Operational Experiences Proving Mass Flow Meters with Small Volume Provers

Presented at:
Energy Week Conference and Exhibition
February 1, 1996

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Introduction

Small Volume Provers were introduced several decades ago, and numerous papers have been presented covering the technical and empirical operation of these provers. During this time, mass flow meters based upon the Coriolis effect have evolved. The measurement accuracy of these meters has continually improved to the degree that the Hydrocarbon Industry is closely evaluating them for custody transfer measurement.

Flow meters used in custody transfer measurement normally require some means of verification, which is generally referred to as "meter proving." Meter proving methods for traditional volumetric meters are well established, while those for mass flow meters are still evolving.

Coriolis mass flow meters are fundamentally different from traditional custody transfer meters. Therefore, a basic understanding of the principles of operation is necessary to properly prove mass flow meters.

This paper will focus on the basic knowledge needed to prove mass meters, with actual case histories to demonstrate operational experiences with small volume provers.

Understanding the Coriolis Meter

A Coriolis meter is different from other meters in that it requires two primary components: the sensor (the pipe tube in which the fluid flows) and the transmitter (the electronics which processes sensor outputs) to provide the flow and density outputs. The transmitter is typically programmable with at least the calibration information specific to the sensor and the desired signal output range.

The pulse output from most meters is commonly referred to as a K-factor. The K-factor for a Coriolis meter does not define its calibration, as it does with other meters, and should not be used to adjust for any errors. Coriolis meter K-factors are typically scalable and are based upon the time conversion of the flow rate output. They are usually in multiples of ten (e.g., 10, 100, 1000) or six (e.g., 6, 60, 600, 6000) and are not expressed as a K-factor, but as a frequency/flow rate setting (e.g., 100 Hz = 100 lb/min). The

FIGURE 1

K-Factor Scaling

Prover Data
Volume: 20.04270 gal
Temperature (ºF): 96.8
Pressure (psig): 25.53

Meter Data
Base K: 6.00 P/lb
Size: 3"
Temperature (ºF): 96.8
Pressure (psig): 25.53

Frequency Setpoint: 750 Hz
Flowrate Setpoint: 7500 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
166.30703	167.60882	0.99223	972.546	98.018	6.05
166.30497	167.63564	0.99206	973.876	98.169	6.05
166.30286	167.55110	0.99255	973.913	98.124	6.05
166.30047	167.59063	0.99230	974.179	98.176	6.05
166.29887	167.63279	0.99204	975.901	98.375	6.05
Average: 166.30284	167.60380	0.99224	974.083	98.173	6.05

Repeatability: 0.05140% Average number of pulses **1,005.62**

K-Factor Scaling

Prover Data
Volume: 20.04270 gal
Temperature (ºF): 96.8
Pressure (psig): 25.53

Meter Data
Base K: 60.0 P/lb
Size: 3"
Temperature (ºF): 96.8
Pressure (psig): 25.53

Frequency Setpoint: 7500 Hz
Flowrate Setpoint: 7500 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
166.34738	167.62244	0.99239	975.288	982.787	60.46
166.34444	167.61218	0.99244	974.264	981.713	60.46
166.34291	167.67281	0.99207	975.721	983.546	60.48
166.34123	167.61102	0.99242	974.873	982.339	60.46
166.33771	167.66470	0.99209	974.856	982.657	60.48
Average: 166.34273	167.63663	0.99228	975.000	982.609	60.47

Repeatability: 0.03729% Average number of pulses **10,058.2**

ability to scale a K-factor without changing the meter calibration is demonstrated in Figure 1.
A Coriolis meter also has the unique ability to determine density independently of mass flow. The complete calibration of the meter is defined by, and typically expressed as, the density and flow calibration factors. Adjustments for errors in a meter's calibration should be made to the respective measurement factor that is incorrect.

Proving Expectations

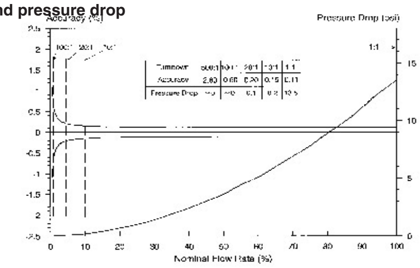
Due to the Coriolis meter's unique characteristics and capabilities, there is a significant amount of misunderstanding in what to expect from this instrument when trying to "prove it" to current standards. This has been due, in part, to the lack of information and guidance available, especially from the meter manufacturers.

A specification sheet will provide more details on a meter's capabilities. They do vary, depending upon the manufacturer, model, and pressure rating. Figure 2 is an example of a new, more informative specification sheet expressing the meter's accuracy, based upon its flow rate and/or turndown. Additional information of this kind on different models of meters would be extremely useful.

FIGURE 2

Performance Specifications

accuracy, turndown, and pressure drop



Flow

Nominal flow range	Accuracy[1]	Repeatability
0 to 1600 lb/min (0 to 43,550 kg/h) **Maximum flow rate** 3200 lb/min (87,100 kg/h)	**Liquid** + 0.10% + [(zero stability / flow rate) x 100]% of rate **Gas** + 0.5% + [(zero stability / flow rate) x 100]% of rate	**Liquid** + 0.05% + [1/2(zero stability / flow rate) x 100]% of rate **Gas** + 0.25% + [1/2(zero stability / flow rate) x 100]% of rate
	Zero stability 0.08 lb/min (2.18 kg/h)	

[1]Accuracy includes the combined effects of repeatability, linearity, and hysteresis. All specifications are based on

One of the first problems usually encountered is that the meter has been installed in an application in which no other type of meter could be proved. This is normally due to one of several conditions, such as widely varying flow, changing density, product flowing at or near equilibrium pressure, or pulsation occurring at the measurement station. These conditions should be avoided, because the quality of the proving results from Coriolis meters is dependent upon flow conditions which are consistent with accepted practices.

Another feature unique to these meters, and one that directly affects proving results, is called the "meter zero." Attaining a proper zero procedure can be difficult because most installations have not made provisions for it. To zero a meter, it must be completely full of the operating fluid, which is free of any entrained gases, and there must be no flow. To repeat, there can be absolutely no flow through the meter for a proper zero. A zero is typically achieved by pushing a button on the transmitter. Variations in the meter zero are the result of changes in pipe stress, temperature, external vibrations and improper zeroing.

So can acceptable results be obtained? Yes, they can, with optimum pipe and flow conditions, and correct meter zeroing, as illustrated in Figures 3 and 4. These illustrations are not meter provings, but rather they are calibrations at 20, 40, 60, 80, & 100% of the meter output range, on the same meter, performed four months apart. The quality of these results is impressive, but not necessarily consistent with the majority of meters we have calibrated. Although there are many meters that perform comparably, further research and development is needed to bring the performance of all Coriolis meters to this level.

FIGURES 3 & 4

Figure 3

Prover Data
Volume: 0.05070 bbl

Temperature (ºF): 67.2
Pressure (psig): 27.04

Meter Data
Base K: 600.00 P/lb

Size: 1"
Temperature (ºF): 67.2
Pressure (psig): 27.04

Frequency Setpoint: 2000 Hz
Flowrate Setpoint: 200 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
17.74373	17.74154	1.00012	197.402	1973.81200	599.93
17.74346	17.73774	1.00032	152.299	1522.52550	599.81
17.74347	17.74517	0.99990	130.141	1301.56325	600.06
17.74335	17.74198	1.00008	84.724	847.19498	599.95
17.74308	17.73800	1.00029	46.029	460.16827	599.83
Average:					
17.74342	17.74089	1.00014	122.119	1221.053	599.92

Repeatability: 0.04199% Average Error %: –0.01

Figure 4

Prover Data
Volume: 2.12944 gal

Temperature (ºF): 94.3
Pressure (psig): 31.61

Meter Data
Base K: 600.00 P/lb

Size: 1"
Temperature (ºF): 94.3
Pressure (psig): 31.61

Frequency Setpoint: 2000 Hz
Flowrate Setpoint: 200 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
53.05326	53.05115	1.00004	41.214	412.138	599.98
53.04866	53.02615	1.00042	83.314	832.802	599.75
53.04443	53.02617	1.00034	117.914	1178.763	599.79
53.04014	53.02197	1.00034	156.995	1569.451	599.79
53.03643	53.03104	1.00010	199.912	1998.964	599.94
Average:					
53.04458	53.03130	1.00025	118.870	1198.424	599.85

Repeatability: 0.03799% Average Error %: –0.02

Small Volume Provers

Small volume provers are probably the most practical and acceptable type of proving devices available. The gravimetric method of proving Coriolis meters is not practical in pipeline applications, and commonly lacks the accuracy required for high flow rate applications. Sophisticated computer based electronics, which are more commonly used on small volume provers, give them an advantage over conventional ball provers. They also have a greater range of fluid compatibility, and reduced fluid disposal quantities, which minimizes the potential for environmental problems.

Recent publications on proving Coriolis meters with small volume provers suggest that these provers have trouble with pass-to-pass repeatability. They recommend pass averaging (i.e., ten to fifteen passes averaged into one run) to compensate for repeatability problems. To date, we've found that achieving repeatability has not been a problem and there has been no need to average a large number of passes. A typical single-pass proving is illustrated in Figures 1 and 3, and a three-pass average in Figure 4. Obtaining repeatability in proving Coriolis meters can be more complicated than in proving other meters. Problems associated with achieving repeatability should not be obscured by averaging large amounts of data, but rather identified and eliminated.

Case Histories

The three case histories presented are of provings using a small volume prover in actual pipeline applications. Case History I demonstrates that, with the correct methods and equipment, good results can be achieved even in an extreme application. Case History II involves a routine application using a prover of a different size than the first case history, and indicates that consistent results are obtainable using the single-pass method. Case History III illustrates the accuracy of the meter and proving in a bidirectional application.

Case History I (Figure 5):

This proving was performed on a 1.5" Coriolis meter measuring liquid carbon dioxide on a pipeline. The operating conditions were rather extreme for this product, since a stable density was difficult to maintain. A smaller than normal prover (e.g., two gallons) was used to obtain stability more quickly, and to maintain that stability. The product density was approximately 0.427 gm/cc.

Once stability had been achieved, a good proving was obtained. This proving used a three-pass average method to get better than 0.05% repeatability over five consecutive runs.

CASE HISTORY I

Figure 5

Case History I

Prover Data

Volume: 2.12944 gal

Temperature (ºF): 107.7

Pressure (psig): 1344.98

Meter Data

Base K: 180.00 P/lb

Size: 1.5"

Temperature (ºF): 107.7

Pressure (psig): 1344.98

Frequency Setpoint: 2500 Hz

Flowrate Setpoint: 833.33 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
22.81231	22.74201	1.00309	352.003	1052.861	179.45
22.81443	22.74123	1.00322	353.280	1056.465	179.42
22.81394	22.74300	1.00312	353.474	1057.151	179.44
22.81912	22.74536	1.00324	351.952	1052.469	179.42
22.74675	22.68354	1.00279	352.660	1055.066	179.50
Average:					
22.80131	22.73103	1.00309	352.679	1054.802	179.45

Repeatability: 0.04486%

Average Error %: –0.31

Case History II (Figure 6):

This case history involves a truck loading rack station measuring a refined hydrocarbon product. Loading rack applications usually offer good flow and product stability, as in this situation. This proving used a fifteen-gallon prover to achieve 0.045% repeatability on a product with a density of 1.048 gm/cc.

The single-pass method was used in this proving and it demonstrates that multiple pass averaging is not always necessary, and may actually be the exception.

CASE HISTORY II

Figure 6

Case History II

Prover Data

Volume: 15.02207 gal

Temperature (ºF): 74.0

Pressure (psig): 19.91

Meter Data

Base K: 60.00 P/lb

Size: 3"

Temperature (ºF): 74.0

Pressure (psig): 19.91

Frequency Setpoint: 5500 Hz

Flowrate Setpoint: 5500 lb/min.

Prover Mass	Meter Mass	Meter Factor	Flow Rate lb/min	Meter Fequency Hz	Meter Net K P/lb
131.34136	131.32254	1.00014	1746.915	1746.70769	59.99
131.34140	131.31449	1.00020	1746.949	1746.63359	59.99
131.34142	131.36154	0.99985	1748.319	1748.62937	60.01
131.34144	131.30050	1.00031	1747.490	1746.98788	59.98
131.34147	131.32496	1.00013	1746.890	1746.71358	59.99
Average:					
131.34142	131.32481	1.00013	1747.313	1747.13400	59.99

Repeatability: 0.04599%

Average Error %: –0.01

Case History III (Figures 7 and 8):

The question often arises about the accuracy of a Coriolis meter in the reverse or a bidirectional flow situation. This case history demonstrates the results of that type of proving.

The provings were volumetric rather than mass, at the request of the operator. The data was taken at a fifteen-day interval with a 35% change in flow. The results of these tests are excellent, considering the degree of flow and direction of flow change.

The three-pass average method was employed on this proving of an LPG product at a pipeline station.

CASE HISTORY III

Figure 7

Case History III – Forward Flow

Prover Data
Volume: 0.47721 bbl

Temperature (ºF): 88.7
Pressure (psig): 1180.84

Meter Data
Base K: 3600.06 P/bbl

Size: 3"
Temperature (ºF): 88.7
Pressure (psig): 1180.84

Frequency Setpoint: 1500 Hz
Flowrate Setpoint: 1500 bbl.hr

Prover Volume bbl	Meter Volume bbl	Meter Factor	F*low Rate bbl/hr	Meter Fequency Hz	Meter Net K P/bbl
1.43278	1.43271	1.00005	351.906	351.89360	3599.87
1.43278	1.43208	1.00049	345.924	345.76135	3598.30
1.43278	1.43208	1.00049	342.928	342.76533	3598.29
1.43278	1.43215	1.00044	339.705	339.56193	3598.48
1.43278	1.43212	1.00046	338.257	338.10595	3598.40
Average:					
1.43278	1.43223	1.00039	343.744	343.61763	3598.67

Repeatability: 0.04398%

Average Error %: –0.04

Figure 8

Case History III – Reverse Flow

Prover Data
Volume: 0.47721 bbl

Temperature (ºF): 91.9
Pressure (psig): 1105.57

Meter Data
Base K: 3600.06 P/bbl

Size: 3"
Temperature (ºF): 91.9
Pressure (psig): 1105.57

Frequency Setpoint: 1500 Hz
Flowrate Setpoint: 1500 bbl/hr

Prover Volume bbl	Meter Volume bbl	Meter Factor	Flow Rate bbl/hr	Meter Fequency Hz	Meter Net K P/bbl
1.43276	1.43262	1.00009	532.996	532.95462	3599.72
1.43276	1.43241	1.00024	532.765	532.64645	3599.20
1.43276	1.43220	1.00039	532.345	532.14666	3598.66
1.43276	1.43284	0.99994	532.531	532.57066	3600.27
1.43276	1.43255	1.00015	534.026	533.95647	3599.53
Average:					
1.43276	1.43252	1.00016	532.933	532.85497	3599.48

Repeatability: 0.04499%

Average Error %: –0.02

Conclusion

This paper has provided information derived from actual operational experiences to demonstrate that Coriolis meters can be properly proven or calibrated using small volume provers. In addition, this information should provide some insight as to the type of results that are achievable by this method and which should be attained by other methods.

References:

American Petroleum Institute, " Manual of Petroleum Measurement Standards," Chapter 4, Proving Systems, Section 3, Small Volume Provers.

Apple, Cathy, " Proving Coriolis Flow Meters," presented at the 70th International School of Hydrocarbon Measurement, Oklahoma City, Oklahoma, May 16-18, 1995.