Badger Series 4000 flow sensors have been calibrated on the Badger Meter flow bench, shown schematically in figure 1. The calibrated fluid is untreated tap water, at ambient temperature and at various pressures. Data accuracy is estimated to be:

± 0.15% on average flow rate, **q**
± 0.10% on average frequency, **f**

for each individual test of sensor/flow rate combination. The combined uncertainty in the data, by addition in quadrature, is ± 0.18% . Tests on at least 12 points across the rated flow range of the specified sensor, including at least one slightly above maximum rated flow and at least one slightly below minimum, were performed on at least 6 different production samples of each of the basic designs.

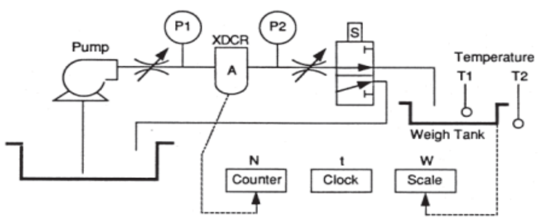

Figure 1

Output data points (72 minimum) for each basic model were analyzed, using standard regression techniques, to find the best linear least square fit describing flow rate (**q**) as a function of frequency (**f**) in the form:

q = k**f** + b (EQ1)

The values of k and b are developed to produce the minimum sum squared differences between the observed flow rate at an observed frequency and the flow rate predicted by EQ1 at that observed frequency. The results of this analysis imply that:

1) at constant pressure
2) at constant temperature
3) with water as the fluid medium

the calibration constants given below produce rate and cumulative flow values accurate within ±1% of full scale. This 1% covers the effects on non-linearity in the flow rate/frequency relationship and dimensional variations from sensor to sensor.

Shafter and Ruegg, in their paper "Liquid Flowmeter Calibration Technique" (Trans. ASME, October 1958, page 1369), caution that: "…meter calibration may be considered accurate only for the conditions existing at the time calibration data were taken. Thus those quantities which can influence the performance of the meter must be known, measured, and controlled during precise calibration work. Factors influencing the performance of different type meters …are the density, viscosity, and temperature of the liquid; upstream and, to a lesser extent, downstream flow disturbances; the vapor pressure and the absolute pressure level; and the orientation and scale sensitivity of the meter."

The Badger Meter series flow sensors, like all impeller or turbine flow meters, operate by converting kinetic energy in the flow stream into rotation of an impeller. Almost all flow sensors work on the principle of converting flow energy to output signal. The only arguable exceptions are ultrasonic and electromagnetic sensors. The interaction of the flow stream and the impeller depend on a currently unqualified extent on fluid properties – density, viscosity, and pressure, etc. – and on the physical properties of the impeller.

The Badger Meter impeller design features:

1) a low mass polar moment of inertia
2) no magnetic drag
3) very low eddy current drag
4) low bearing friction

The impeller housing forms the periphery of a rotating fluid stream, the only other source of drag tending to retard the impeller. The efficiency of this design is key to the repeatability of sensor output at very low rates and is the reason that the pressure drop across the installed sensor is so low.

Testing to date indicates that, over a relatively broad range of operating pressure (20 psig to 60 psig) and temperature (60°F to 120°F) factory calibration should be adequate to yield results accurate to within ± 1% of full scale in fluids not markedly different in density and viscosity from water. Repeatability with most compatible fluids at constant pressure and temperature should be within ±0.7% or less, although the actual readings may be significantly in error if the viscosity and density of the sensed fluid depart drastically from water.

All calibration tests are based on average flow rate and average frequency measured during the delivery of 200 lbs. of water over the time period required to deliver that weight of water at a given approximate flow rate. The Badger Meter flow bench and calibration practice conform to **ASME/ANSI MFC-9M-1988, Measurement of Liquid Flow in Closed Conduits by Weighing Method.** Sensors are calibrated based on the average flow rate; flow velocity in feet per second is calculated therefrom based on theoretical pipe diameters.

PVC Sensor calibration is based on flow through standard Schedule 80 PVC pipe. The effects on calibration of joining the standard Schedule 80 pipe terminations in a system of other than PVC Schedule 80 have not been investigated; we caution that we would anticipate some deviation in calibration lengths with other pipe schedules. This effect can be minimized if an additional 10 to 20 diameter lengths of PVC Schedule 80 pipe of the appropriate diameter is installed upstream of the sensor, and a similar 5 to 10 diameter length downstream.

PVDF Sensor calibration is based on flow through industry standard PVDF pipe. Additional pipe diameter length allowances, similar to those described for PVC pipe, should be taken if the PVDF sensor is used in a systems based on other piping technologies, or installed in a system using PVDF pipe sizes other than that used in calibration, if calibration accuracy to be maintained.

Measurement Accuracies:
Weight: 200 lb. sample ± 0.2 lb. ± 0.1%
Time: 20-1200 sec. ±0.01 sec. ± 0.05%
Count: 1600-12000 pulse ±1. ± 0.06%

Derived Assuracies:
Average Flow Rate: ± 0.15%
Average Frequency: ± 0.10%

CALIBRATION TABLE-DIGITAL OUTPUT

The following table provides calibration and operational data for the various models of the Series 4000 sensor. The data is organized as follows:

Column 1: Model number, to which the data listed in the particular column pertains
Column 2: Housing material
Column 3: Nominal pipe size
Column 4: Pipe O.D., per applicable standards
Column 5: Pipe I.D., per applicable standards
Column 6: Slope of the regression line used in calibration (k)
Column 7: Intercept of the regression line (Offset)
Column 8: Minimum recommended flow rate (GPM)
Column 9: Maximum recommended flow rate (GPM)
Column 10: Pulse rate at minimum flow (Hz)
Column 11: Pulse rate at maximum flow (Hz)

The calibration constants in Columns 6 and 7 relate frequency (Hz) to flow rate (GPM) in the equations:

$$\text{Freq(Hz)} = \frac{\text{GPM}}{K} - \text{Offset}$$

$$\text{GPM} = k\,(\text{Hz} + \text{Offset})$$

1 Sensor #	2 Mat'l	3 Nom. Pipe	4 Pipe OD	5 Pipe ID	6 K	7 Offset	8 GPM min	9 GPM max	10 Hz min	11 Hz max
400200	PVC	1/2 #80	.0840 in	0.546	0.413	0.3496	0.75	15.00	1.46	35.97
401200	PVC	3/4 #80	1.050 in	0.824	0.5735	0.2638	1.75	35.00	2.78	60.76
402200	PVC	1 #80	1.315 in	0.957	0.6134	0.1826	2.25	45.00	3.48	73.17
410200	PVC	1/2 #80	.0840 in	0.546	0.1421	0.8474	0.18	6.00	0.48	41.37
411200	PVC	3/4 #80	1.050 in	0.824	0.3287	0.2159	0.40	13.00	1.00	39.33
400300 400400 400500	PVDF	1/2"	20mm (0.787in)	16.2mm (0.638in)	0.5987	0.0008	1.00	20.00	1.66	33.40
401300 401400 401500	PVDF	3/4"	25mm (0.984in)	21.2mm (0.835in)	0.613	0.02664	1.75	35.00	2.82	57.06
402300 402400 402500	PVDF	1"	32mm (1.260in)	27.2mm (1.071in)	0.6266	0.0314	3.00	50.00	4.75	79.76
410300 410400 410500	PVDF	1/2"	20mm (0.787in)	16.2mm (0.638in)	0.1445	0.4841	0.25	8.00	1.24	54.87
411300 411400 411500	PVDF	3/4"	25mm (0.984in)	21.2mm (0.835in)	0.3195	0.4679	0.40	14.00	0.78	44.28

Calibration Table

Data Industrial®

Please see our website at **www.badgermeter.com** for specific contacts.

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