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Performance of Coriolis meters in transient gas flows

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ABSTRACT

For steady flows, Coriolis flow meters accurately measure mass flow. To study the performance of Coriolis meters under transient flows, we measured the instantaneous and totalized flow determined by two Coriolis meters. The tests used a Transient Flow Facility (TFF) developed to generate transient flow, pressure, and temperature conditions similar to those that occur when a hydrogen powered vehicle is refueled. During simulated cascade fills, the TFF discharged 3 kg of helium in 3 min at flows between 10 g/s and 45 g/s through the Coriolis meters and the TFF's standard. The TFF's expanded uncertainty (95% confidence level) for totalized mass during this cascade fill was 0.45%. For the same simulated cascade fill, both Coriolis meters measured the instantaneous flow within the uncertainty of the TFF and measured totalized flow within the International Organization of Legal Metrology Recommendation 139 maximum permissible errors for meters in gaseous fuel dispensers (1.0%).

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1. Introduction

Flow meters are sometimes used to measure unsteady flows, under conditions where the temperature and pressure also vary. For example, dispensing stations for hydrogen-fueled vehicles comprise a set of pressure vessels (a cascade tube bank) filled to different pressures. As a vehicle is refueled, valves are sequentially opened to connect the vehicle's fuel tank to the cascade tubes in order of increasing pressure. As each tube is opened, surges of flow and pressure occur at the flow meter that totalizes the flow for customer billing. Rapid, large changes in temperature also occur due to flow work and the subsequent adiabatic cooling and heat transfer to the surroundings. Consumers and inspectors expect $<1\%$ accuracy from meters used in gaseous fuel dispensers [1], but errors greater than 10% have been reported. At natural gas refueling stations, turbine meters subjected to pulsatile flow over-reported totalized flow by as much as 15% [2].

The National Institute of Standards and Technology (NIST) has constructed a Transient Flow Facility (TFF) to test gas flow meters under rapidly changing pressure, temperature, and flow conditions (Fig. 1). The TFF has four, 40 L high pressure tanks (HPTs) that serve as a source of nitrogen or helium[1] at an initial pressure of 42 MPa. These high pressure tanks can be sequentially discharged to simulate cascade filling of a vehicle. The gas is discharged in 3–5 min (depending on whether helium or nitrogen is used) into eight, 250 L low pressure tanks (LPTs) that are then the gas source for a 3-stage diaphragm compressor that periodically refills the HPTs back to 42 MPa. An extra set of 18 HPTs can also be pressurized so that flow can be maintained for >1 min at nearly steady-state conditions. In this mode of operation, gas must be discharged to the atmosphere because the LPTs have insufficient capacity. The TFF can operate with any inert gas, although changing the gas requires approximately one week because successive evacuations and purges are required to assure gas purity.

The flow reference for the TFF is a 1 mm throat diameter, critical flow venturi (TFF CFV) with rapidly responding pressure and temperature sensors (<20 ms) [3]. The TFF CFV has a flow calibration traceable to the NIST 677 L *PVTt* standard [4]. During transient flows, the gas density changes in the volume connecting the test section and the TFF CFV; therefore, the instantaneous flow through the meter under test (in this case a Coriolis meter) differs from the flow through the CFV. The flow due to this "storage effect" is larger than the CFV flow during the most extreme flow transients. The uncertainty of the instantaneous flow measurements is $<24\%$ ($k=2$),[2] and it is primarily driven by two apparatus-specific effects: (1) the response time of the pressure

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[1] At the present time, only non-explosive and non-toxic gases can be safely used in the Transient Flow Facility.

[2] Uncertainties will be labeled $k=1$ or $k=2$ depending on their confidence levels of approximately 68% or 95.5%.

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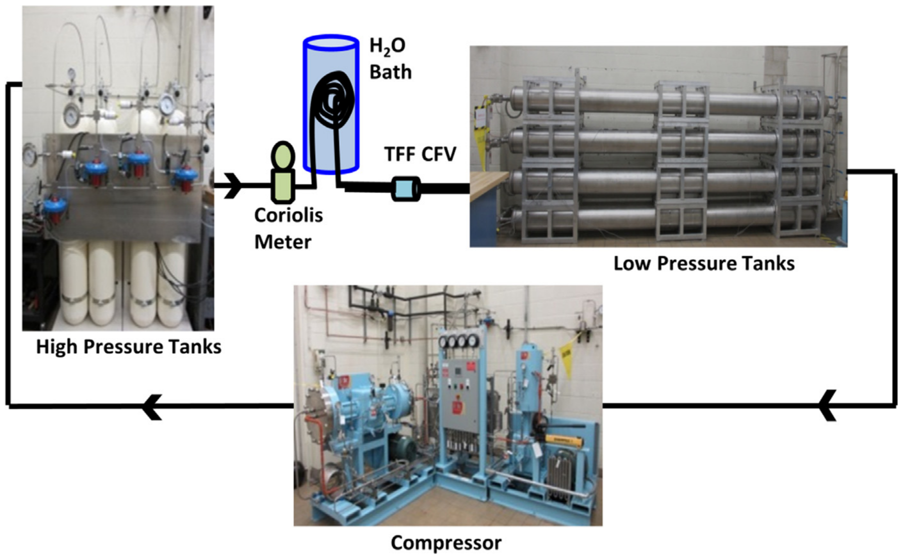

Fig. 1. The Transient Flow Facility (TFF).

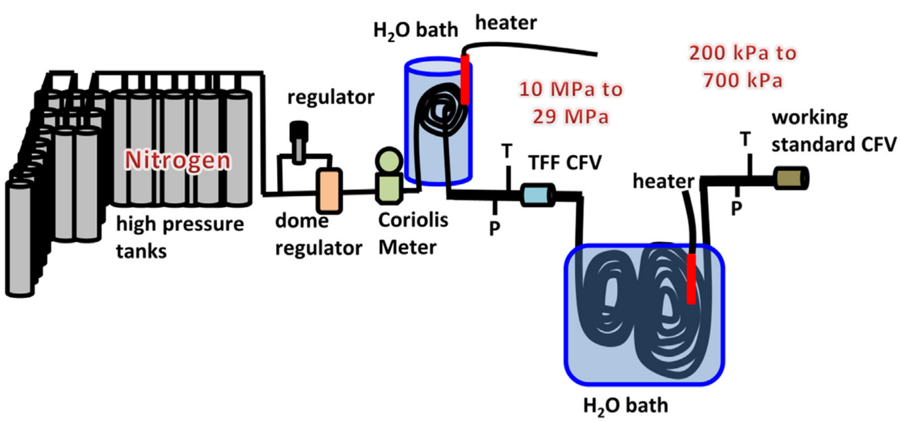

Fig. 2. Setup for the steady state calibration of the TFF CFV.

and temperature instrumentation associated with the TFF CFV and (2) the variation of the pressure and temperature measurements made in the connecting volume. Totalized mass flows during a simulated cascade fill have uncertainty $<0.45\%$ ($k=2$). Totalized uncertainties are much smaller than the instantaneous uncertainty due to the averaging of sensor variance and because the most extreme transients occur over only a small fraction of the total discharge time.

NIST used the TFF to test the performance of two Coriolis meters (Coriolis meter A and Coriolis meter B) under steady state flow conditions and during a simulated cascade fill. As presented later in this paper, both meters are capable of metering mass within the TFF uncertainty for both the instantaneous and the totalized flow measurements.

The gasses used in the TFF for the Coriolis meter tests were nitrogen and helium. When the TFF uses nitrogen, flows ranging from approximately 20 g/s to 120 g/s are achieved in the test section during the sequential discharge of the four HPTs, which correspond to Reynolds (*Re*) numbers of 6.7×10^5 to 4.0×10^6. The total mass of nitrogen discharged by the four HPTs is approximately 11 kg in 5 min. The TFF uses helium to better simulate hydrogen gas refueling, and it allows for flows in the test section from approximately 10 g/s to 45 g/s, which correspond to *Re* numbers of 4.9×10^5 to 2.2×10^6. The total mass of helium discharged by the four HPTs is approximately 3 kg in 3 min.

2. Calibration of the TFF reference CFV

The TFF operates at pressures up to 42 MPa; however, pressure losses in the plumbing reduce the maximum pressure to 39 MPa at the Coriolis meter and to 32 MPa at the TFF CFV. Before the Coriolis meters were tested, the TFF CFV was calibrated up to 29 MPa, the maximum steady pressure that could be maintained. As previously described in reference [5], the TFF CFV was calibrated in nitrogen up to 10 MPa using the NIST 677 L *PVTt* flow standard. Additional calibrations up to 29 MPa were performed by installing in series with the TFF CFV individual larger, calibrated “working standard” CFVs that had been calibrated with the 677 L *PVTt* flow standard. As shown in Fig. 2, all 22 HPTs were filled with nitrogen and a pressure regulator and heat exchangers were used to achieve approximately steady state conditions at the two CFVs. The gas was vented to the atmosphere to prevent over pressurization of the LPTs and to ensure that critical flow conditions were maintained across the CFVs. The series arrangement of CFVs allowed us to calibrate the TFF CFV at pressures up to 29 MPa while the