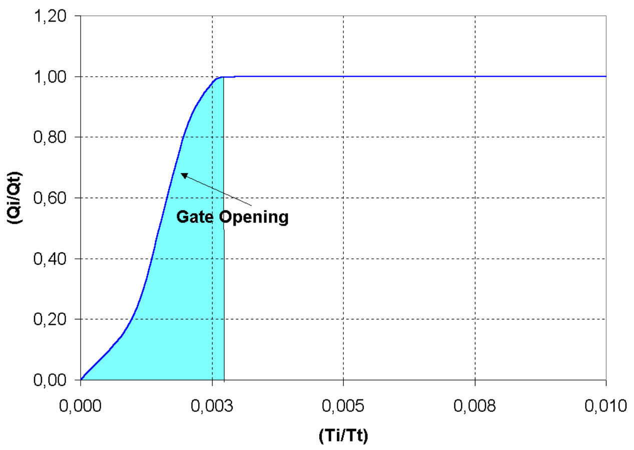

Fig. 7a. Opening Process

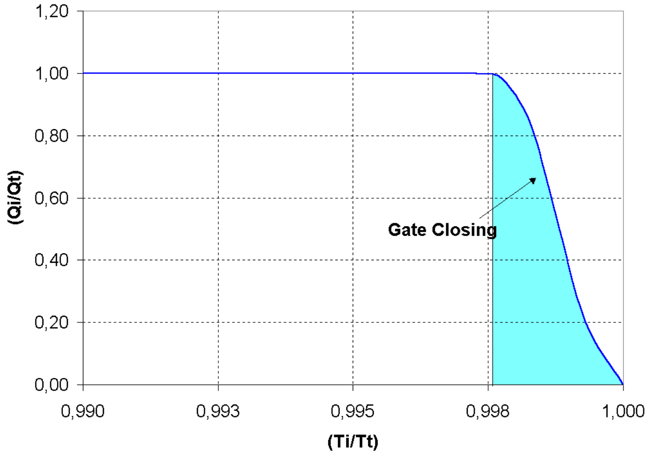

Fig. 7b. Closing Process

Figure 8 presents the time it takes to the gate to reach every one of the preset positions. The x-axis corresponds to Tim, while the x-axis to Pos.

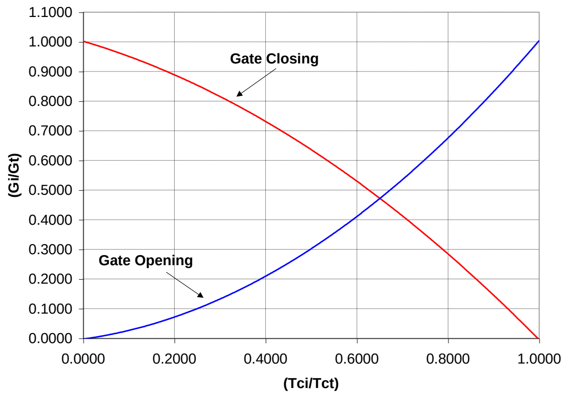

Fig. 8. (Gi/Gt) vs. (Tci/Tct)

Figure 9 depicts relationship between (Gi/Gt) and (Qi/Qt), for both numerical analysis and experiments.

The numerical results show a linear dependency between the flow rate and the gate position as opposed to the experimental results for which the curve is definitively non-linear. What is believed to happen refers to the fact that the flow coming out of the manifold contains a larger amount of momentum towards the outer radius, obeying to centrifugal force, and therefore the flow velocity, and the resultant volumetric flow through the gate is larger around that section. This effect is not considered in the simulation and then the distribution appears as unperturbed.

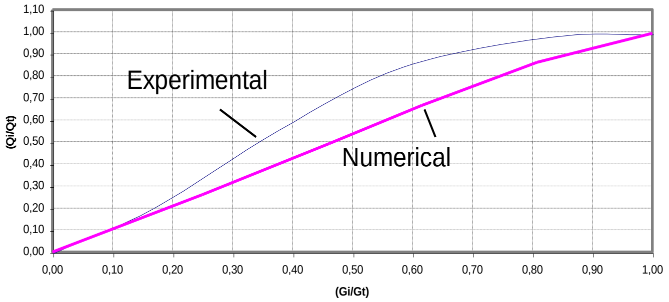

Fig. 9. (Gi/Gt) vs. (Qi/Qt)

ANALYSIS OF RESULTS

The study of the gate performance during operation permitted to account for the portion of water that incomes the calibrated tank while the gate opens and closes. The accurate determination of this volume permits to know, with more precision, the USB-FCF absolute volumetric and relative errors in the tests. The relative error with respect to time is calculated by means of the existent relationship between the times of opening and closing of the gate and the total time of the filling operation (51.6 s for 280 l/s, maximum flow rate).

The non-linear relationship between flow through gate and time, depicted in Fig. 8, obeys to non-uniformities in the flow derived through the gate. Also it is appreciated how the gate takes more time to open than to close. This, still a point of study, might result from the water impact on the gate body which is more intense during the opening. In fact, Gi/Gt = 0.48 during opening, compared to Gi/Gt = 0.52, while closing.

The existent bend in the manifold head generates a non-uniform velocity distribution that is later discharged through the diverting gate. Figure 9 shows the relationship between **Pos** (Gi/Gt) and **Flo** (Qi/Qt). This plot allows to distinguish ranges of gate operation with uniform and non-uniform flow going through it. This is because the plot does not include the time of gate angular displacement, but the flow rates at different fixed positions of the gate.

In fact, the flow discharge is mainly concentrated around the outer radius of the bend, producing larger discharge contributions in that sector and diminishing as it comes closer toward the inner radius of the bend.

DERIVATION OF THE GATE VOLUMETRIC ERROR

Since the diverting gate takes more time to open than to close, the gate performance is different while developing both processes. Figure 10 shows the deficit volume during opening and the superavit volume during closing, as it refers to the water volume derived towards the calibrated tank. Volume A is smaller than B, and the difference permits to define the error of the calibration associated to the gate operation.

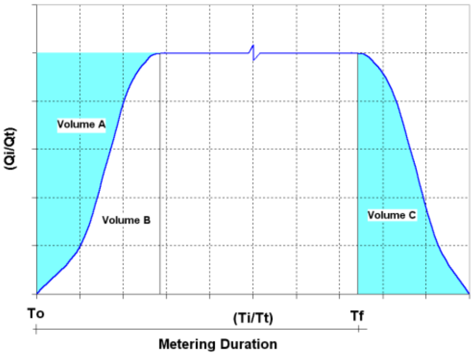

Fig. 10. Schematics of Flow vs. Time during Gate Operation

Therefore, the gate-associated error is calculated dividing the differential of volume by the total volume allowed in the calibrated tank during the time of the volumetric measurement. Consequently,

Relative Error = (Differential Volume / Total Volume)

$$\text{Absolute Error} = \frac{(\text{Volume A} + \text{B}) - (\text{Volumen C})}{\text{Total Volumen}} * 100$$

For the maximum flow generated by the system, the absolute error generated by the gate is found to be 0.0042%.

CONCLUSIONS

The flow measurement precision when using a volumetric system for calibration purposes is influenced by the action speed of the diverting gate. In this work, the precision of a large scale flowmeter calibration facility is studied in regard to the diverting gate used to direct the flow to the recirculation circuit or to by pass it to a calibrated tank. In the facility here explored, the gate takes an average of 0.2 seconds for complete the opening process and 0.18 seconds while closing (a total angle of 14° in either way).

The differences in opening and closing times is found to respond to the gate asymmetry, the non-uniform flow at the gate entrance and the retractile or tensile action of the pneumatic actuator.

The distribution of the flow obtained from the numerical simulation, derived in a linear relationship between the flow and gate position. This result, though shed light on the understanding of the gate behavior, did not take into account the non-uniformity of the flow, due to centrifugal effects in the manifold head, at the gate entrance. This result also suggested that the manifold head could be improved to guarantee a uniform flow and therefore a uniform source of error that would tend to reduce the total error of the system. However, a 0.0042% error, which is quite small, is guaranteed in the current system.

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