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 Provers by the Master Meter Method of Calibration

FIRST EDITION, APRIL 2010

REAFFIRMATION, MARCH 2015

AMERICAN PETROLEUM INSTITUTE

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Foreword

This multi-part publication consolidates and standardizes calibration procedures for displacement and volumetric tank provers used in the metering of petroleum liquids. It provides essential information on the operations involved in obtaining a valid, accurate and acceptable prover volume by different calibration methods. Units of measure in this publication are in the International System (SI) and United States Customary (USC) units consistent with North American industry practices. This section consists of the following four parts:

— Part 1—*Introduction to the Determination of the Volume of Displacement and Tank Provers*;

— Part 2—*Determination of the Volume of Displacement and Tank Provers by the Waterdraw Method of Calibration*;

— Part 3—*Determination of the Volume of Displacement Provers by the Master Meter Method of Calibration*;

— Part 4—*Determination of the Volume of Displacement and Tank Provers by the Gravimetric Method of Calibration*.

Throughout this document issues of traceability are addressed by references to the National Institute of Standards and Technology (NIST). However, other appropriate national metrology institutes (NMIs) can be referenced.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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1 Scope

This standard covers the procedures required to determine the field data necessary to calculate a Base Prover Volume (BPV) of a field displacement prover by the master meter method of calibration.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 4.2, *Displacement Provers*

API *MPMS* Chapter 4.4, *Tank Provers*

API *MPMS* Chapter 4.6, *Pulse Interpolation*

API *MPMS* Chapter 4.8, *Operation of Proving Systems*

API *MPMS* Chapter 4.9.1-2005, *Methods of Calibration for Displacement and Volumetric Tank Provers*, Part 1—*Introduction to the Determination of the Volume of Displacement and Tank Provers*

API *MPMS* Chapter 4.9.2-2005, *Methods of Calibration for Displacement and Volumetric Tank Provers*, Part 2—*Determination of the Volume of Displacement and Tank Provers by the Waterdraw Method of Calibration*

API *MPMS* Chapter 12.2.3-1998, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*, Part 3—*Proving Reports*

API *MPMS* Chapter 12.2.5-2001, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*, Part 5—*Base Prover Volume Using Master Meter Methods*

NOTE For readability, references to API *Manual of Petroleum Measurement Standards* are abbreviated as API *MPMS*. Reference to parts of chapters will follow the convention of "Chapter.Section.Part.Subpart". For example, this standard, *American Petroleum Institute Manual of Petroleum Measurement Standards*, Chapter 4, Section 9, Part 3, would be called API *MPMS* Chapter 4.9.3.

3 Terms and Applications

3.1 Terms

No definitions are unique to this document. Unfamiliar terms not explained in adjoining text are found in the publications listed in Section 2 and the Bibliography, chiefly API *MPMS* Ch. 1, API *MPMS* Ch. 4.9.1, and API *MPMS* Ch. 12.2.

3.2 Applications

3.2.1 General

API *MPMS* Ch. 4.9.1 is the introduction and discusses the provers, master meters, related equipment and general troubleshooting applicable to all the different methods of prover calibration. Information contained in API *MPMS* Ch. 4.9.1 is not repeated in this standard. Detailed calculation procedures are not included in this standard. The reader is referred to the latest edition of the API *MPMS* Ch. 12.2.5 for the complete calculation details applicable to this standard. Accordingly, API *MPMS* Ch. 4.9.1, API *MPMS* Ch. 4.9.3, and API *MPMS* Ch. 12.2.5 together are needed to conduct a calibration of a displacement prover by the master meter method.

The technique used to calibrate the master meter introduces various levels of uncertainty into the petroleum measurement hierarchy. While this does not necessarily mean the master meter method is less accurate than other methods, the calibration chain is longer than that of a direct method.

A prover calibration is initially performed at the manufacturing plant after the field prover is built and often again after it has been installed at the operating facility. From this time forward, periodic calibrations occur. See API *MPMS* Ch. 4.8 and API *MPMS* Ch. 4.9.1 for more discussion on the necessity for and frequency of subsequent field prover calibrations.

3.2.2 Applicable Liquids

Performing a prover calibration requires a liquid as a medium. This standard applies to liquids that for all practical purposes are considered to be clean, single-phase, homogeneous, and Newtonian at metering conditions. The application of this standard is limited to liquids for which API *MPMS* Ch. 11.1 is applicable and water. To accomplish this, the density of a liquid shall be determined by the appropriate technical standard, by use of the proper density correlation or by use of the correct equations of state.

3.2.3 Base Conditions

Historically the measurement of some liquids for custody transfer and process control has been stated in volume units at base conditions. The base conditions for the measurement of liquids such as crude petroleum and its liquid products having a vapor pressure equal to or less than atmospheric at base temperature are indicated in Table 1.

Table 1—Base Conditions

	Pressure	Temperature
USC units	14.696 psia	60 °F
SI units	101.325 kPa	15 °C

For fluids, such as liquid hydrocarbons, having a vapor pressure greater than atmospheric pressure at base temperature, the base pressure shall be the equilibrium vapor pressure at base temperature. For liquid applications, base conditions may change from one country to the next due to governmental regulations. Therefore, it is necessary that the base conditions be identified and specified for standardized volumetric flow measurement.

3.2.4 Applicable Provers

The field prover shall be a displacement prover; this standard shall not apply to a field tank prover. The master prover may be a displacement or tank prover. Volume of the master prover shall be established in accordance with any approved API *MPMS* direct method. Volume of the master prover shall not be established by the Master Meter Method because the calibration chain is longer using the Master Meter Method.

An additional requirement connected with using a tank prover as the master prover is the calibration fluid used to calibrate the field prover shall be water due to clingage and evaporation issues. Using a tank prover as a master prover requires extra care to be taken to be sure that the master meter flow rate is essentially the same as that of the field prover calibration runs for any given calibration set.

For readability, this standard is written as though a displacement prover is used as the master prover because the physical setup and operation of the two types of provers is very different. The user deciding to use a tank prover as the master prover shall follow API *MPMS* Ch. 4.4 and API *MPMS* Ch. 4.8 for how to set up and use the tank prover and shall follow Section 6 of this standard for when the tank prover is to be used.

4 Pre-calibration Planning and Activities

4.1 Fluids used for Master Meter Calibration

Non-homogenous fluids may impact or negate the validity of this procedure. Examples of non-homogenous fluids are fluids with varying amounts of entrained air or gas, mixed or multi-phased fluids, varying or large amounts of water within the fluid, or non-Newtonian fluids. Possible impacts or problems caused by inconsistent or inappropriate fluid quality may be: irregular sphere movement (skipping) due to insufficient lubricity, inability to generate or inconsistent meter factors, failure to achieve prover calibration run or set repeatability, or inappropriate application of volume correction factors. The fluid used to make the master meter proving runs shall be the same fluid used to make the prover calibration runs.

4.2 Master Prover/Master Meter

Typically a master meter and master prover are close-coupled as a single unit mounted on a trailer or truck. The master meter and master prover shall be connected as close as good piping practice allows. Further explanation of the master meter, master prover, and field prover connection is found in Annex B. More detail with diagrams on the instrumentation required for calibration and how to set it up is discussed in API *MPMS* Ch. 4.2 if the master prover is a displacement prover, and in API *MPMS* Ch. 4.4 and API *MPMS* Ch. 4.9.2 if the master prover is a tank prover.

The master meter shall display very good reproducibility and repeatability throughout its operating range. Suggested acceptable performance of a master meter is that a flow variation of ±5 % results in no greater than 0.02 % change in meter factor and at any flow rate used in the calibration, the repeatability should be no greater than 0.02 %. The master meter shall not have been calibrated by another master meter but shall be calibrated by either a displacement or tank prover in accordance with procedures of this standard. In no case shall electronic pulse multiplication be used but the use of pulse interpolation in accordance with API *MPMS* Ch. 4.6 is acceptable.

The calibration fluid used shall be compatible with the master meter. For switch accuracy refer to API *MPMS* Ch. 4.2.

4.3 Calibration Records

4.3.1 Master Prover

The master prover volume shall have been determined per the current API *MPMS* Ch. 4.9 and API *MPMS* Ch. 12 and shall be traceable to the National Institute of Standards and Technology (NIST) or an appropriate national metrology institute (NMI).

The latest calibration certificate of the master prover shall be available for review.

4.3.2 Field Prover

The relevant maintenance records and calibration history of the field prover should be available for review. This review will provide a sense of the expected volume and provide clues for troubleshooting should problems occur.

4.3.3 Other Calibrated Equipment

Each device requiring calibration/verification shall have a valid calibration/verification certificate available. The identification on each piece of equipment shall be identical to that on the corresponding certificate.

Refer to API *MPMS* Ch. 4.9.1 for more details.

4.4 Inspections

4.4.1 Field Prover

Any work performed on the field prover that would potentially affect its calibrated volume such as a hydro-test or cleaning needs to be completed prior to its calibration. It is recommended that while the field prover is open for the switch and displacer inspections mentioned below, the user should assess the general internal condition of the field prover.

4.4.2 Field Prover Detector Switches

It is recommended that the field prover detector switches be removed, cleaned, inspected, parts repaired or replaced as required and re-installed as part of the normal preparation of the prover for calibration. In certain circumstances, the operator may wish to determine an "as found" calibration before this preparation takes place; however, this would be in unusual troubleshooting circumstances and is not the prevailing practice. Once the inspection is completed, consideration may be given to sealing the switches. Detector switch settings are critical and any adjustments may affect the prover volume. Detectors shall not be adjusted between any of the calibration runs.

For switch accuracy refer to API *MPMS* Ch. 4.2.

4.4.3 Field Prover Displacer

It is recommended that elastomeric sphere displacers be checked for condition prior to the calibration, as part of the preparation of the field prover. If the displacer is a piston, then the piston and its seals need to be intact.

NOTE Any changes to the sphere either during or after the calibration that affect the seal of the sphere or the actuation of the detector switches may alter the volume of the prover.

Refer to API *MPMS* Ch. 4.8 and API *MPMS* Ch. 4.9.1 for more details.

4.4.4 Hoses, Pumps, and Connections

Piping is preferred for connecting the field prover and the master prover/master meter. If flexible hoses are used, they should be inspected for kinks, buckles, and leaks. All hoses should be of a non-collapsible type and shall have the same shape at beginning and end of any calibration run.

All the flexible hose connectors, pumps, and hoses should have gaskets in good condition, unbroken locking arms or connectors, and all hose and piping connections shall be leak free.

4.4.5 Four-way and Interchange Valves

All four-way and interchange valves shall be of a double block-and-bleed construction. The function of the four-way or interchange valve may be replicated by the use of a combination of valves, which shall have the capability to ascertain the integrity of the valve combination. Various valve integrity detection devices are often installed on four-way and interchange valves, and their functions shall be verified before the start of the calibration.

4.5 Venting and Circulation

4.5.1 Connection

In the order specified in Annex B, connect the master prover and master meter in series with the field prover.

4.5.2 Leaks

Prior to commencement of calibration activities ensure that all associated lines, connections, and valves are checked for leaks. If a valve cannot be checked for leakage, it shall be blinded. Leaks may cause the calibration to fail. All leaks shall be identified and the equipment repaired to eliminate the leak before starting the prover calibration. Continue to monitor for leaks throughout the calibration procedure.

The four-way valve, interchange valve or equivalent valve combination shall be checked for integrity on each calibration pass.

Refer to API *MPMS* Ch. 4.9.1, Section 6.3 and Section 6.4 for more detail.

4.5.3 Air

Air shall be vented from all high points in the system before beginning the calibration. The presence of air and/or vapor in the system during a run may cause poor repeatability and will cause poor accuracy. Vent valves are used to remove all air or vapor present in the system before and after calibration runs. Under no circumstances shall drain valves or vent valves be operated during a calibration pass. Ensuring the master meter and master prover are as level as possible and cycling the field prover displacers will help move entrained air to a vent. Continually monitor and vent all high points throughout the certification procedure at intervals between calibration runs to ensure air is not being added or accumulated.

4.5.4 Temperature Stability

Temperature shall be stabilized prior to calibration, and shall be maintained as stable as possible throughout the calibration process. Variations in temperature greater than 0.2 °C (0.4 °F) at any single measurement point may make it difficult to complete a successful calibration. Failure to achieve temperature stability may cause the calibration to fail.

Because temperature stability is so important, it may be necessary to cover the master meter, master prover, and possibly the field prover (if above ground and not insulated), in very hot or very cold weather and consider performing the calibration during stable weather conditions (e.g. at night). Consider protecting the equipment from the effects of wind and direct sunlight. This reduces the impact of ambient temperature on the field prover. The length of the field prover connections should be kept to a minimum to limit the effects of ambient temperature.

The reported field prover temperature should be representative of the fluid and steel temperature within the field prover's calibrated section. To help ensure this during calibration of a bi-directional prover, the sphere should travel to the launch chamber before changing the direction of the sphere for the following pass. Circulation through the equipment should occur for an adequate amount of time for steel temperature stabilization before commencing the process.

4.5.5 Pressure Stability

During master meter calibrations it is very important to maintain adequate back pressure and sufficient flow. Inadequate back pressure or flow will cause the line to become slack. This in turn causes erratic movement of the displacer in the prover during a calibration run. The length of the field prover connections should be kept to a minimum to limit the effects of pressure drop. If system pressures are fluctuating greater than 70 kPa (10 psi), the calibration may fail. Operating pressure during the calibration shall be sufficiently above the equilibrium vapor pressure of the fluid found at the lowest pressure in the proving system to prevent cavitation.

4.5.6 Flow Rates

The flow rates shall be chosen so that they are within the operating range of the master meter and the master prover. Care should be taken to ensure the displacers in both the master and field prover move smoothly throughout the calibration pass. It is recommended that flow rate changes be based on travel time of the displacer between switches rather than a flow rate indicating device. In addition, between calibration sets, the flow rate shall be changed by an amount that is at least 25 % of the greater of the flow rates of the two consecutive calibration sets being compared. Users may consider changing the flow rate by a percentage higher than 25 % to provide more confidence in the ability of the rate change procedure to discover otherwise undetected leaks. Any flow rate pattern (high, low, high; low, high, low; high, low, lower or low, high, higher) can be followed as long as the flow rates of consecutive calibration run sets differ by an amount that is at least 25 % of the higher flow rate of the pair.

Caution—Give some thought to the flow rates before actually running each calibration run set to prevent inadvertent violation of this requirement. This differs from API *MPMS* Ch. 4.9.2 (2005) and API *MPMS* Ch. 12.2.5 (2001) in that here the user is told how to calculate the 25 % change. Flow rates of 800, 600, and 750 would fail this criteria.

The flow rate during a calibration run set should be stable. Maintaining the flow rate of each pass of a calibration run set within a range of 5 % will aid in fulfilling the other repeatability criteria.

4.6 Temperature, Pressure, and Density Device Verification

4.6.1 Temperature Device Verification

Inspect all temperature devices to be used for defects and accuracy.

See API *MPMS* Ch. 4.9.1 and API *MPMS* Ch. 7 for more information.

4.6.2 Pressure Device Verification

Inspect all pressure devices to be used for defects and accuracy. See API *MPMS* Ch. 4.9.1 for more information.

4.6.3 Density Device Verification

The density determination device shall have a scale reading resolution of at least 0.5 kg/m^3 (0.1° API) and its accuracy shall be within 1.0 kg/m^3 (0.2° API) against a laboratory standard or any device traceable to NIST or appropriate NMI. The current calibration certificate and/or calibration records of the device should be available for review.

4.7 Calculations

See API *MPMS* Ch. 12.2.5 for complete details of the input precision, algorithm(s), order of calculation and rounding that shall be used to perform the calculations.

This standard assumes a computerized method will be used to organize the data, perform the needed calculations and create the calibration forms.

See API *MPMS* Ch. 4.9.1 and API *MPMS* Ch. 12.2.5 for the information that should appear on the calibration forms.

4.8 Readings

4.8.1 Temperature Readings

During each pass, temperature readings shall be taken on the master meter and the associated prover. All temperature readings are recorded and averaged to the precision stated in the current version of API *MPMS* Ch. 12.2.5.

4.8.2 Pressure Readings

During each pass, pressure readings shall be taken on the master meter and the associated prover. Pressure readings are taken to the precision stated in the current version of API *MPMS* Ch. 12.2.5.

4.8.3 Other Readings

Other required readings for each pass are pulses and density. Note that this standard does not prohibit the use of interpolated pulses. Average flow rate may be read or calculated. Record all of these per the decisions made in Section 5 and API *MPMS* Ch. 12.2.5.

4.8.4 Recording the Readings

4.8.4.1 Manual Recording

For calibration data that is collected manually for future entry into a computer, the pressures and temperatures for the associated prover and master meter shall be taken as often as necessary, in an equally spaced manner, to obtain average representative values for each associated device during any given pass of the displacer. As a practical matter this means one time for each associated device when the displacer is approximately midway between detectors in very stable process conditions or two or more times when the process is less stable. For example, if three readings are taken, they would be taken at $^1/_4$, $^1/_2$, and $^3/_4$ intervals between the switches where the intervals are based on time or pulses. Multiple readings shall be averaged and reported per API *MPMS* Ch. 12.2.5.

All manual readings shall be recorded and become a part of the certification package. All readings manually entered into the computer shall be verified against the written records for accuracy and credibility before the calibration documents are signed. See API *MPMS* Ch. 4.9.1 for detailed information.

4.8.4.2 Automatic Recording

For calibration data that is collected automatically by a computer, the weighted average function may be used to determine and report the associated prover and master meter pressures and temperatures and fluid density during each pass.

5 Other Preliminary Considerations

Since this procedure can take 12 or more hours to complete on large provers, the user should consider performing the appropriate repeatability calculations each time a new proving or calibration run is completed.

The following decisions shall be made before the calibration starts. Once the calibration begins, these decisions shall not be changed. Decide on the following items.

— How flow rates, temperature, pressure and density will be measured and reported. If more than one discrete reading is used, the reported averages shall be rounded per API *MPMS* Ch. 12.2.5.

— How many runs will be performed to determine meter factors and prover volumes.

NOTE This standard does not allow users to run “extra” runs in order to “improve” a meter factor or calibrated prover volume (CPV). Once the repeatability requirements are met for the number of runs decided upon (usually five for a meter factor and three for a prover calibration), the runs are complete. This is to prevent “picking and choosing.” See Example 2 in Annex A for more information.

— Which of the three methods of determining the CPV described in 6.2 will be used.

— Which of the two methods of determining master meter factor (MMF) described in 6.3 will be used.

6 Calibration Procedures for Field Provers

6.1 Considerations Common to all Procedures

6.1.1 General

The master meter method of calibration involves making repeated meter proving runs of a master meter against a master prover (master meter prover) and making repeated prover calibration runs of the field prover against the master meter in an exactly defined sequence in a minimum amount of time.

The underlying assumption of this process is that the performance of the master meter remains essentially unchanged throughout the meter proving runs and prover calibration runs occurring within each calibration run set. Because this assumption cannot be established directly in two of the three procedures explained in 6.2, the stability of the meter performance is inferred by the repeatability checks mentioned in these procedures. Additional assurance of system stability comes from the requirement that all meter and prover calibration runs that make up the calibration run set should occur with a minimum possible delay between runs and from the monitoring of system parameters.

6.1.2 Logic of Section 6.2 and Section 6.3

Section 6 details six different ways for determining the BPV of a field displacement prover by using a master meter. The progression of explanation is from the general to the specific. 6.2.1 through 6.2.3 will detail each of the three ways to determine a CPV and 6.3 will give an overview of the two different calculation methods for determining a meter factor.

6.1.3 Basic Procedure to Determine BPV

The following general steps shall be performed in the order given to determine a BPV of a field prover.

1) Gather preliminary information related to the master meter, master prover and field prover required for reporting and calculation purposes.
2) In the order specified in Annex B, connect the master prover and master meter in series with the field prover.
3) Establish flow at the desired flow rate and check for leaks.
4) Purge all air and wait for temperature to stabilize.
5) Using one of the procedures detailed in 6.2, determine CPV_I for the first flow rate demonstrating that flow rates, intermediate master meter factors (IMMFs) or pulses, meter factors, and intermediate calibrated prover volumes (ICPVs) meet each respective repeatability criterion within this calibration run set. This is calibration run set I.

   NOTE See one of the methods in 6.2 for repeatability criteria.
6) Change flow rate by at least 25 % per the requirements of 4.5.6.
7) Using the same procedure used in step 5, determine CPV_{II} for the second flow rate demonstrating that flow rates, IMMFs or pulses, meter factors, and ICPVs meet each respective repeatability criterion within this calibration run set. This is calibration run set II.
8) Demonstrate CPV_I and CPV_{II} meet their repeatability criterion of 0.020 %.
9) Change flow rate by at least 25 % per the requirements of 4.5.6.

10) Using the same procedure used in step 5, determine CPV_{III} for the third flow rate demonstrating that flow rates, IMMFs or pulses, meter factors, and ICPVs meet each respective repeatability criterion within this calibration run set. This is calibration run set III.
11) If CPV_{I}, CPV_{II} and CPV_{III} meet their repeatability criterion of 0.020 %, go to step 13. If CPV_{I}, CPV_{II}, and CPV_{III} do not meet their repeatability criterion of 0.020 %, go to step 12.
12) Continue the process by performing steps 9, 10 and 11 until three consecutive CPVs meet their repeatability criterion of 0.020 %.
13) BPV equals the average of the three consecutive CPVs from step 11 or 12 as applicable.

6.2 Methods for Determining the Calibrated Prover Volume for a Calibration Run Set

6.2.1 Standard Method

Inability to obtain any of the repeatability criteria, except for the flow rate repeatability criterion, within the designated number of trials means the process has failed. See A.2 for further discussion of process failure.

1) Perform a minimum of five consecutive out of a maximum of ten consecutive master meter proving runs against the master prover to determine MMF_{start}. The intermediate results shall agree to within 0.020 %. See 6.3 for a discussion of intermediate results.
2) Perform a minimum of three consecutive out of a maximum of six consecutive field prover calibration runs with the master meter to determine the ICPV for each prover calibration run. The ICPVs are calculated using MMF_{start} and shall agree to within 0.020 %. Calculate the average of the ICPVs calling the result CPV.
3) Perform a minimum of five consecutive out of a maximum of ten consecutive master meter proving runs against the master prover to determine MMF_{stop}. The intermediate results shall agree to within 0.020 %. See 6.3 for a discussion of intermediate results.
4) MMF_{start} and MMF_{stop} shall agree to within 0.020 %.
5) Calculate the average of MMF_{start} and MMF_{stop} calling the result MMF.
6) Recalculate CPV using MMF; report this result as the CPV of this calibration run set.

6.2.2 Alternate Method A

This method of calibration allows the MMF_{stop} to be the MMF_{start} of the next prover calibration run. This method is useful for large provers or when problems are encountered with flow stability. Proving the meter between each field prover calibration run allows for early detection of meter factor drift.

Inability to obtain any of the repeatability criteria, except for the flow rate repeatability criterion, within the designated number of trials means the process has failed. See A.2 for further discussion of process failure.

1) Perform a minimum of five consecutive out of a maximum of ten consecutive master meter proving runs against the master prover to determine MMF_{start}. The intermediate results shall agree to within 0.020 %. See 6.3 for a discussion of intermediate results.
2) Initiate a field prover calibration run and calculate $ICPV_i$ (i=1) using MMF_{start}.
3) Perform a minimum of five consecutive out of a maximum of ten consecutive master meter proving runs against the master prover to determine MMF_{stop}. The intermediate results shall agree to within 0.020 %. See 6.3 for a discussion of intermediate results.
4) MMF_{start} and MMF_{stop} shall agree to within 0.020 %.
5) Calculate the average of MMF_{start} and MMF_{stop} calling the result MMF.
6) Recalculate $ICPV_i$ using MMF. This completes the first prover calibration run.
7) Let MMF_{start} equal the previous MMF_{stop}.

8) Initiate a field prover calibration run and calculate $ICPV_{i+1}$ using MMF_{start}.

9) Perform a minimum of five consecutive out of a maximum of ten consecutive master meter proving runs against the master prover to determine MMF_{stop}. The intermediate results shall agree to within 0.020 %. See 6.3 for a discussion of intermediate results.

10) MMF_{start} and MMF_{stop} shall agree to within 0.020 %.

11) Calculate the average of MMF_{start} and MMF_{stop} calling the result MMF.

12) Recalculate $ICPV_{i+1}$ using MMF. This completes the next prover calibration run.

13) Repeat steps 7 through 12 until three consecutive ICPVs out of a maximum of six consecutive attempts agree to within 0.020 %. If no three consecutive attempts out of the six consecutive attempts agree to within 0.020 %, the process has failed.

14) Calculate the average of the three consecutive ICPVs determined in step 13 calling the result the CPV of this calibration run set.

6.2.3 Alternate Method B

This method can be used for calibrating a field prover that has a large enough calibrated volume to complete a minimum of seven consecutive meter proving runs of the master meter while the field prover is being calibrated; that is, both provers running simultaneously using a separate counter for each prover. Proving the master meter during each field prover calibration run allows for direct indication of the master meter performance during the field prover calibration run. See 6.4 for an explanation for the requirement for seven runs instead of five runs.

Inability to obtain any of the repeatability criteria, except for the flow rate repeatability criterion, within the designated number of trials means the process has failed. See A.2 for further discussion of process failure.

1) Initiate a field prover calibration run.

2) Once flow has stabilized in the field prover, initiate a meter factor run. Continue doing meter factor runs until obtaining seven consecutive runs out of a maximum 14 consecutive runs whose intermediate results agree to within 0.020 %. See 6.3 for a discussion of intermediate results. These seven consecutive runs shall be started after the sphere leaves the launch chamber and completed prior to the sphere entering the launch chamber on the field prover.

3) Calculate MMF using the intermediate results from the seven consecutive meter proving runs obtained in step two.

4) Using MMF, calculate ICPV.

5) Repeat steps one through four until obtaining three consecutive ICPVs out of a maximum of six consecutive ICPVs agreeing to within 0.020 %. The MMFs for these ICPVs shall agree to within 0.02 %.

6) Calculate the average of the ICPVs obtained in step five calling the result the CPV of this calibration run set.

NOTE Alternate Method B may be used on unidirectional and bidirectional provers. If the field prover is bidirectional, the meter proving runs may occur in any proportion during the “out” pass and the “back” pass of each field prover calibration run. There is no technical reason to restrict the meter proofs to occur only when the field prover displacer is within the calibrated section of the prover as long as the flow rate is stable during the meter factor runs. The idea is to do the meter proofs while the field prover sphere is not in the launch chamber to avoid impact of the rate changes occurring when the ball enters or leaves the launch chamber. If the user cannot determine whether or not the sphere is in the launch chamber, then use the switch activation on the field prover as a signal to start and stop the meter factor runs.

6.2.4 Method Comparison Table

See Table 2 for the comparison of the three methods for prover calibration using the Master Meter Method.

Table 2—Comparison of the Three Methods for Prover Calibration using the Master Meter Method

Standard Method		Alternate Method A		Alternate Method B	
		Uses MMF_{stop} as the MMF_{start} for next run		**Simultaneous MMF and Field Prover Calibration**	
Calibration Run Set I		**Calibration Run Set I**		**Calibration Run Set I**	
MMF_{start}	MMF1	MMF_{start}	MMF1		
Calibration Run 1	1st consecutive	Calibration Run 1	1st consecutive	MMF	MMF1
		MMF_{stop}	MMF2	and Calibration Run 1	1st consecutive
		MMF_{start}	Same as MMF2		
Calibration Run 2	2nd consecutive	Calibration Run 2	2nd consecutive	MMF	MMF2
		MMF_{stop}	MMF3	and Calibration Run 2	2nd consecutive
		MMF_{start}	Same as MMF3		
Calibration Run 3	3rd consecutive	Calibration Run 3	3rd consecutive	MMF	MMF3
MMF_{stop}	MMF2	MMF_{stop}	MMF4	and Calibration Run 3	3rd consecutive
Above pattern can be continued up to a maximum of six consecutive calibration runs		Above pattern can be continued up to a maximum of six consecutive calibration runs		Above pattern can be continued up to a maximum of six consecutive calibration runs.	
Allowable for Calibration Runs		**Allowable for Calibration Runs**		**Allowable for Calibration Runs**	
Three consecutive runs, within a range of 0.020 %, out of a maximum of six consecutive calibration runs		Three consecutive runs, within a range of 0.020 %, out of a maximum of six consecutive calibration runs		Three consecutive runs, within a range of 0.020 %, out of a maximum of six consecutive calibration runs	
Allowable for Each MMF		**Allowable for Each MMF**		**Allowable for Each MMF**	
Five consecutive runs, within a range of 0.020 %, out of a maximum of ten consecutive proving runs		Five consecutive runs, within a range of 0.020 %, out of a maximum of ten consecutive proving runs		Seven consecutive runs, within a range of 0.020 %, out of a maximum of 14 consecutive proving runs	
MMF1 shall be within 0.020 % of MMF2		MMF1 shall be within 0.020 % of MMF2		MMF1 shall be within 0.020 % of MMF2	
		MMF2 shall be within 0.020 % of MMF3		MMF2 shall be within 0.020 % of MMF3	
		MMF3 shall be within 0.020 % of MMF4			
Calibration Run Set II		**Calibration Run Set II**		**Calibration Run Set II**	
Conduct the same as calibration run set I except at different flow rate		Conduct the same as calibration run set I except at different flow rate		Conduct the same as calibration run set I except at different flow rate	
Calibration Run Set III		**Calibration Run Set III**		**Calibration Run Set III**	
Conduct the same as calibration run set II except at different flow rate		Conduct the same as calibration run set II except at different flow rate		Conduct the same as calibration run set II except at different flow rate	

6.3 Calculation Methods for Proving the Master Meter

6.3.1 General

Two different meter factor calculation methods are in common use: the Average Meter Factor Method, and the Average Data Method. See API *MPMS* Ch. 12.2.3 for more detail.

6.3.2 Average Meter Factor Method

The Average Meter Factor Method calculates an IMMF based on the individual temperatures and pressures of the prover and meter, the relative density or API gravity and pulses obtained from each meter proving run. The average of these separately calculated IMMFs that agree to within 0.020 % is used as the Master Meter Factors, MMF_{start} and MMF_{stop}, as appropriate.

6.3.3 Average Data Method

The Average Data Method calculates the MMF using the average temperatures and pressures of the prover and meter, the average relative density or API gravity and average pulses obtained from all the selected meter proving runs in which the pulses agree to within 0.020 %. This MMF is the MMF_{start} or MMF_{stop} as appropriate.

6.4 Repeatability and Uncertainty

The uncertainty due to random effects at the 95 % confidence level of the average of the results of three to ten consecutive runs that agree to within 0.020 % are given in Table 3. The uncertainty associated with the Master Meter Factor in the standard method and Alternate Method A is 0.0078 % (0.011 % $/\sqrt{2}$) since the average of MMF_{start} and MMF_{stop} is used to determine MMF. Therefore, for Alternate Method B to have no more uncertainty than the other methods, a minimum of seven consecutive runs to determine MMF shall be performed.

Table 3—Estimated Uncertainty

Number of Consecutive Runs	Uncertainty, %
3	0.029
4	0.016
5	0.011
6	0.0083
7	0.0068
8	0.0059
9	0.0052
10	0.0046

Annex A
(informative)

Troubleshooting

A.1 General

Problems in prover calibrations manifest themselves in the inability to obtain repeatable results between consecutive calibration passes or in extreme cases the inability to even complete a successful calibration pass. Failure usually occurs due to air in the system, leaks or too great of variability of the process but may occur for other reasons. The user shall determine and resolve the reasons for failure and also decide how to proceed once all problems are resolved.

The following discussion may be helpful in troubleshooting the system.

A.2 Possible Courses of Action upon Failure

Failure of the repeatability criteria has different ramifications depending on which criterion has failed and when the failure occurred. The following two examples may help the user decide on a course of action should a failure of a repeatability criterion occur.

EXAMPLE 1

Assume the CPVs from the first two consecutive Calibration Run Sets are 10.23000 and 10.23300 respectively. These two results differ by 0.029 %, fail the repeatability test and so the “process has failed”. The user is encouraged to run a third calibration run set. If, for example, the third CPV is 10.23400, then while the repeatability of the three consecutive CPVs is 0.039 %, the repeatability of the last two consecutive CPVs is 0.010 % and, if the next consecutive CPV is within the range of 10.23191 to 10.23509 inclusive, then the user will have obtained three consecutive CPVs agreeing to within 0.020 % and will successfully determined the BPV. The ramification of this particular failure is the user would have had to run one extra calibration run set.

EXAMPLE 2

Assume the CPVs from the first two consecutive calibration run sets are 10.23300 and 10.23400 respectively. Further assume for the third consecutive calibration run set, the MMF_{start} is 1.000205 and the CPV is 10.23400 as calculated with the MMF_{start}. The set of three CPVs agree to within 0.010 % with the third CPV being calculated with MMF_{start}. If, for example, the MMF_{stop} turns out to be 1.000000 then the MMF_{start} and MMF_{stop} for the third calibration run set agree only to within 0.021 % and fail their repeatability criterion. The ramification of this particular failure is the user has to start completely over because obtaining three consecutive CPVs with all repeatability criteria satisfied is not possible using the work thus far performed.

NOTE As stated in Section 5, users are not permitted to make “extra” runs in order to “improve” a meter factor or CPV. Once the repeatability requirements are met for the number of runs decided upon, the runs are complete.

A.3 Leaks

Any leakage, whether internal or external, between the inlet of the calibrated section of the field prover up to the master meter and master prover, will result in errors in the calibration. This may be indicated by poor repeatability but will result in the over-statement or under-statement of the field prover volume.

The most obvious sources of external leaks are from the gaskets in the connections joining flexible hoses. However, there are many other possible leak sources such as air vents, pumps, valves, flanges, and screwed connections. All need to be checked for leaks.

Internal leaks can be much more difficult to diagnose and detect. The most obvious source of a fluid leak is around the sphere displacer. However, other sources of internal leakage can be through sphere interchanges and four-way valves. Leakage may be consistent or inconsistent and can contribute to increasing or decreasing the determined field prover volume. Leakage may often manifest itself in an inability to obtain repeatable results.

If enough information has been gathered from calibration run data, there may emerge a clear pattern of bias in volumes obtained between slow and fast runs. This can be an indication of leakage (e.g. displacer, four-way valve, sphere interchange assembly, drain valve etc.). It should be noted that most other deficiencies also show up as a lack of repeatability, and therefore leakage is only one of many areas to be considered when trouble-shooting calibration problems.

A.4 Sphere Interchanges

Prover sphere interchanges can cause problems by leakage or improper operation. A ram type interchange can leak through damaged seat or seals. A launching carriage type interchange may not seal properly due to the accumulation of trash, cuts or abrasions in the elastomeric seals or distortion to the interchange seal or seat. Incorrectly set torque switches, limit switches, hydraulic switches, low hydraulic pressure or the inability to launch the displacer due to back flow problems, may all cause the improper operation of a prover interchange.

In the case of losing hydraulic pressure on the interchange plunger, the use of pressure gauges may be required to determine when it is necessary to apply additional pressure.

A.5 Four-way Valves

Integrity of the four-way valve is extremely important for successful calibration. Leakage of the seals or improper seating of a plug valve can both cause problems. Leaking seals may be caused by trash accumulation, or by cuts, nicks or abrasions to the elastomer in the valve seal or seat, or by physical distortion of the valve. Improper plug seating of a four way valve may be a function of improperly set torque switches, limit switches, hydraulic switches, low hydraulic pressure, or incorrect manual or automatic operation.

A.6 Displacers

A.6.1 Types

Prover displacers generally consist of two types: spheres made of elastomers (elastomeric type spheres) and pistons with seals made of elastomers (elastomeric type seals).

A.6.2 Elastomeric Sphere Displacers

Excessive over-inflation normally has no significant effect on the calibration results since a prover sphere that is sealing at 3 % oversize, will not show any additional benefits by inflating it to 6 % oversize. In some cases, depending upon the durometer (hardness) of the sphere material, a large over-inflation of a prover sphere may actually cause it to leak. However, it will certainly increase the wear to the sphere and may cause it to move with an irregular (shuddering) motion through the pipe at the lower flow rates used in the calibration. Shuddering movements of a sphere during a calibration run, particularly as it approaches a detector switch can affect the detector actuation point and therefore impact the repeatability of the results obtained.

Under-inflation however, will always result in leakage around the sphere, and will therefore result in poor sphere movement and irregular detector switch actuation. This will cause inaccuracies in the calibrated volume and may result in poor repeatability.

Repeatability problems require all aspects of sphere inflation to be considered. As a general rule, the larger the size of the prover, the larger the percent oversize required to ensure sphere displacer sealing. For example, a sphere inflation of 3 % oversize may seal well in a 12 in. prover, whereas a 3 % sphere in a 30 in. prover may leak. It is quite possible that the 30 in. prover will require a higher oversize sphere inflation to seal effectively. Roundness (ovality) is essential to achieving repeatability and accuracy. See API *MPMS* Ch. 4.9.1 for guidelines in determining allowable variations in ovality.

Varying the flow rate between calibration runs is the prescribed method for detecting leakage around the sphere. In the case of a leaking displacer, a repeatable rate of leakage can usually be obtained at a fixed flow rate. Changing the flow rate of the fluid can produce a different amount of leakage. Changing the flow rate by as much as 50 % can make any sphere leakage problem more apparent and easy to detect.

A.6.3 Piston Type Displacers

Piston displacers can experience leakage past the seals just as with a sphere displacer. On provers with piston displacers the front seal activates the detector while the rear seal is driving the movement of the piston. Differences in friction, especially between the top and bottom of the rear seal cup, can result in an uneven shuddering movement of barbell style pistons. In addition, corrosion can sometimes cause bypass leaks through the body of the piston. Captive displacer type pistons are often specialized devices and the manufacturer may have to be consulted regarding particular problems with piston leakage. With some types of provers, checking the integrity of the seals of the piston displacer may require a special test to indicate seal failure.

Some piston displacers have valves contained within the body of the piston, which may be subject to leakage. Leakage may also occur around the body of the displacer. Any leakage will cause error in the master meter calibration. For these specialized type piston displacers, consultation with the manufacturer may be required regarding the special tests necessary for checking internal valve and seal integrity.

A.7 Drains and Vents

If problems are encountered with repeatability during the calibration, the system should be re-vented.

A.8 Temperature and Pressure

Changes in ambient conditions may have an influence on the calibration of above ground non-insulated provers. For example, variations in cloud coverage, rain, snow or sleet showers, direct or indirect sun, winds, etc. may significantly impact the ambient temperature, causing changes in the piping temperatures, piping dimensions and most importantly the circulating fluid temperature. These temperature changes can cause the calibration fluid temperature to increase or decrease continually during the calibration runs, and make it difficult or even impossible to obtain repeatable results.

When difficulty is being experienced in achieving temperature stability, a possible way to remedy this includes one of the following procedures:

— covering the prover with a tarpaulin,

— waiting until nightfall,

— erecting a covering shelter or enclosure,

— minimizing the length of connecting hoses,

— insulating provers and connecting hoses.

Continuous and uninterrupted flow of the calibration fluid through the prover has been found to be the most effective method available for maintaining a stable fluid temperature. The importance of temperature stabilization in prover calibration cannot be over emphasized.

Variations in pressure are normal during a prover calibration pass. However, changes in pressure are usually an indication of a rate change and should be investigated. In addition, the system should be checked for adequate back pressure.

A.9 Pumps, Hoses, and Connections

Ensure there are no leaks in the pumps, hoses, and connections. Ensure the hoses maintain their shape during the calibration. The packing gland or mechanical seal in circulating pumps and the inlet piping to the circulating pump should all be inspected for leaks. Note that suction leaks may be difficult to detect. Normally a continuous aeration of the fluid will occur if there are any suction leaks. Aeration of the fluid can be detected by checking the top vents on the field prover between runs. A constant accumulation of air at the top vents is an indication of a suction leak.

A.10 Detector Switches

The detector switches on master meter provers should be properly maintained for optimal performance. This is necessary in order to provide consistent and accurate calibrations. Very small changes in detector switch tolerances, typically 0.05 mm to 0.13 mm (0.002 in. to 0.005 in.), can cause problems with meter repeatability. See API *MPMS* Ch. 4.2 for more information.

A.11 Master Meter

Two types of meters typically used in master meter calibration of provers are turbine and displacement (PD) meters as their linearity and signal output frequency are better suited for this application. In some cases, the meter signal output may be increased mechanically to obtain higher resolution.

When either type of meter is suspected of not performing properly, an oscilloscope may be connected to the meter's pulse output to help determine what is causing the problem. If the meter signal is cyclic, a turbine meter blade could be damaged or if a PD meter is used, the displacement mechanism could be damaged or out of adjustment or there could be misalignment in the meter accessory stack. If the meter signal is erratic, there may be electrical noise on the pulse transmission wiring.

A.12 Prover Pipe Condition

Poor prover construction can cause difficulties in obtaining a repeatable calibration. If visual inspection of the prover sphere shows cuts, abrasions, gouges, etc., it may be indicative of sub-standard prover construction. For example, a non-coated prover calibrated section may produce rust, corrosion, deposits and excessive friction. Small diameter internal pipe fittings and pipe welds that are not ground smooth may cause sphere damage, sphere leakage, or both.

Internally coated provers can swell, wear, flake, crack, peel, and have detachment of the coating which may alter the prover volume. Coating deterioration can occur due to exposure to the product. In addition this may result in a greater probability of leakage past the prover sphere. Larger sphere inflation may be necessary to compensate for leakage due to coating loss and pipe irregularities.

The internal surface of the prover should be inspected for these conditions if problems are encountered during calibration.

Annex B
(normative)

Connections

These not-to-scale diagrams below show a typical way to connect the master meter, master prover and field prover in series as required to perform the calibration procedure. While the diagrams imply the fluid source to be a pipeline, this standard allows the fluid to be supplied via a pump in a recirculation loop.

While these diagrams show one configuration the pieces of equipment may be connected hydraulically in series in any one of the following orders:

1) master meter, master prover, field prover;
2) master prover, master meter, field prover;
3) field prover, master prover, master meter;
4) field prover, master meter, master prover.

No other configurations are allowed.

Caution—Turbine meters are sensitive to changes in flow profile. Configuration 1 provides the greatest chance of an unchanging profile as the calibration progresses and is therefore mandatory when using a turbine meter as the master meter.

In order to maintain temperature and rate stability, flow should occur continuously through all pieces of equipment throughout the entire calibration procedure. In the event this does not occur, temperature and flow rate stability shall be reestablished before resuming the calibration. Figure B.2 shows the area of interest when performing the master meter runs. Figure B.3 shows the area of interest when performing field prover calibration runs.

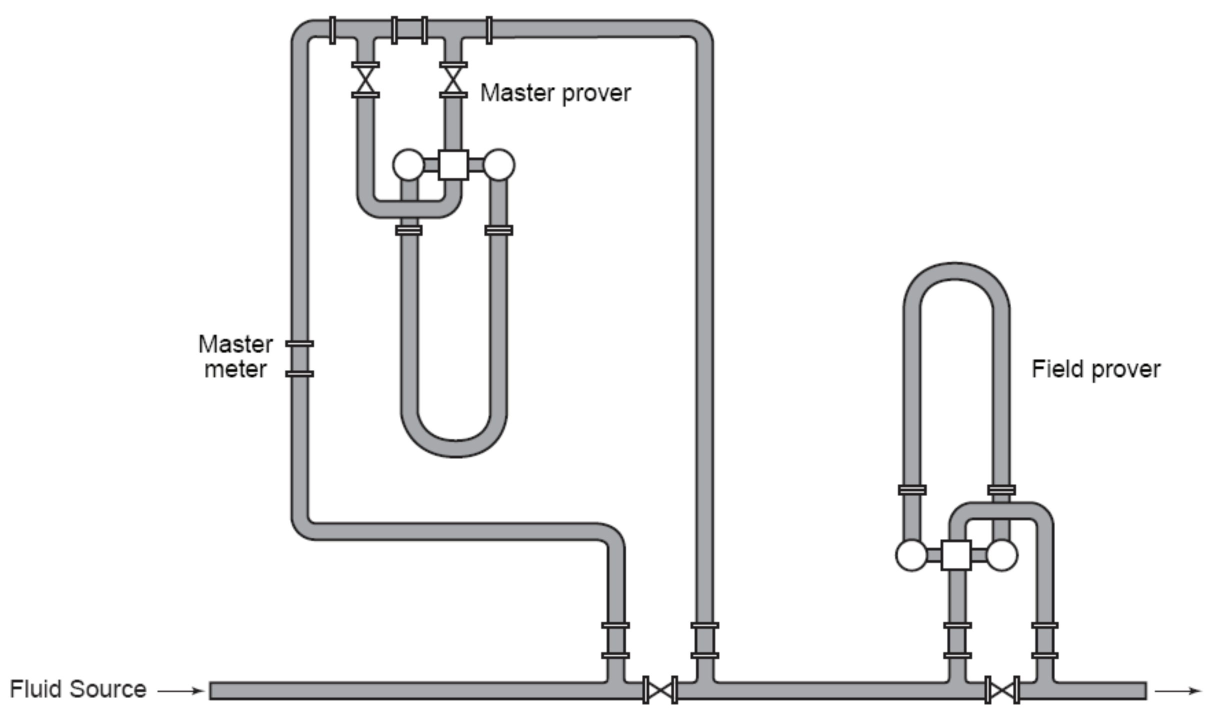

Figure B.1—Flow Path Throughout Calibration

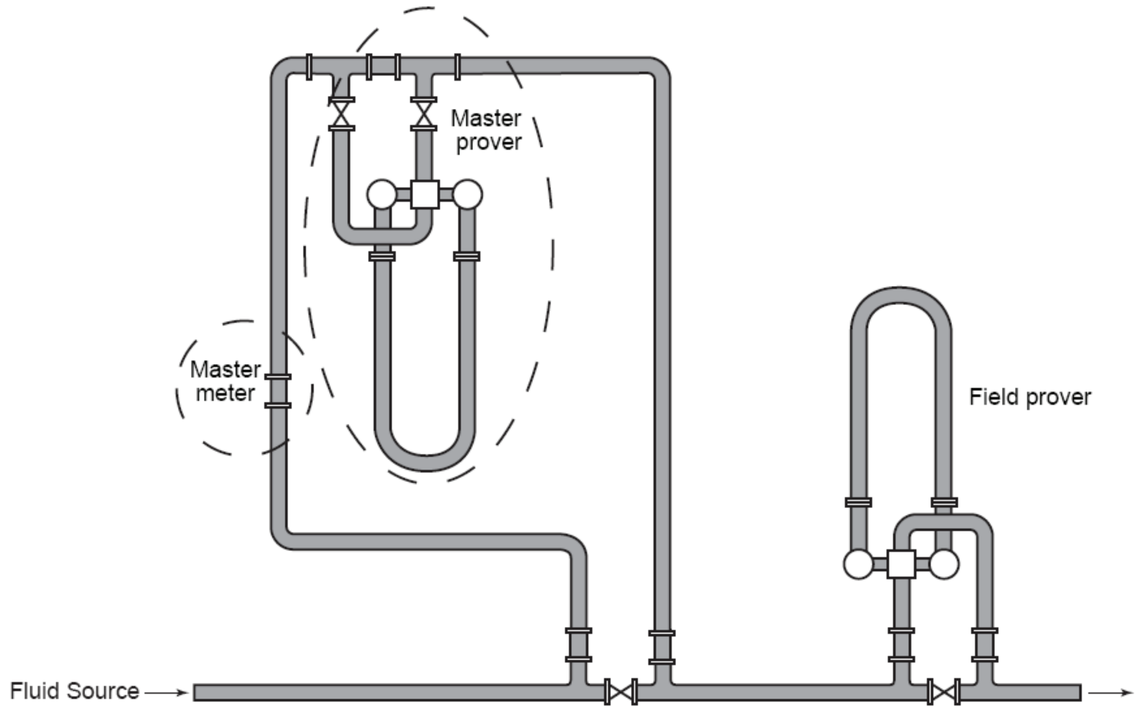

Figure B.2—Master Meter Calibration

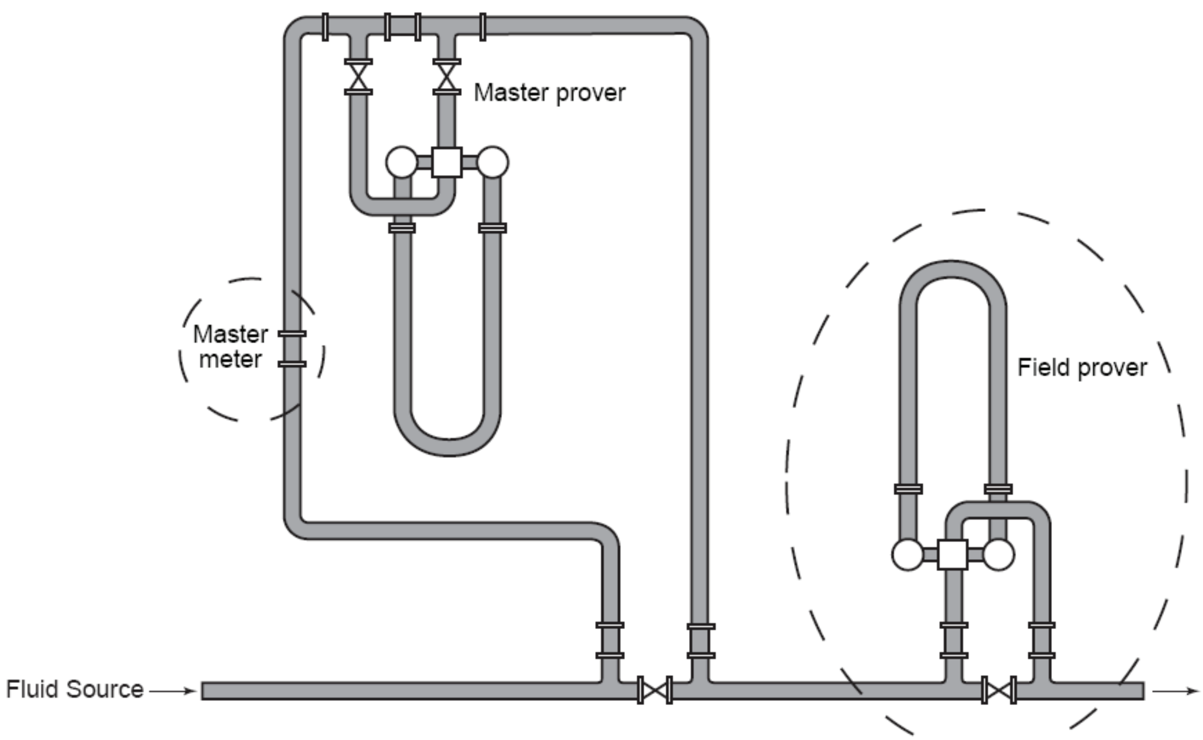

Figure B.3—Field Prover Calibration

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