Master Meter Prover Calibrations Per API MPMS 4.9.3
Class #2510.1

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Introduction:
When discussions about prover calibrations occur, they normally end with a disagreement about the accuracies of the different approved methods. This paper will discuss the procedures and advantages of the master meter method. This method was developed over 20 years ago to minimize difficulties in calibrating very large volume provers. In the fast pace world of today, where down time means money, many companies use the master meter method to save time and money on a variety of prover sizes. Accurate calibrations require good technique from a knowledgeable technician. Having the proper knowledge and equipment to perform the master meter method will improve the accuracy and minimize the time to complete the calibration. This paper will discuss the Master Meter Method of prover calibration as described in API MPMS Chapter 4.9.3.

Master Prover:
A master prover is required in the method to determine a K-factor or meter factor for the master meter. This meter factor and/or K-factor is used to determine the field prover's volume. Prover volume determinations using the master meter method are only as accurate as the calibration performed on the master prover. The master prover volume shall be determined per the current API Chapter 4.9 and 12 standards and must be traceable to NIST or appropriate NMI. Errors in the master prover calibration directly transfer to the volume of the field prover.

Master Meter:
The master meter chosen for this method must produce good reproducibility and repeatability throughout its operating range. The API standards require run repeatability no higher than 0.02% for five consecutive runs and 0.02% deviation between meter factor averages for the pre and post runs sets at the same flow rate. The performance of the master meter should essentially remain unchanged throughout the meter proving runs.

Master meter placement should be close coupled to the field prover to create a single unit with the master prover. It is typically referred to as the master meter prover system.

Field Prover (prover under calibration):
The field prover should be a displacement prover. Any and/or all inspections of the field prover should be performed prior to calibration. Inspect and verify that there is no damage to the prover, 4-way valve, switches, and etc. Inspections should include all piping, valves, drains, and vents. Verify that each drain and vent valve can be checked for leaks prior to starting and during the calibration process. If these valves cannot be checked, each valve should have a blind installed or disconnected so that there is no possibility of leakage. For sphere provers, verify the condition and size of the ball if at all possible. For piston provers, the seals should be checked for wear or damage. Switches should be inspected, cleaned, or replaced if necessary. If the proper steps are taken during the inspection process, the calibration will go smoother.

If the calibration is to be performed on the same product (fluid) as used during normal operations, field prover cleaning may not be required or needed. Aside from the cost savings, the advantage of "NOT" cleaning the prover is that it accounts for any foreign pipe wall coating (typical in heavy crude application) that may have decreased or changed the volume of the prover. Cleaning the prover prior to calibration can produce a volume different than the actual operating volume, and thus an error or bias occurs. Pre-Calibration Process:

Before the actual process begins, one should consider and review the flow rates and operating conditions that the process will incur. All of these must be compatible with the master meter prover system. Prior to the calibration, select a flow rate range that will result in the best performance of the master meter. Typically, a master meter's performance is best in its upper flow range.

Our system uses a 4" PD meter. Its best performance is from 600 and 1000 BPH. Therefore, when operating conditions allow, we will perform the prover calibration at 1000 BPH for the high rate and 750 BPH for the low rate.

Pressure and temperature considerations should also be made to maximize the master meter's performance. Also, they should not vary during the process.

The master prover, master meter, and field prover should be aligned in series and coupled as close as possible. This ensures that all product/fluid passing through the field prover passes through both the master meter and master prover. Varying temperatures and pressures have a tremendous effect on the calibration results. Take all precautions possible to stabilize the conditions under which the calibration takes place. Stabilizing operating conditions is the biggest factor in determining how well this method of calibration turns out.

In situations where the main line flow rates are above the master meter's range, it is common to slip stream flow through the field prover and the master meter system from the main line. An example would be that the main line flow is higher than 2000 BPH. To obtain flow rates in the master meter's range, the main line block and bleed valve is used to divert the desired flow to the field prover by partially closing it so that only 1000 BPH flows to the field prover and master meter system.

To start the process, connect the master meter prover system (MMP) to the main line. An example is in Figure 1 below. Begin to fill the MMP with product. Once the system is full and completely pressurized, establish flow. Next adjust flow to the highest intended rate. Perform temperature and pressure checks to determine stabilization. While operating conditions are stabilizing, preliminary runs can be made on the master meter. Preliminary runs speed up the stabilization process and also help remove any air in the system. Open and check all high point vents to ensure all air is removed and no air remains in the entire system. Also make several passes on the field prover to stabilize temperature and again remove air. While the field prover pre-runs are being made, verify that all valves including the 4-way have no leaks. Special attention should be given to valves that may bypass product between the field prover and the MMP. Once these steps are completed, the calibration process can begin.

Calibration Sequence:

A. Verify the target flow rate #1 has been achieved and perform the operations below at that rate.

- Start the pre-master meter prove. Make five consecutive runs with the master prover that result in meter repeatability within 0.02% and determine the average master meter factor.

- Begin field prover volume determination #1 by making three consecutive proving runs on the master meter using the field prover. These three runs must be within 0.02%. Remember when calibrating a bidirectional prover, a run consist of the sum of both forward and reverse directions. During these runs, the flow rate must be within 5% of the pre and post runs of the master meter. Flow rate adjustments are common due to different flow characteristics of each prover.
- Once the field prover runs are complete, begin the post master meter prove. This prove must again be five consecutive runs that repeat at 0.02%. The average meter factor from the pre and post master meter proves must be within +/- 0.02%. This completes calibration set #1.

B. Calibration set #2 has to be performed at a different flow rate. This flow rate must vary from set #1 by 25% of the highest rate used in the calibration. Typically this rate is at a lower flow rate than set #1.

- Begin pre-master meter prove set by making five consecutive runs with 0.05% repeatability using the master prover. Establish a pre-run meter factor at this second flow rate.
- With pre-master meter prove complete, start three consecutive field prover runs on the master meter. These runs must have a repeatability of 0.02%.
- Begin the post master meter prove by making five runs with 0.02% repeatability at flow rate #2. Verify that the average meter factors of pre and post runs are within 0.02%. Verify the flow rate between the pre and post runs are within 5% of the field prover runs.

C. A third set of calibration runs are now required. Typically these runs are performed at or near the flow rate of the first set, if it is the higher rate. Flow rate #3 does not have to be at the #1 rate, but it has to vary from #2 by 25% of the highest flow rate. Therefore, you could decrease the flow rate by 25% instead of increasing it. The main key in making this decision is to consider the accuracy of the master meter at the third rate selected. Once that rate is selected, change the actual flow rate of the system to the third rate and begin the process.

- Begin pre-master meter prove set by making five consecutive runs with 0.05% repeatability using the master prover. Establish a pre-run meter factor at the third flow rate.
- With pre-master meter prove complete, start three consecutive field prover runs on the master meter. These runs must have a repeatability of 0.02% and the flow rate within 5% of the pre- master meter prove flow rate.
- Begin the post master meter prove by making five runs with 0.02% repeatability at flow rate #3. Verify that the average meter factors of pre and post run are within 0.02%. Verify the flow rate between the pre and post runs are within 5% of the field prover runs.

Three requirements that make this method difficult are:

1. Each set of proving runs has its repeatability and reproducibility specifications that must be met. If any of the specifications are not met, then the calibration has failed and must be restarted and repeated.
2. All proving runs (pre and post runs on the master meter or field prover) must be consecutive.
3. Consecutive proving runs repeatability requirements must be met within:
   a. 10 consecutive runs for either the pre or post runs by the master prover.

b. 6 consecutive runs for the field prover run.

Experiences:
The process begins and ends with the quality of the master meter. Select a meter that performs well. The better the repeatability and reproducibility results a meter can produce, the easier the master meter prover calibration is.

Below is a performance history of a meter we have used. This meter was under daily use on a portable prover for more than two years prior to being selected as master meter. As the table demonstrates, the meter factor variance barely changed over this two year period. Twice during this period there was a problem. During meter inspection, trash was found to have passed through it. The meter was cleaned prior to continuing. Provings during the 2007 to 2009 were on crude or condensate. Operating conditions varied from 70 up to 400 BPH, gravity from 25 to 55 API, and temperatures and pressures varied over a wide range.

PROVING DATE	AV. FLOW RATE	TEMP	PRES	OBSERVED DENSITY	MF	REPEAT-ABILITY	MF VARIATION
2/17/09	114.5	70	39.5	49.4	0.99999	0.005	-0.00048
1/20/09	195.9	72	41.3	55.8	1.00047	0.022	0.00017
11/18/08	265.5	86	42.1	58.1	1.00030	0.012	-0.00019
8/19/08	251.4	86	48.6	42.3	1.00049	0.015	5E-05
7/15/08	190.7	87	53.2	45.4	1.00044	0.016	0.00024
6/17/08	163.8	84	53.1	46.5	1.00020	0.023	-0.00045
5/21/08	127.8	80	47.7	61.1	1.00065	0.003	-0.00022
4/15/08	290	86	44.3	46.8	1.00087	0.003	0.00096
4/3/08	463.5	76.4	12.4	32.5	0.99991	0.016	-9E-05
3/18/08	86.9	78	100.3	55.7	1.00000	8.617	0.00011
2/20/08	159.7	71	57.1	51.7	0.99989	0.023	-0.0009
1/8/08	119.9	72	27.5	56.4	1.00079	0.026	0.00107
12/5/07	171.4	74	14.9	58.4	0.99972	0.008	0.00082
12/4/07	179.3	74	32.7	25.3	0.99890	0.35	-0.00234
11/13/07	129.3	100	77.6	54.4	1.00124	0.036	0.00056
11/12/07	89.1	83	32.7	57.6	1.00068	0.008	-0.00031
11/8/07 PM	79.6	78	27.8	57.8	1.00099	0.011	0.00057
11/8/07 AM	142.4	72	17.7	36.9	1.00042	0.007	0.00011
11/7/07	390.3	80	19.8	36.5	1.00031	0.021	0.00037
11/6/07 PM	152	60	13	58.9	0.99994	0.014	5E-05
11/6/07 PM	222.8	75.7	16.6	36.7	0.99989	0.008	0

As previously discussed, one of the most important attributes to have a successful calibration is to have good procedures and consistency with those procedures. For instance, in choosing the master meter, a lot of meters have a very good repeatability but not necessarily the linearity to achieve 0.02% between pre and post proves if the flow rate or conditions are not exactly the same. So be sure to make flow rate adjustments as necessary to maintain flow deviations of 5% or less at the same operating conditions.

In our procedures, we try to achieve a master meter factor as close to 1.0000 as possible for the pre-runs. This helps to identify problems once field prover runs begin. For example: Any difference in pre-master meter factors and field prover's meter factors indicate that the new or projected field prover's volume will be different by that amount for the current volume. There are numerous issues that may contribute to a difference, but determining there is a possible problem early in the process leads to little or no wasted time.

Decreases in the field meter factor from the master meter factor indicate a leak or leaks associated with the field prover. The true test or verification of a leak will come once a calibration set at a different flow rate occurs. When the flow rate is lowered by 25%, the factor will continue to decrease if there is a leak. Changes are proportional to time as related to the leak.

The runs listed below are from a new field prover where the volume was unknown. Several passes were made to determine the volume of the field prover prior to beginning the calibration. Notice the first set does not repeat, but the meter factor matches the meter factor from the master meter. The second data set was after the flow rate change. The field prover's meter factor at the new flow rate dropped considerably to 0.74493. This drop in meter factor indicates a serious leak. An investigation verified that the prover 4-way valve was leaking.

PULSES N	Run Accepted?		IMF	Flow Rate
108922.252	1	No	0.99797	298.259
108889.099	2	No	0.99828	299.620
108868.083	3	No	0.99848	299.316
108943.356	4	No	0.99780	300.085
108880.246	5	No	0.99838	299.319
108912.608	6	No	0.99808	299.327
108902.607			**0.99817**	**299.321**

PULSES N	Run Accepted?		IMF	Flow Rate
108930.914	1	No	0.74467	191.927
108902.938	2	Yes	0.74486	191.672
108901.022	3	Yes	0.74488	191.315
108890.365	4	Yes	0.74496	190.034
108873.045	5	Yes	0.74508	191.399
108902.000	6	Yes	0.74488	191.874
108893.874			**0.74493**	**191.259**

Results from another field prover with a problem are below. As the tests begin, it was oblivious that the prover had a serious problem. The new volume was 0.5% different from the previous, and the master meter would not repeat on the field prover. The calibration continued and runs at the slow rate were made. The meter repeatability was 1.3% on the slow flow rate, and the prover volume changed 0.76%. The process was stopped and a scope was brought in to look at the internal lining. The prover lining was pitted and needed replacement.

	Repeatability	Set I CPVavg
Fast Run 800 BPH Base Prover Volume	0.044%	43.0394 Bbl

	Repeatability	Set II CPVavg
Slow Run 500 BPH Base Prover Volume	1.324%	43.3671 Bbl

Conclusion:

The Master Meter prover calibration method has several advantages over the other type of prover calibrations. Some of the advantages are:

- Eliminates the need to clean field prover.
- Eliminates the expense of cleaning, water disposal, and down time.
- Good method to verify prover operating condition and volume prior to a volumetric or gravimetric calibration.

Excellent results can be achieved when this method is performed by experienced technicians using high quality equipment. Master meter calibrations may be one tier lower on the traceability ladder, but results can be and are equivalent to other methods. Their accuracy is totally dependent on the accuracy and quality of the master prover calibration. With the tight tolerances and specifications of this method and good historical data on the field prover calibration, the Master Meter prover calibration might be the most effective way to calibrate displacement provers.

References:

American Petroleum Institute *Manual of Petroleum Measurement Standards*, Chapter 4 “Proving Systems,” Section 9 “Methods of Calibration for Displacement and Volumetric Tank Provers,” Part 3 “Determination of the Volume of Displacement and Tank Provers by the Master Meter Method of Calibration”

American Petroleum Institute *Manual of Petroleum Measurement Standards*, Chapter 12 “Calculation of Petroleum Quantities,” Section 2 “Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors,” Part 5 “Calculation of Base Prover Volumes by the Master Meter Method”