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Best Practices for Proving Coriolis Meters with Small Volume Provers

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Abstract

Coriolis meters have many advantages for mass flow and volumetric measurement in a wide variety of applications. Inherent reliability, linearity, and stable meter factor (MF) on a wide variety of products make them an ideal choice for pipeline transfer. With the recent introduction of high flow rate meters, Coriolis technology can now be used in line sizes up to 16”. Custody transfer of products is very common in these large pipelines; in many applications contractual requirements dictate that meters be proved in situ periodically to ensure accurate measurement over time and/or product changes.

Traditionally, large pipe provers have been employed at metering stations. The overall size of a pipe prover and the maintenance costs of the complex four-way valve integral to a bi-directional pipe prover can be a concern. Small volume “piston-type” provers are becoming more common because they have a much smaller foot-print and reduced maintenance costs. Even the largest small volume provers are small (as much as 10 times smaller) compared to pipe provers of similar flow capacity. Small volume provers tend to perturb the flow rate when the piston launches. Because the measuring volume of a small volume prover is so much smaller, this rate change caused by the operation of the prover becomes an integral part of the proving cycle that is measured by the metering device.

Proper sizing of a small volume prover to pair with a Coriolis meter(s) can result in greater proving efficiency, optimum prover size, and reduced maintenance on the prover. This selection and pairing process is especially important when using small volume provers to prove high-precision, high-flowrate Coriolis meters. Data collected to validate Coriolis meter performance with small volume provers in lab testing and field proving has been analyzed to determine which procedural and design factors yield the best results. This analysis has resulted in the development of the concept called “Total Prove Time” (TPT).

In addition, proving methods that apply incremental uncertainty analysis to determine when proving is completed will afford operators the opportunity to attain even greater efficiency. This method of proving involves continuing to collect runs until the repeatability that is equivalent to a meter factor random uncertainty of better than ±0.027% has been reached. This method is outlined in the American Petroleum Industry (API) Manual of Petroleum Measurement Standards (MPMS) Chapter 4.8, Second Edition, Operation of Proving Systems, Annex A, Evaluating Meter Proving Data.

The TPT concept is simple to apply and useful for selecting a small volume prover and Coriolis meter to achieve maximum freedom of choice between prover size selection and operational trade-offs including wear and tear. Diagnostic tools for enhancing overall measurement systems design, troubleshooting, and assessing future pipeline capacity expansions are another benefit that have resulted from this research.

1. Introduction

Proper sizing of a meter prover and flow meter(s) can result in greater proving efficiency, minimum prover size and cost for stationary provers, and reduced wear and tear on the prover. This selection process is exceptionally important when using small volume provers to prove high-precision, high-flowrate meters. Data collected to validate Coriolis meter performance with small volume provers in lab testing and field proving has been analyzed to determine which procedural and design factors yield the best results. This analysis has resulted in the development of the concept called "Total Prove Time" (TPT). The TPT concept is a useful tool for pairing a small volume prover with a high-precision, high-flowrate meter to achieve maximum freedom of choice between prover size selection and operational trade-offs including wear and tear.

In addition, proving methods that apply incremental uncertainty analysis to determine when proving is completed will afford operators the opportunity to attain even greater efficiency. This method of proving involves continuing to collect runs until the repeatability that is equivalent to a meter factor random uncertainty of better than ±0.027% has been reached. This method is outlined in the *American Petroleum Industry (API) Manual of Petroleum Measurement Standards (MPMS) Chapter 4.8, Second Edition, Operation of Proving Systems, Annex A, Evaluating Meter Proving Data*.

2. Basics of Meter Proving

There are three main reasons to prove meters:

- To make the meter measure accurately using a traceable Meter Factor.
- To determine how much different process conditions affect the Meter Factor.
- To assess the proving data as a diagnostic of meter health.

Meter proving establishes a Meter Factor (MF) that reflects the accuracy performance of the meter under actual application conditions and with the actual fluid(s) that are being metered. The MF is determined by how the meter indicates flow compared to a traceable flow measurement field reference standard. The MF is applied to future measurements so that the meter indications will reflect traceability to the prover. Proving must be done on an ongoing basis to establish the MF over time for those metering technologies that may drift due to meter wear.

It is important to prove a meter at all the different conditions that it will see in service. If different flow rates will occur, proving should occur at each flow rate. If different fluid products will be metered, as in multi-product pipelines, proving should be done with each fluid. Proving at all conditions and on all fluids will reveal whether or not the MF will be the same or different as conditions change. If the MF changes as conditions change, it will be necessary to apply an array of different Meter Factors to apply the correct one for current conditions each time the conditions change.

Analysis of meter proving data patterns can provide indications of when a meter may need repair or replacement. For example, if the repeatability of the proving data should suddenly become more erratic, or if an uncharacteristically large shift in the average MF compared to the last proving should occur, this would normally be a good indicator that the meter should be thoroughly inspected and/or refurbished.

Two important metrics are applied to judge the quality of proving results:

- Repeatability
- Reproducibility

Repeatability is a measure of short-term variability in the proving data from each proving event. Repeatability performance is critical because it is used during proving to decide whether the prove has been successful or has failed to comply with the minimum standards as defined by industry standards such as the *American Petroleum Institute Manual of Petroleum Measurement Standards Chapter 4.8 (API MPMS Ch. 4.8) Operation of Proving Systems, Second Edition*.

API MPMS Ch. 4.8 prescribes several different methods that can be applied to assess the repeatability of proving data. All are designed to ensure that the uncertainty of the average meter factor that is the result will be 0.027% or better. If repeatability fails, it is common practice to discard the data and start over with a new proving attempt.

Reproducibility is the long-term stability and variation of the Meter Factors that were found for a meter resulting from a long series of proving events over time. Reproducibility is also critical because it is the best indication of how accurately the meter is measuring product during all the time that it is in service between proving events. If the MF that results changes from one proving event to the next, this should be a concern because this indicates that the true measurement accuracy may also be varying considerably on an ongoing basis.

The variation in MF from one prove to the next (i.e., reproducibility) is typically not used to decide whether to reject any one set of proving data in the same way that the repeatability is used. However, many meter operators will define limits on the reproducibility variation that will result in action being taken, such as meter inspection and/or replacement if the MF value varies by too much from one prove to the next.

The reproducibility is also the only indicator of how wear and tear over time may be affecting the meter measurement accuracy. The repeatability will not reveal this because it is based entirely on a set of data that is all collected over a relatively short period of time (i.e., one proving event).

Proving methods fall into two main categories and several sub-categories:

- Fixed-volume static provers
- Fixed-volume dynamic provers
  - Ball / Pipe conventional provers
    - Bi-directional
    - Uni-directional
  - Compact/Small-volume provers
- Master meter provers
  - Volume meter (e.g., PD, turbine)
  - Coriolis meter (for mass and/or volume)

An example of a small volume prover is shown in Figure 1. The subject of this study focuses on fixed-volume dynamic provers and how they interact and perform with high-precision, high-flowrate meters while proving.

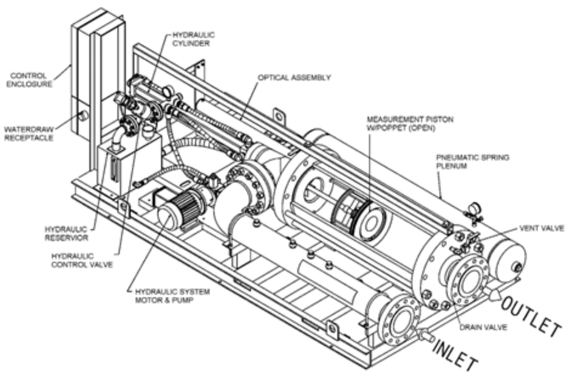

Figure 1: Small Volume Prover [1].

By their nature, fixed-volume dynamic provers are constrained to collecting data only during each pass of the displacer (i.e., the ball or the piston). Furthermore, as the flow rate becomes higher, the time that it takes for each pass of the displacer in a fixed-volume prover gets shorter and shorter as shown in Figure 2. It is the statistical analysis of this type of data that is of greatest interest here.

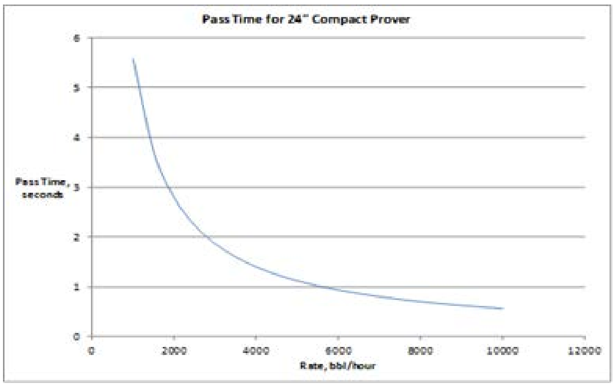

Figure 2: Pass Time vs. Flow Rate [1].

Proving with a master meter is not constrained by a fixed volume. Because the size of each proving run can be made as long or as short as desired with a master meter proving system, the fundamental concerns of this study do not apply.

3. Importance of Meter Response Speed with Small Volume Provers

Proving can present many challenges. The flow rate and other conditions must remain stable to ensure good repeatability. However, it is often quite possible that the proving equipment may cause unintended instability in the flow rate. For example, if a proving sphere is over-inflated, this can result in jittery flow as the ball slides past the walls of the pipe prover. Even more commonly, a small volume prover can cause a sudden change in the hydraulic resistance of the prover system when the poppet valve in the displacer closes to launch a proving pass. This change in the pressure drop across the displacer can result in a sudden change in the flow rate through the entire system, including the meter.

Meters must have sufficient speed of response to be able to prove successfully in situations where the flow rate is unstable during proving runs. Figure 3 shows an example of sufficient meter speed of response. In this case, the indicated rate has caught up to the true flow rate prior to the displacer reaching the first detector switch D1, so all the data collected between the two detector switches D1 and D2 is valid because it represents a period while the meter is indicating the true flow.

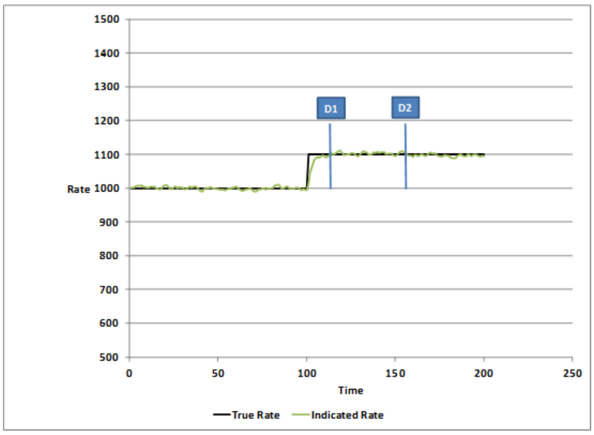

Figure 3: Sufficient Speed of Response [1].

Conversely, Figure 4 shows an example where the meter has insufficient speed of response. In this case, the indicated rate is still approaching the true flow rate as the displacer reaches the first detector switch D1. The total volume indicated by the meter for the period when the displacer is between the two detector switches D1 and D2 will be missing a small amount that is equal to the difference between the true flow rate and the indicated rate for the time that it takes for the meter indication to catch up to the true flow rate.

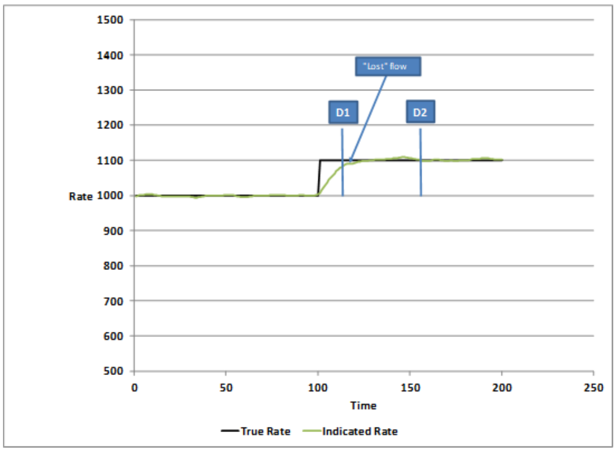

Figure 4: Insufficient Speed of Response [1].

The speed of response that will be required depends on the time that it takes for the displacer to reach the first detector switch D1 after it has been launched. This time and the related volume are known as the "pre-run" of the prover.

Mechanical meters (e.g., PD, turbine) have speed of response that is dependent on the inertial damping which will determine how quickly the angular momentum of the mass of the rotating elements of the meter can respond to changes in the flow rate.

Coriolis and Ultrasonic meters output manufactured pulses that are produced by microprocessor electronics to represent the measured flow. These manufactured pulses are subject to the response rate of the meter electronics signal processing speed and any additional delay selected by electronic filtering/damping settings. Electronic filtering/damping settings in these types of devices should be set to respond as fast as possible for proving applications. However, this will lead to the flow indication being noisier. Noisier flow indication can lead to repeatability issues if the prover pass time gets shorter due to a smaller prover size and/or an increasing flow rate.

4. Prior Meter Testing

Prior studies on this subject [1] have analyzed data collected with small volume provers together with large Coriolis meters in both laboratory and field environments. Some of this earlier work was done to establish good estimates for the noise levels of flow meter indication as a function of flow rate and meter size.

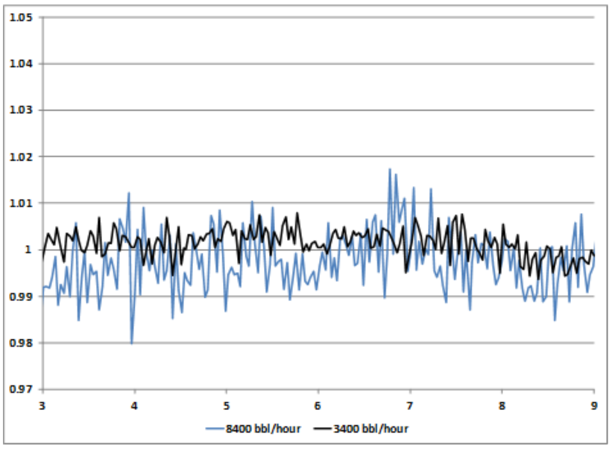

Figure 5: Normalized Noise Levels and Increasing Flow Rate [1].

These estimates have demonstrated that the normalized flow indication as shown in Figure 5 will consistently have an increasing noise level as the flow rate increases. A good correlation has been observed between the velocity of the fluid passing through the meter's flow tubes and the noise level of the flow indication when the meter damping is set for the fastest possible speed of response.

5. Estimated Minimum Total Prove Time (TPT) and Prover Sizing

The uncertainty of the average of the flow total output by a meter during the period of a single pass of a prover displacer is a function of the time duration of that prover pass and the standard deviation of the meter flow indication noise. This relationship is shown in equation (1) where σ is the standard deviation of the flow indication, and n_{pass} is effective number of flow readings computed by the meter in the time that it takes for the displacer to pass between the two detector switches, which is also the time interval during which pulses from the meter are being counted.

$$U_{pass} = \frac{2\sigma}{\sqrt{n_{pass}}} \qquad (1)$$

The uncertainty of the meter factor that results from a proving event is equal to the uncertainty of the average of the meter factors from all the runs taken. The uncertainty of each run was estimated by equation (1). One way to estimate the combined uncertainty of the average meter factor from a proving event is shown in equation (2) where n_{prove} is the effective number of flow readings for each pass (n_{pass}) times the total number of passes taken for the prove.

$$U_{prove} = \frac{2\sigma}{\sqrt{n_{prove}}} \qquad (2)$$

Together, equations (1) and (2) illustrate that the uncertainty of the average Meter Factor from a proving can be related to two factors:

- The noise level of the indicated flow output, and
- The total amount of time that data is collected from the meter.

The noise level of the indicated flow signal can be predicted from experience and testing at different flow rates through different flow meter sizes and geometries. With these predicted noise levels, it becomes possible to construct a model for predicting the minimum amount to total data collection time that may be needed to achieve the 0.027% uncertainty for the MF that is the goal of proving, as described in API MPMS Ch. 4.8. This total amount of accumulated time for data collection during a prove is referred to as Total Prove Time (TPT) and is defined in equation (3).

$$TPT = \frac{Base\ Prover\ Volume\ (BPV)}{Flow\ Rate} \times (\#of\ runs) \times (\#of\ passes\ per\ run) \qquad (3)$$

With TPT defined in this way, it becomes possible to state the estimated minimum TPT that will be required to pass API requirements and thus achieve 0.027% MF uncertainty. It is important to note that estimated minimum TPT values are based on the anticipated flow indication noise levels observed during past experiences and testing, and that these numbers are conservative. In applications where the flow noise is less than the norms observed in the past, it may be possible to meet API repeatability requirements with less TPT than was estimated.

There are two methods whereby an estimated minimum required TPT could be used to help size the flow meter and the prover to work well together in a measurement system. The first method is to start by settling on a total number of passes that will be taken during proving and then calculate the Base Prover Volume (BPV) that will be needed to pass repeatability 95% of the time with that number of passes. This relationship is shown in equation (4).

$$BPV = \frac{TPT \times Flow\ Rate}{(\#of\ runs) \times (\#of\ passes\ per\ run)} \qquad (4)$$

The second method is to start by selecting a desired prover size and then use that to calculate the total number of passes that will be needed to pass repeatability at that flow rate with a prover of that size using equation (5).

$$(Total\ \#of\ passes) = TPT \times \frac{Flow\ Rate}{(BPV)} \qquad (5)$$

Once the total number of passes is known, this will either be equal to the total number of runs in the case where each run will consist of a single pass, or the total number of runs that will be needed can be determined by dividing the total number of passes needed by the number of passes that will be averaged per run.

The estimated minimum TPT can also be used as a troubleshooting tool when a measurement system is having problems passing repeatability consistently. By comparing the TPT that is actually being accumulated during a prove during the current process to the estimated minimum TPT stated by the manufacturer, it is possible to gauge how close these two values are to each other. If the actual TPT is close to the estimated minimum TPT, then it is likely that the meter will start passing repeatability by simply adding as many additional passes as it will take to accumulate the estimated minimum TPT. If, however these two values are very far apart, this will be a strong indication that either a larger meter size or a larger prover size or both will be needed to improve the situation.

There are four key points to consider related to these conclusions about the relationship between flow rate, meter size, and TPT:

- A larger prover (BPV) means that, for a given flow rate, the time for each pass of the prover, and thus n_{pass}, will be greater, so fewer passes should be needed to reach n_{prove} and to pass repeatability requirements.
- More passes will mean that n_{pass} can be less, so a smaller prover (BPV) could be possible to use successfully.
- More passes can be added without changing the number of runs per prove if you average multiple passes per run, as explained in API MPMS Ch. 4.8.
- For any given flow rate, a larger meter size will result in a lower velocity flowing through the meter flow tubes and a lower noise level in the flow output, so less TPT should be required. In this way, increasing the meter size could open the door to successful proving with a smaller prover and/or fewer passes than would otherwise be needed.

6. Incremental Uncertainty Analysis for Proving Efficiency

We have seen how each additional run added to a set of proving data has the potential of turning a meter proving that is failing to meet repeatability requirements into a successful proving with a MF uncertainty of 0.027% or better.

Figure 6 shows an example set of five proving runs. These are failing repeatability because the difference between the maximum and the minimum Meter Factors exceeds the tolerance of 0.0005 (0.05%) taken from API MPMS Ch. 4.8 for a MF uncertainty of 0.027%. In fact, the uncertainty of the average MF according to equation (2) would be 0.032% in this case.

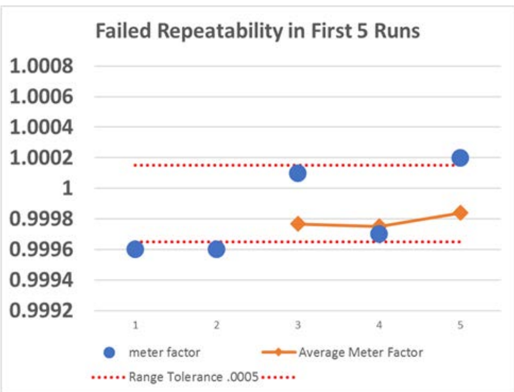

Figure 6: Failing Repeatability with 5 Runs [2].

The same set of five proving runs will pass with the addition of just one additional run as shown in Figure 7. Although the addition of the sixth run has not changed the value of the difference between the maximum and the minimum Meter Factors because this new point falls between those two previous extremes, the result has changed because the tolerance from API MPMS Ch. 4.8 for six data points is now 0.0006 (0.06%). This new wider tolerance still results in the target uncertainty for the average MF of better than 0.027% because the additional run has reduced the uncertainty of the average. In this case, the uncertainty of the average MF according to equation (2) would be 0.025% because of the additional point that was added.

Figure 7: Passing Repeatability with 6 Runs [2].

Figure 8 shows that, with another additional four runs, making a total of ten runs for the prove, the meter passes the repeatability requirements easily because the tolerance from API MPMS Ch. 4.8 to meet a MF uncertainty of 0.027% or better with a set of 10 runs is a difference between the maximum and the minimum Meter Factors not to exceed 0.0012 (0.12%). The uncertainty of the average MF in this case, according to equation (2) would be 0.019%.

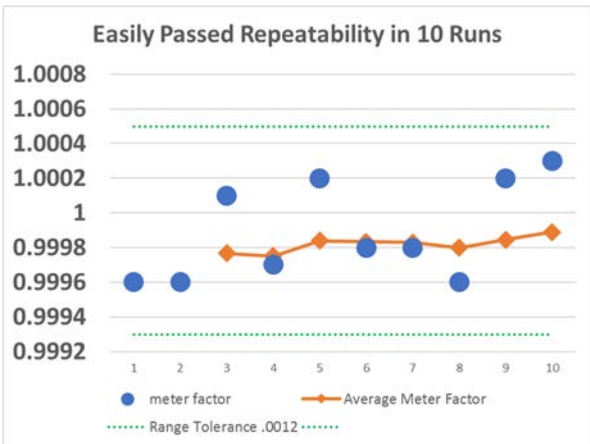

Figure 8: Passing Repeatability Easily with 10 Runs [2].

In Figure 9, the increasing Range Tolerance from API MPMS Ch. 4.8 is shown as expanding while the number of runs increases up to 20. Similarly, the uncertainty of the MF average according to equation (2) continues to decrease as more runs are added until it drops below 0.027% uncertainty. Although the uncertainty of the average MF continues to drop as more runs are added, it is worth noting that the actual average MF value itself changes only negligibly after the first six runs.

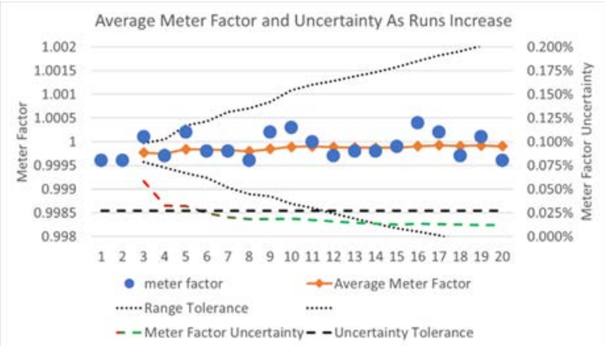

Figure 9: Tolerances and Uncertainty with 20 Runs [2].

A proving method that makes use of the incremental improvement to the average MF uncertainty that comes with each additional point would help to improve efficiency and minimize wear and tear on provers during operation. The basis of the method would be to avoid deciding how many runs or passes to take prior to proving, but instead just continue taking one more run until you reach the point where the 0.027% target uncertainty for the average MF has been reached. This approach would bring three benefits compared to a method that commits to a fixed number of passes and/or runs in advance of proving.

- It will always eventually achieve the target 0.027% average MF uncertainty.
- It will achieve the target uncertainty with the minimum number of passes, saving time and wear on the prover by eliminating unnecessary additional runs.
- It will avoid unnecessary additional runs and wasted data that happens when proving fails to meet repeatability and the process is started over at the beginning.

7. Conclusion

Meter proving is an essential function in some systems used for critical custody transfer and fiscal measurements. Selecting the right equipment and operating and maintaining it properly will enable good traceable measurements with the smallest possible uncertainty. The response speed of the meter and the size of the prover are important variables to consider in system design and operation.

Collecting more data while proving reduces the uncertainty of the Meter Factor. Repeatability during proving is a good measure to ascertain the uncertainty of the meter factor. By using a flexible approach in determining the number of runs to take, the optimum balance between proving efficiency, maintenance costs, and capital cost of equipment can be reached.

References

[1] T. Patten, “Proving Coriolis Meters with Small Volume Provers”, *34th International North Sea Flow Measurement Workshop*, 2016.

[2] M. Buttler, “Pairing Small Volume Provers with High-Precision, High-Flowrate Meters”, *North Sea Flow Measurement Workshop*, 2018.