

FLOW CALIBRATION OF DIFFERENTIAL PRESSURE FLOW METERS

Richard L. Wakeland, PE

Wakeland Engineering PLLC

Flow calibration is a procedure utilized to determine a flow meter's performance characteristic and uncertainty. For differential pressure (dP) flow meters, the performance characteristic is the coefficient of discharge.

Two common methods of flow calibration include the weighing method or comparison to a master meter.

Laboratory flow calibration of a differential pressure (dP) flow meter can be utilized to reduce the uncertainty of the coefficient of discharge or verify the performance of the flow meter.

dP Flow Meters include orifice, flow nozzle, venturi tubes, wedge and cone type meters. Equation (1) is the flow rate equation which has been derived for these meters based on the principles of Conservation of Energy and Conservation of Mass.

$$\dot{m} = \frac{\pi d^2}{4} \sqrt{\frac{2\rho\Delta P}{1-\beta^4}} \quad (\text{Equation 1})$$

Where:

$\dot{m}$ = mass flow rate

d = bore diameter

ΔP = differential pressure

β = diameter ratio, $\frac{\text{bore diameter, } d}{\text{inlet diameter, } D}$

Eq.1 does not include compensation for energy losses due to friction and turbulence as well as changes in the fluid density. Flow measurement standards provide additional terms to the theoretical equation. A Coefficient of Discharge, C, has been introduced to compensate for the energy losses. The Gas Expansion Factor, Y, compensates for the change in fluid density between the high and low differential pressure sensing points for compressible fluids. N, is a unit conversion constant and varies according to the units selected. Equation (2) is the flow rate equation commonly provided in Flow Measurement Standards.

$$\dot{m} = d^2 N C Y \sqrt{\frac{2\rho\Delta P}{1-\beta^4}} \quad (\text{Equation 2})$$

American Society of Mechanical Engineers (ASME), International Organization of Standardization (ISO), American Gas Association (AGA) and American Petroleum Institute (API) are some of the organizations that have published standards for dP flow meters.

These standards specify design and manufacturing details such as geometries, tolerances, surfaces finishes and installation requirements.

The standards provide a value or an equation to determine the value of the coefficient of discharge. The values or equations are provided for specific ranges of pipe size, Reynolds Numbers and Beta Ratios. Within the stated limits, the standards provide an uncertainty value for C. These values or equations and the associated uncertainties have been determined by many flow calibrations of each type of flow meter.

Installation requirements include the amount of straight pipe required between the flow element and various disturbances upstream and downstream of the flow element. The required lengths are based on the flow element, type of disturbance and

the beta ratio. Elbows, tees, expanders, reducers and valves are some of the listed disturbances. For some types of disturbances, the standards provide an optional shorter length; however, an additional uncertainty of 0.5% must be added to the published uncertainty of the coefficient of discharge.

Example,

ASME MFC-3Ma-2007 High Beta Flow Nozzle

Equation for the coefficient of discharge:

$$C = 0.9965 - 0.00653\beta^{0.5} \left(\frac{10^6}{Re_d} \right)^{0.5} \quad (\text{Equation 3})$$

Beta Ratio Range $0.2 \leq \beta \leq 0.8$

Pipe Size Range $50 \text{ mm (2 in)} \leq D \leq 630 \text{ mm (25 in)}$

Reynolds Number Range $10,000 \leq Re_d \leq 10,000,000$

The uncertainty of the coefficient of discharge is +/-2% if the metering section is designed, manufactured and installed in accordance with the standard.

Flow Calibration utilizing the weighing method requires accurate measurement of the weight of the fluid flowing through the flow meter during a recorded time. The basic flow circuit is shown in Figure 1 below. Sufficient pipe and flow conditioning must be provided upstream of the flow element. Water is commonly used as the fluid. Water is pumped from the source tank through the meter to a diverting valve which directs the fluid back to the source tank or to the weigh tank. Pump controls or throttle valves are utilized to set the flow rate at each calibration point. The system is allowed to recover from the transient condition created each time the pump speed or throttle valve is adjusted. The diverter valve is then repositioned to divert water into the weigh tank and synchronized to start the timer. The diverter valve repositions to recycle the water and the timer is stopped when the tank is filled to an appropriate level. The weigh tank is emptied and the process is repeated until the specified number of data points has been obtained, typically 12 to 20.

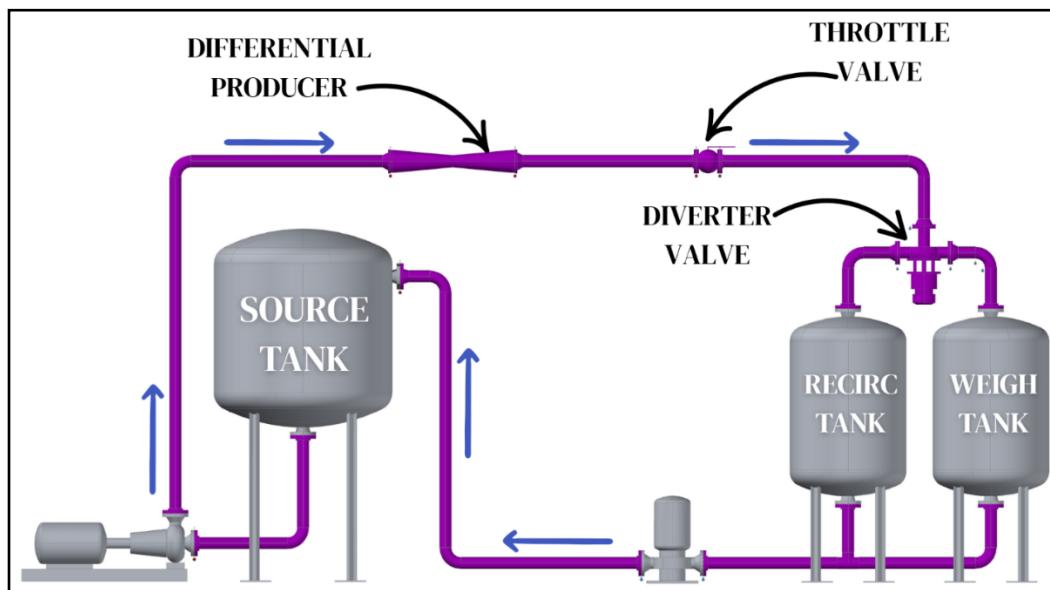


Figure 1: Weighing Method Flow Circuit

Another method of flow calibration utilizes a master meter or meters with known performance characteristics that are periodically verified. Critical flow nozzles, ultrasonic or Coriolis meters are commonly used as master meters. The calibration system may be a closed loop as shown in Figure 2 and Figure 3.

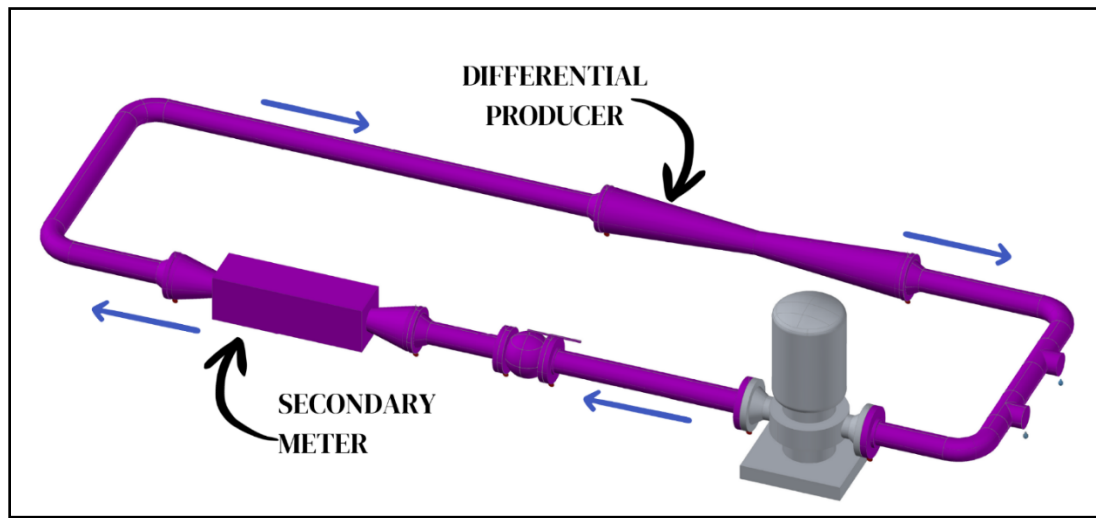


Figure 2: Master Meter Closed Circuit, Ultrasonic or Coriolis Secondary Meter

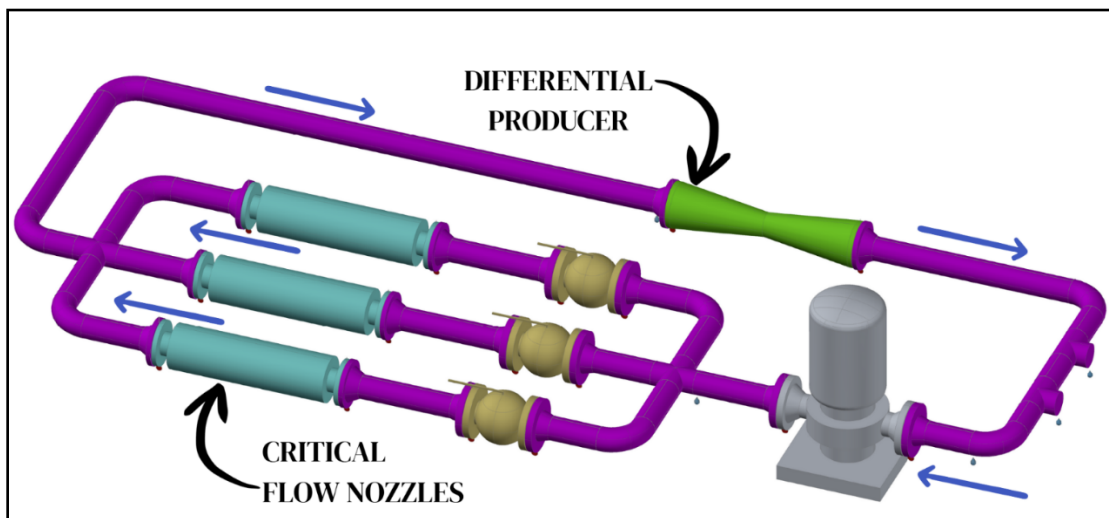


Figure 3: Master Meter Closed Circuit, Critical Flow Nozzles

An “open” system is shown in Figure 4. The supply line might be a service or transmission line.

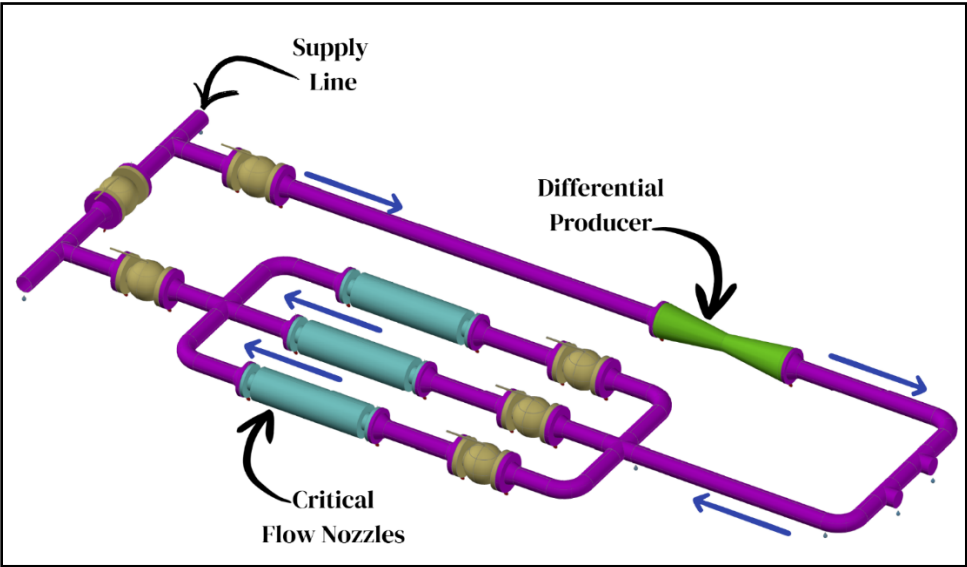


Figure 4: Master Meter Open Circuit

A flow nozzle assembly complete with pipe and differential pressure taps was designed, manufactured and installed in accordance with ASME MFC-3Ma-2007. The assembly was flow calibrated with water using the weighing method. The calibration results are presented as Coefficient of Discharge versus Pipe Reynolds Number. Figure 5 shows the calibration points with the published coefficient of discharge and uncertainty lines of +/- 2%.

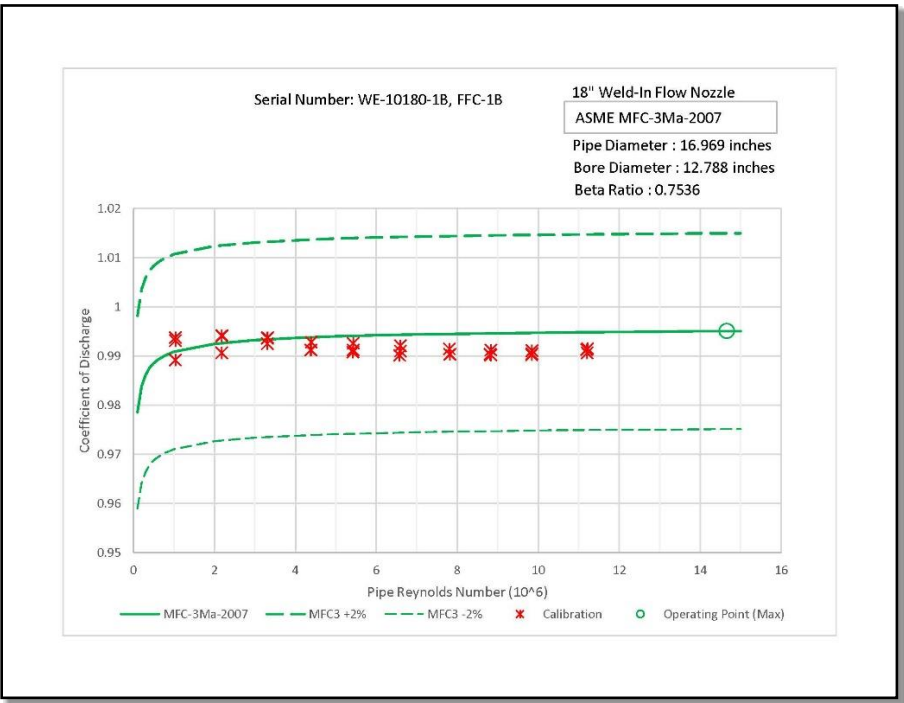


Figure 5: Flow Nozzle Flow Calibration Data Plot, Uncertainty 2%

Figure 6 indicates the same data; however, the uncertainty lines have been reduced to ½%. If the operating point was within the flow calibration range, then no extrapolation would be necessary and the uncertainty of the coefficient of discharge could be reduced thereby reducing the overall flow measurement uncertainty. ASME Performance Test Code (PTC) 19.5-2 Flow Measurement provides guidance for extrapolating flow calibration data.

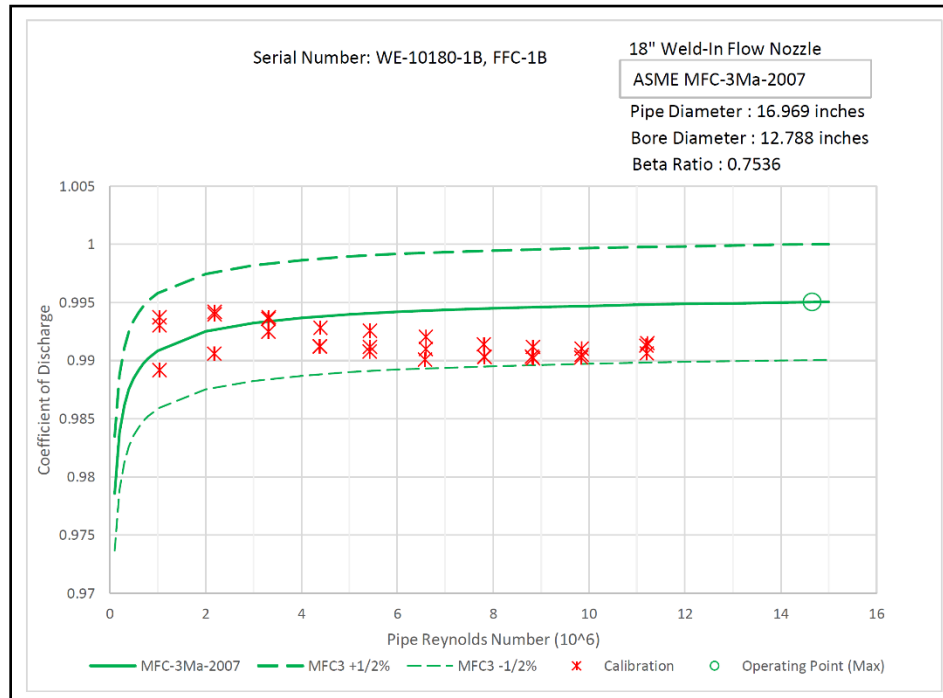


Figure 6: Flow Nozzle Flow Calibration Data Plot, Uncertainty 0.5%

When the recommended installation requirements cannot be met, the effect of the disturbance may be determined by flow calibration. The entire piping configuration including the flow meter and disturbance(s) shall be flow calibrated as a complete assembly. Comparison of the calibrated coefficient of discharge to the published values indicates the effect of the installation.

For differential pressure producing flow meters, the performance characteristic is the coefficient of discharge and the uncertainty of this coefficient is utilized in determining the overall flow measurement uncertainty of the flow meter. Flow calibrations are performed to verify that the flow meter is designed, manufactured and installed according to the requirements of the flow standard. The flow calibration results may be used to reduce the uncertainty of the flow meter below the published value. Effects of piping components on the flow measurement may be determined by flow calibration.