Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 2—Displacement Provers

THIRD EDITION, SEPTEMBER 2003

REAFFIRMED, MARCH 2011

ADDENDUM, FEBRUARY 2015

AMERICAN PETROLEUM INSTITUTE

Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 2—Displacement Provers

Measurement Coordination

THIRD EDITION, SEPTEMBER 2003

REAFFIRMED, MARCH 2011

ADDENDUM, FEBRUARY 2015

AMERICAN PETROLEUM INSTITUTE

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Standards department telephone (202) 682-8000. A catalog of API publications, programs and services is published annually and updated biannually by API, and available through Global Engineering Documents, 15 Inverness Way East, M/S C303B, Englewood, CO 80112-5776.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the Director of the Standards department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should be addressed to the Director, Business Services.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

FOREWORD

Chapter 4 of the *Manual of Petroleum Measurement Standards* was prepared as a guide for the design, installation, calibration, and operation of meter proving systems used by the majority of petroleum operators. The devices and practices covered in this chapter may not be applicable to all liquid hydrocarbons under all operating conditions. Other types of proving devices that are not covered in this chapter may be appropriate for use if agreed upon by the parties involved.

The information contained in this edition of Chapter 4 supersedes the information contained in the previous edition (First Edition, May 1978), which is no longer in print. It also supersedes the information on proving systems contained in API Standard 1101 *Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter* (First Edition, 1960); API Standard 2531 *Mechanical Displacement Meter Provers*; API Standard 2533 *Metering Viscous Hydrocarbons*; and API Standard 2534 *Measurement of Liquid Hydrocarbons by Turbine-meter Systems*, which are no longer in print.

This publication is primarily intended for use in the United States and is related to the standards, specifications, and procedures of the National Institute of Standards and Technology (NIST). When the information provided herein is used in other countries, the specifications and procedures of the appropriate national standards organizations may apply. Where appropriate, other test codes and procedures for checking pressure and electrical equipment may be used.

For the purposes of business transactions, limits on error or measurement tolerance are usually set by law, regulation, or mutual agreement between contracting parties. This publication is not intended to set tolerances for such purposes; it is intended only to describe methods by which acceptable approaches to any desired accuracy can be achieved.

Chapter 4 now contains the following sections:

Section 1, "Introduction"
Section 2, "Displacement Provers"
Section 4, "Tank Provers"
Section 5, "Master-meter Provers"
Section 6, "Pulse Interpolation"
Section 7, "Field-standard Test Measures"
Section 8, "Operation of Proving Systems"
Section 9, "Calibration of Provers"

Suggested revisions are invited and should be submitted to API, Standards department, 1220 L Street, NW, Washington, DC 20005.

CONTENTS

Page

Figures

Tables

Chapter 4—Proving Systems

Section 2—Displacement Provers

1 Introduction

This document, including figures, graphs and appendices addresses displacement provers. It includes provers that were commonly referred to as either "conventional" pipe provers or "small volume" provers. "Conventional" pipe provers were those with sufficient volume to accumulate a minimum of 10,000 whole meter pulses between detector switches for each pass of the displacer. "Small volume" provers were those with insufficient volume to accumulate a minimum of 10,000 whole meter pulses between detector switches for each pass of the displacer.

Displacement provers may be straight or folded in the form of a loop. Both mobile and stationary provers may be constructed in accordance with the principles described in this chapter. Displacement provers are also used for pipelines in which a calibrated portion of the pipeline (straight, U-shaped, or folded) serves as the reference volume. Some provers are arranged so that liquid can be displaced in either direction.

When using a displacement prover the flow of liquid is not interrupted during proving. This uninterrupted flow permits the meter to be proved under specific operating conditions and at a uniform rate of flow without having to start and stop.

The reference volume (the volume between detectors) required of a displacement prover depends on such factors as the discrimination of the proving counter, the repeatability of the detectors, and the repeatability required of the proving system as a whole. At least 10,000 whole meter pulses are required for Meter Factors (*MF*s) derived to a resolution of 0.0001. The relationship between the flow range of the meter and the reference volume must also be taken into account. For provers that do not accumulate a minimum of 10,000 whole meter pulses between detectors for each pass of the displacer, meter pulse discrimination using pulse interpolation techniques is required (see API *MPMS* Chapter 4.6).

1.1 SCOPE

This chapter outlines the essential elements of provers that do, and also do not, accumulate a minimum of 10,000 whole meter pulses between detector switches, and provides design and installation details for the types of displacement provers that are currently in use. The provers discussed in this chapter are designed for proving measurement devices under dynamic operating conditions with single-phase liquid hydrocarbons. These provers consist of a pipe section through which a displacer travels and activates detection devices before stopping at the end of the run as the stream is diverted or bypassed.

1.2 DISPLACEMENT PROVER SYSTEMS

All types of displacement prover systems operate on the principle of the repeatable displacement of a known volume of liquid from a calibrated section of pipe between two detectors. Displacement of the volume of liquid is achieved by an oversized sphere or a piston traveling through the pipe. A corresponding volume of liquid is simultaneously measured by a meter installed in series with the prover.

A meter that is being proved on a continuous-flow basis must be connected at the time of proof to a proving counter. The counter is started and stopped when the displacing device actuates the two detectors at the ends of the calibrated section.

The two types of continuous-flow displacement provers are unidirectional and bidirectional. The unidirectional prover allows the displacer to travel in only one direction through the proving section and has an arrangement for returning the displacer to its starting position. The bidirectional prover allows the displacer to travel first in one direction and then in the other by reversing the flow through the displacement prover.

Both unidirectional and bidirectional provers must be constructed so that the full flow of the stream through a meter being proved will pass through the prover. Displacement provers may be manually or automatically operated.

1.3 DEFINITION OF TERMS

Terms used in this chapter are defined below.

A **prover pass** is one movement of the displacer between the detectors in a prover.

A **prover round trip** refers to the forward and reverse passes in a bidirectional prover.

A **prover run** is equivalent to a prover pass in a unidirectional prover, a round trip in a bidirectional prover, or a group of multiple passes.

A **meter proof** refers to the multiple prover runs for purposes of determining a *MF*.

Interpulse deviations refer to random variations between meter pulses when the meter is operated at a constant flow rate.

Interpulse spacing refers to the meter pulse width or space when the meter is operated at a constant flow rate.

Pulse rate modulation refers to a consistent variation in meter pulse spacing when the meter is operated at a constant flow rate.

Pulse stability (P_S) refers to the variations of time between meter pulses.

A **proving counter** is a device that counts the pulses from the meter during a proving run.

1.4 REFERENCED PUBLICATIONS

API *Manual of Petroleum Measurement Standards*

- Chapter 1, "Vocabulary"
- Chapter 4, "Proving Systems,"
- Chapter 5, "Metering Systems"
- Chapter 6, "Metering Assemblies"
- Chapter 7, "Temperature Determination"
- Chapter 11, "Physical Properties Data"
- Chapter 12, "Calculations of Petroleum Quantities"
- Chapter 13, Statistical Concepts and Procedures in Measurement

DOT[1]

49 *Code of Federal Regulations* Parts 171 – 177 (Subchapter C, "Hazardous Materials Regulations") and 390 – 397 (Subchapter B, "Federal Motor Carrier Safety Regulations")

NFPA[2]

70 *National Electrical Code*

2 General Performance Considerations

2.1 REPEATABILITY AND ACCURACY

Repeatability of a meter proving should not be considered the primary criterion for a prover's acceptability. Good repeatability does not necessarily indicate good accuracy because of the possibility of unknown systematic errors. Carrying out a series of repeated measurements under carefully controlled conditions and analyzing the results statistically can determine the repeatability of any prover/meter combination. The ultimate requirement for a prover is that it proves meters accurately.

The accuracy of the proving system depends on the accuracy of the instrumentation and the uncertainty of the prover's base volume. The repeatability and accuracy of the prover is established by calibration of the prover.

2.2 BASE PROVER VOLUME

The base volume of a unidirectional prover is the calibrated volume between detectors corrected to standard temperature and pressure conditions. The base volume of a bidirectional prover is expressed as the sum of the calibrated volumes between detectors in two consecutive one-way passes in opposite directions, each corrected to standard temperature and pressure conditions.

[1]U.S. Department of Transportation. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington D.C., 20402.

[2]National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts, 02269.

The base prover volume is determined with three or more consecutive calibration runs that repeat within a range of 0.02% by one of the three following methods—waterdraw, master meter or gravimetric (see API *MPMS* Ch. 4.9).

For the initial base volume determination of a new, modified, or refurbished prover, more than three calibration runs may be used to establish higher confidence in the calibration. When conditions exist that are likely to affect the accuracy of the calibrated volume of the prover, (e.g., corrosion, coating loss) the prover shall be repaired and recalibrated. For deposit buildup, which can be cleaned without affecting the surface of the calibrated volume, the prover need not be recalibrated.

Historical calibration data should be retained and evaluated to judge the suitability of prover calibration procedures and intervals.

2.3 VALVE SEATING

All valves used in displacement prover systems that can provide or contribute to a bypass of liquid around the prover or meter or to leakage between the prover and meter shall be of the double block-and-bleed type or an equivalent with a provision for seal verification.

The displacer-interchange valve in a unidirectional prover or the flow-diverter valve or valves in a bidirectional prover shall be fully seated and sealed before the displacer actuates the first detector. These and any other valves whose leakage can affect the accuracy of proving shall be provided with some means of demonstrating before, during, or after the proving run that they are leak-free.

2.4 FLOW STABILITY

The flow rate must be stable while the displacer is moving through the calibrated section of the prover (see API *MPMS* Ch. 4.8). Some factors affecting flow rate stability include adequate pre-run length, types of pumps in system, operating parameters, etc.

2.5 FREEDOM FROM HYDRAULIC SHOCK

A properly designed prover operating within its design flow range, the displacer will decelerate and come to rest safely at the end of its travel without excessive hydraulic shock to the displacer, displacement prover, and its associated piping.

2.6 TEMPERATURE STABILITY

Temperature stability is necessary to achieve acceptable proving results. This is normally accomplished by circulating liquid through the prover section until temperature stabilization is reached. When provers are installed aboveground, external insulation of the prover and associated piping may be necessary to improve temperature stability.

2.7 PRESSURE DROP ACROSS THE PROVER

In determining the size of the piping and openings to be used in the manifold and the prover, the pressure loss through the displacement prover system should be compatible with the acceptable pressure loss in the metering installation. Excessive pressure drop may prevent the meter from being proved at its normal flow rate(s) and/or minimum backpressure required for the meter.

2.8 METER PULSE TRAIN

The electrical pulse output from the meter can exhibit variations even though the flow rate through the meter is constant. These variations may be caused by mechanical and electrical imperfections of the meter, pulse generator, and in signal processing technique. Ideally, under stable flow conditions, the meter pulse train should be uniform. However, mechanical gears, bearing wear, blade imperfections, couplings, adjusting devices, counters, mechanical temperature correction devices, and other accessories reduce the uniformity of the meter pulses. For meters installed with a gearstack, the further the pulse generator is from the meter, the more erratic the pulse train becomes.

Variations in the meter pulse output may result in unacceptable proving performance. Appendix E discusses the evaluation of pulse variations of meters.

2.9 DETECTORS

Detectors must indicate the position of the displacer within ± 0.005% of the linear distance between switches (a range of 0.01%). The repeatability with which a prover's detector can signal the position of the displacer (which is one of the governing factors in determining the length of the calibrated prover section) must be ascertained as accurately as possible. Appendix A discusses this in more detail. For prover with external detectors, care must be taken to correct detector positions that are subject to temperature changes throughout the proving operation.

A detector switch is an externally mounted device on a prover, which has the ability to precisely detect, the displacer entering and exiting the prover calibrated section. The amount of fluid that is displaced between two detector switches is the calibrated volume of the prover. Provers typically have two detector switches. Additional switches may be used if more than one calibrated volume is required on the same prover, or they can also be used to signal the entrance of a displacer into the sphere receiving chamber.

3 General Equipment Considerations

3.1 MATERIALS AND FABRICATION

The materials selected for a prover shall conform to applicable codes, pressure and temperature ratings, corrosion resistance, and area classifications. Pipe, fittings, and bends should be selected for roundness and smoothness to ensure consistent sealing of the displacer during a prover pass. Detailed inspection should be performed on pipe and fittings used in the calibrated section to insure the roundness of the pipe and the fittings are free of mandrel marks from shaping or forming.

3.2 INTERNAL AND EXTERNAL COATINGS

Internally coating the prover with a material that provides a hard, smooth, long-lasting finish will reduce corrosion, prolong the life of the displacer and the prover. This will improve the meter repeatability when proving at low flow rates. Experience has shown that internal coatings are particularly useful when the prover is used with liquids that have poor lubricating properties, such as gasoline or liquefied petroleum gas; however, in certain cases, satisfactory results and displacer longevity may be achieved when uncoated pipe is used. The materials selected for the internal coating application should be compatible with the liquid types expected. The coatings should be applied according to the manufacturer's recommendations. Extreme caution should be exercised in the surface preparation so that the coating is applied over a clean white-blasted metal with a minimum anchor pattern as specified by the manufacturer.

Externally coating the prover section and associated piping will reduce corrosion and will prolong the life of the prover, especially for installations where the prover is buried.

3.3 TEMPERATURE MEASUREMENT

Temperature sensors shall be of suitable range, resolution, and accuracy, and should indicate the temperature within the meter and the temperature within the calibrated section of the prover. A means shall be provided to measure temperature at the inlet and outlet of the prover (see API *MPMS* Ch. 7 for detail requirements). If it can be determined that the temperature of the flowing fluid at the meter and the prover does not vary by an amount that will result in a Ctl factor change of 0.0001 or less, one temperature probe may be used between the prover and the meter being proved. One temperature device is allowed on the outlet of a prover if the prover is upstream of the meter or on the inlet of the prover if the meter is upstream of the prover. Caution must be exercised to ensure that the temperature sensors are located where they will not be isolated from the liquid path.

3.4 PRESSURE MEASUREMENT

Pressure-measurement devices of suitable range and accuracy are to be used and installed at appropriate locations to indicate the pressure in the meter and the pressure in the prover. The pressure-measurement device should be installed near or on the meter and monitor the pressure in the meter. One pressure transmitter can be used if the pressure difference between the meter and the prover does not exceed the value for which the Cpl factor for the flowing fluid will change by more than 1 part in 10,000. The prover pressure should be monitored on the outlet of the prover if the meter is installed downstream of the prover or on the inlet of the prover if the meter is upstream of the prover. Caution must be exercised to ensure that the pressure sensors are located where they will not be isolated from the liquid path.

3.5 DISPLACING DEVICES

Prover displacers are devices, which travel through the prover calibrated section, operating the detector switches, and sweeping out the calibrated liquid volume. There are two types of displacers in common use, inflatable elastomer spheres and pistons. Other types of displacers are acceptable if they provide accuracy and repeatability that is equal to or better than the types described below.

3.5.1 Sphere Displacers

Materials used in the construction of elastomer spheres vary widely according to the applications for which they are to be used. Most commonly used are three basic materials, neoprene, nitrile and urethane. To obtain the best performance from any of these materials the operator should consider the chemical composition of the liquid that will be passing through the prover. Operating temperatures and pressures also affect the performance of these compounds in prover spheres. No one material or compound is ideal for all applications, therefore, proper material selection is extremely important.

Aromatic compounds, certain chemicals and oxygenates (MTBE, etc.) can attack all the above mentioned materials causing various degrees of softening, swelling and distortion of the shape of the sphere. Other materials such as Viton®, Teflon®, Buna®, etc., have also been used in sphere construction for applications that involve proving operations on specialized chemicals. Consultation with the manufacturer is recommended to determine the best material to be used in prover operations on a specific product.

The most common type of displacer is the inflatable elastomer sphere. It is usually made of neoprene, nitrile, or polyurethane. It has a hollow center with one or more valves used to inflate the sphere. The sphere is typically filled with glycol, or a 50/50-glycol and water mixture to prevent freezing. Care must be exercised to ensure that no air remains inside the sphere for compressibility purposes and to provide the sphere with negative buoyancy. Once the sphere has been filled, it is further inflated in order to increase its size over and above the inside diameter of the pipe. This over inflation is usually in the range of 2% – 3% for normal proving operations, depending upon the pipe diameter and condition of the pipe (see Appendix F). This arrangement allows the sphere to form a tight leak proof seal against the inside walls and to sweep the walls clean of any material (wax, etc.) that may accumulate.

Excessive over inflation of the sphere may result in sticking of the sphere, damage to the sphere, excessive wear, increased pressure drops, and damage to the prover. The effect is more pronounced in small diameter provers.

Under inflation can result in bypass around the sphere (leak) causing inaccuracies in the proving volume. This can be caused by the sphere contact length (the part touching the pipe wall) being less than the length of any opening in the pipe wall. It is possible that the prover can produce repeatable results by consistent bypass around the sphere that will be in error.

Measurement of the sphere can be accomplished either by means of a set of calipers, a sizing ring, or a flexible steel tape, by which the circumference is measured and the diameter calculated. Regardless of the method used, the measurement should be taken across several diameters. The smallest diameter measured is to be considered the real diameter of the sphere so that whatever inflation is chosen, the sphere will have a minimum diameter of that amount. Each measurement of a large sphere should be in a vertical plane. The purpose of sizing the sphere is to affect a seal across the displacer during its travel through the calibrated section of pipe. Any leakage across this sphere would result in an error in measurement.

The sphere size shall be verified periodically, and the sphere resized if necessary. Since wear is a function of lubricity, crude oil or lubricating oils give exceptionally long life, as opposed to prolonged service in a non-lubricating product such as LPG which gives no lubrication and enhances wear. Normally, many hundreds of runs can be made without resizing the sphere.

In order to perform maintenance and inspection of the sphere, provisions should be provided to easily and safely remove the sphere from the prover. These may include a quick opening closure to provide access to the launching chamber(s), a sphere removal tool to pick up the sphere, a hoist to lift the sphere, and access platforms around the launching chambers.

3.5.2 Piston Displacers

The design of a piston displacer varies according to different manufacturers and the requirements of the user. They should be made of materials compatible with the liquid or gas fluid service and are designed to weigh as little as possible.

The piston sealing rings or cups are made from either Teflon®, Viton®, polyurethane, nitrile, Buna® or neoprene, depending upon the liquid product and the operating temperatures and pressures to which the seals are exposed in the prover. Piston type displacers should have wear ring(s) to prevent the metal body of the piston from damaging the surface of the prover measuring chamber.

Pistons fitted with scraper cups made from various elastomer compounds do not require extenders to maintain the seal between the cup edges and the bore of the prover. If Teflon®

cups are used then the piston must be equipped with some type of expander device or material since Teflon® is not an elastomer and thus has no shape retention memory.

3.6 VALVES

Manifold valves that can contribute to a bypass of liquid around the prover or meter, or to leakage between the prover and the meter, shall be of the double block-and-bleed type, skilleted, or have provisions for verifying valve integrity. All valves whose leakage will affect the accuracy of proving shall be provided with some means of demonstrating that they are fully seated and completely sealed. This includes valves to adjoining meter runs, vents, and drains.

Pressure relief valves with discharge piping and leak-detection facilities are usually installed to control thermal expansion of the liquid in the prover while it is isolated from the mainstream. These devices should be positioned to avoid being located between the meter and the far most detector of the prover. For example, if the meter prover system is designed with the meter before the prover, the pressure relief should be located after the second detector. If the prover is located ahead of the meter, the pressure device should be installed before the first detector. Pressure relief valves should be avoided between the meter and the prover.

Bypass valves, flow reversal valves and displacer valves shall be fully seated and sealed so that the displacer is traveling at full velocity before it meets the first detector. Valves shall be selected and designed to prevent excessive pressure drop or hydraulic shock.

3.7 CONNECTIONS

Connections shall be provided on the prover or connecting piping to allow for calibration, venting, draining, and if necessary, pressure relief. The calibrated section of the prover between the detectors shall be designed to exclude any appurtenances such as vents or drains. If drains and vents are used between the meter and calibrated sections, a means should be provided to allow inspections for leakage or block-and-bleed valves should be provided on these connections.

3.7.1 Connections for Prover Calibration

Drains and vents for the prover, prover piping, and block-and-bleed valves should be connected to drain systems or other means should be provided to facilitate the handling of vented and drained fluids in a safe and environmentally suitable manner. Drains should be placed at locations to facilitate removal of water used for hydrostatic testing and calibrations. Figures 3, 4 and 5 show connections for water draw and/or master meter calibrations. Drains are not shown on the figures, but they should be placed at numerous low points on the piping. Vents should be installed at all high points on the piping.

3.7.2 Connections for Inspection

Flanges or other provisions should be provided for access to the inside surfaces of the calibrated and prerun sections. Internal access is an important consideration when internal coating of the prover is required. Care shall be exercised to ensure and maintain proper alignment and concentricity of pipe joints. All pipe, flanges, and fittings shall have the same internal diameter in the calibrated and pre-run sections.

3.7.3 Flange Connections in the Calibrated Section

Flanges in the calibrated volume shall be match bored and uniquely doweled or otherwise designed to maintain the match-bored position of the flanges. The calibrated section shall be designed to seal on a flange-face, metal-to-metal makeup, with the sealing being obtained from an O-ring type seal. All internal welds and metal surfaces shall be ground smooth to preclude damage to and leakage around the displacer.

3.8 DETECTORS

A detector switch is an externally mounted device on a prover, which has the ability to detect and repeat, within close tolerances, the displacer entrance into and its exit from the prover calibrated section. The amount of fluid that is displaced between two detector switches is the calibrated volume of the prover. The detector switches gate an electronic meter-proving counter that is connected to a meter pulse generator. Additional switches are used if more than one calibrated volume is required on the same prover, or they can also be used to signal the entrance of a displacer into the sphere resting chamber.

Displacer detectors must accurately and consistently indicate the position of the displacer within at least 1 part in 10,000 (0.01%) of the linear distance between switches. The accuracy with which the detector can determine the position of the displacer is one of the governing factors in determining the length of the prover's calibrated section. The detection devices must be rugged and reliable because replacement may require recalibration of the prover and temporary loss of meter proving capability.

When worn or damaged parts of a detector are replaced, care must be taken to ensure that neither the detector's actuating depth, the linear position, or its electrical switch components are altered to the extent that the prover volume is changed. This is especially true for unidirectional provers because changes in detector actuation are not compensated for round trip displacer travel as they are in bidirectional provers. If replacement of a detector changes the volume of the prover, recalibration is required.

Three types of detector switches (mechanical, proximity magnetic, and optical actuated) are presently in use for displacement provers.

3.8.1 Mechanically Actuated Detector Switches

The mechanical type of detector switch is used primarily with elastomer sphere displacers. Generally, it is actuated when the displacer makes contact with a stainless steel rod or ball which protrudes into the prover pipe. As the prover displacer moves with the flowing stream, the rod or ball is lifted in the detector. At some point in the upward travel of the rod or ball, an electronic switch is activated which indicates the displacer has been detected. Detector switches are normally hydraulically balanced. This prevents the switch from being activated from a pressure spike. In some cases, the switch part of the detector may be serviceable while the detector is in service and under pressure. Detectors on bidirectional provers should be installed under close tolerance so that the sensing characteristics in one direction are similar to those in the reverse direction. The electronic sensing elements in detectors should be designed so that the detector is not significantly affected by rotation of the mechanical plunger or by mechanical shock of the displacer. Openings through the pipe wall for detectors must be smaller than the longitudinal sealing area of the sphere or piston. On some piston designs multiple seals may be necessary.

3.8.2 Proximity Type Magnetically Actuated Detector Switches

Proximity-type magnetically actuated switches are used only with piston type displacers. This type of switch is mounted externally from the prover measuring section, with no parts inserted through the wall of the prover. It is actuated by either a magnetic material, such as a carbon steel or stainless steel exciter ring, or magnets on the piston displacer passing beneath the detector proximity switch. These switches have the ability to detect within close tolerances, the entrance and exit of the displacer into and out of the prover measuring section. These non-contact types of switches do not have to make physical contact with the displacer. However, non-contact sensors have a limited sensing distance that may also be displacer velocity dependent. To ensure consistent detection of the displacer, the distance between the detector and the displacer's detection elements should be no more than half the maximum sensing distance of the detector. It is important to ensure that these distances can be maintained. To accomplish this, the non-contact detectors should be installed on the side of the prover and the piston's seals should have sufficient stiffness to consistently support the weight of the piston. The sensing characteristics of the non-contact detector should be symmetrical and consistent between detectors so that they can be interchangeable.

3.8.3 Optically Actuated Detector Switches

The optical type detector switch is used primarily with piston provers utilizing externally mounted switches. Conventional design of the optical detector has a light source, together with a photoelectric detector cell, mounted opposite each other on a small metal base plate. This plate has the capability of keeping all the components in the same place, and can be mounted in the same exact location each time it is replaced. This makes for a very precise, repeatable location and mounting; which may permit a switch to be replaced without recalibration of the prover. In normal operations, the light source shines into the photoelectric cell until the light beam is interrupted by a lever or plate mounted to a moving rod connected to the displacer. Breaking of the light beam causes the detector switch to operate. These switches typically have a detection range within 0.0001 in. which permits pulse resolution to at least 1 part in 10,000 in a relatively short distance. Because these switches are externally mounted, a correction is required to compensate for any linear movement of these detectors based on thermal expansion/contraction. Normally two switches are used—one at the beginning and one at the ending of the movement of the displacer.

3.9 PERIPHERAL EQUIPMENT

A meter pulse generator shall be used to provide electrical pulses with satisfactory characteristics for the type of proving counter used.

An electronic pulse counter or flow computer is usually used in meter proving because of the ease and accuracy with which it can count high-frequency pulses and its ability to transmit this count to remote locations. The pulse-counting devices are equipped with an electronic start/stop switching circuit that is actuated by the prover's detectors.

A pulse interpolation system is required for those provers that cannot accumulate a minimum of 10,000 whole pulses between detectors on one pass of the displacer.

3.10 UNIDIRECTIONAL SPHERE PROVERS

3.10.1 General

Typical unidirectional prover piping is arranged so that the displacer is returned to a start position using a sphere handling interchange (see Figure 1). The interchange is the means by which the displacer is transferred from the downstream to the upstream end of the loop without being removed from the prover. The separator tee is the means by which the displacer's velocity is reduced to zero to allow it to enter into the interchange. The launching tee provides the means for allowing the displacer to enter the flowing stream.

These provers typically use electro-mechanical detector switches. The design of the prover usually allows the accumulation of 10,000 meter pulses for a proving pass. However, designs that accumulate less than 10,000 may be used for

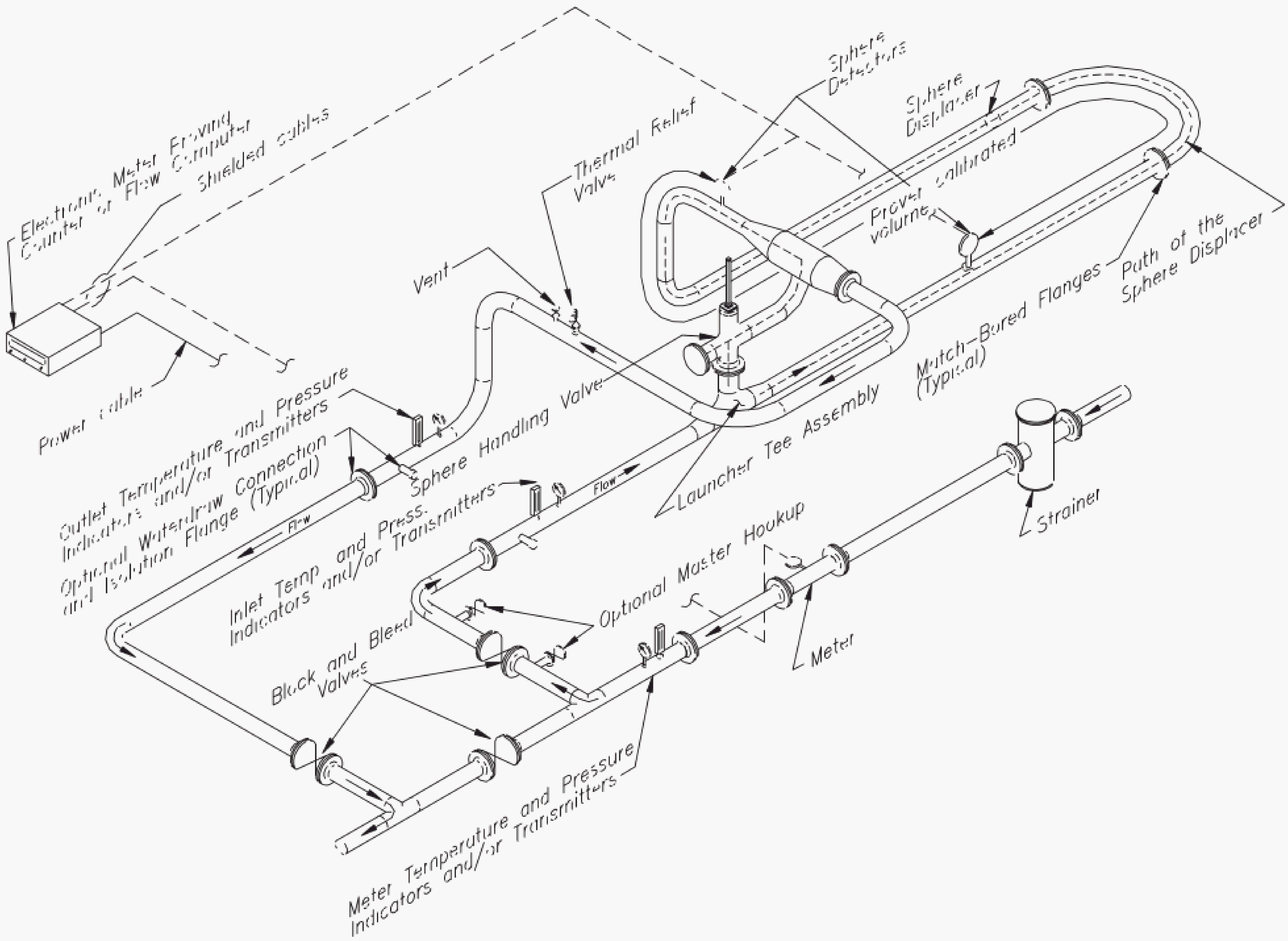

Figure 1—Typical Unidirectional Return-type Prover System

meter proving provided pulse interpolation is used and additional criteria defined in 4.3.2.2 are followed.

3.10.2 Sphere Interchange

The sphere interchange provides a means for transferring the sphere from the downstream end of the proving section to the upstream end. Sphere interchange may be accomplished with several different combinations of valves or other devices to minimize bypass flow or flow reversal through the interchange during the sphere transfer process. Some interchange designs use a launching tee to launch the displacer and a separator tee to receive the sphere and position it for the next proving run. Interchanges using this design typically have some type of valve or plunger to allow the displacer to travel between the separator tee and the launching tee and then seal between the two. In normal operation, a leak-tight seal between the two tees is essential before the sphere reaches the first detector switch of the proving section. To accomplish this, the interchange design must include either a hold ram to retain the displacer until the seal between the two tees is made or a displacer prerun must be installed in the launching tee. The length of the displacer prerun is determined by the operational velocity of the sphere and the travel time of the displacer from the interchange valve to the launching tee.

3.10.3 Separator Tees

Separator tees should be at least two pipe sizes larger than the nominal size of the sphere or loop. Sizing is best determined by experience. The design of the separator tee shall ensure dependable separation of the sphere from the stream for all rates within the flow range of the prover. For practical purposes, the mean liquid velocity through the tee should be reduced to minimize the possibility of damage to the sphere or prover. The tee may sometimes need to be sized more than two pipe sizes larger to reduce the mean liquid velocity. Smooth-flow transition fittings on both ends of the tee are important. A means of directing the sphere into the interchange shall be provided at the downstream end.

3.10.4 Launching Tees

Launching tees should be at least two pipe sizes larger than the nominal size of the sphere or loop to allow the sphere to make the transition from the interchange to the calibrated section and to prevent damage to the sphere and prover.

The launching tee should provide a method ensuring the sphere launches successfully into the calibrated section of the prover during periods of low flow. If ramps are used, there needs to be enough clearance between the ramp and top of the pipe to allow the sphere to move down the ramp.

Launching tees shall have smooth transition fittings leading into the prover. Eccentric fittings are preferred.

3.10.5 Debris Removal

Some means for removal of debris and other contaminants should be considered in the design of new provers.

3.11 UNIDIRECTIONAL PISTON PROVERS

3.11.1 General Description

This section describes those provers historically referred to as "small volume provers." These provers accumulate less than 10,000 whole, unaltered meter pulses between detectors during one pass of the piston displacer, and therefore require pulse interpolation. Optical detector switches used with these provers are externally mounted from the flow media and are able to indicate the position of the displacer with a high degree of precision. As a result of this precision it is possible to have a very short distance between detector switches. The calibrated base volume of this prover is normally much smaller than sphere type unidirectional and bidirectional provers, typically having a maximum calibrated volume of 200 gallons. Since the small volume of these provers may not allow for the accumulation of 10,000 whole, unaltered pulses, the prover electronics must provide means for pulse interpolation. The only practice currently recognized by the API is double chronometry.

These provers allow flow in only one direction and provide a means of proving meters without reversing or disrupting the flow. This is done by an internal or external bypass valve design that allows fluid to pass through the device during non-proving or retraction mode (see Figure 2). The normal operation of these provers begins with the displacer at the starting position. When the bypass (poppet) valve is closed, the displacer is launched and passes through the calibrated section. Once the displacer has passed through the calibrated section, the bypass (poppet) valve opens and the displacer is retracted to the original starting position.

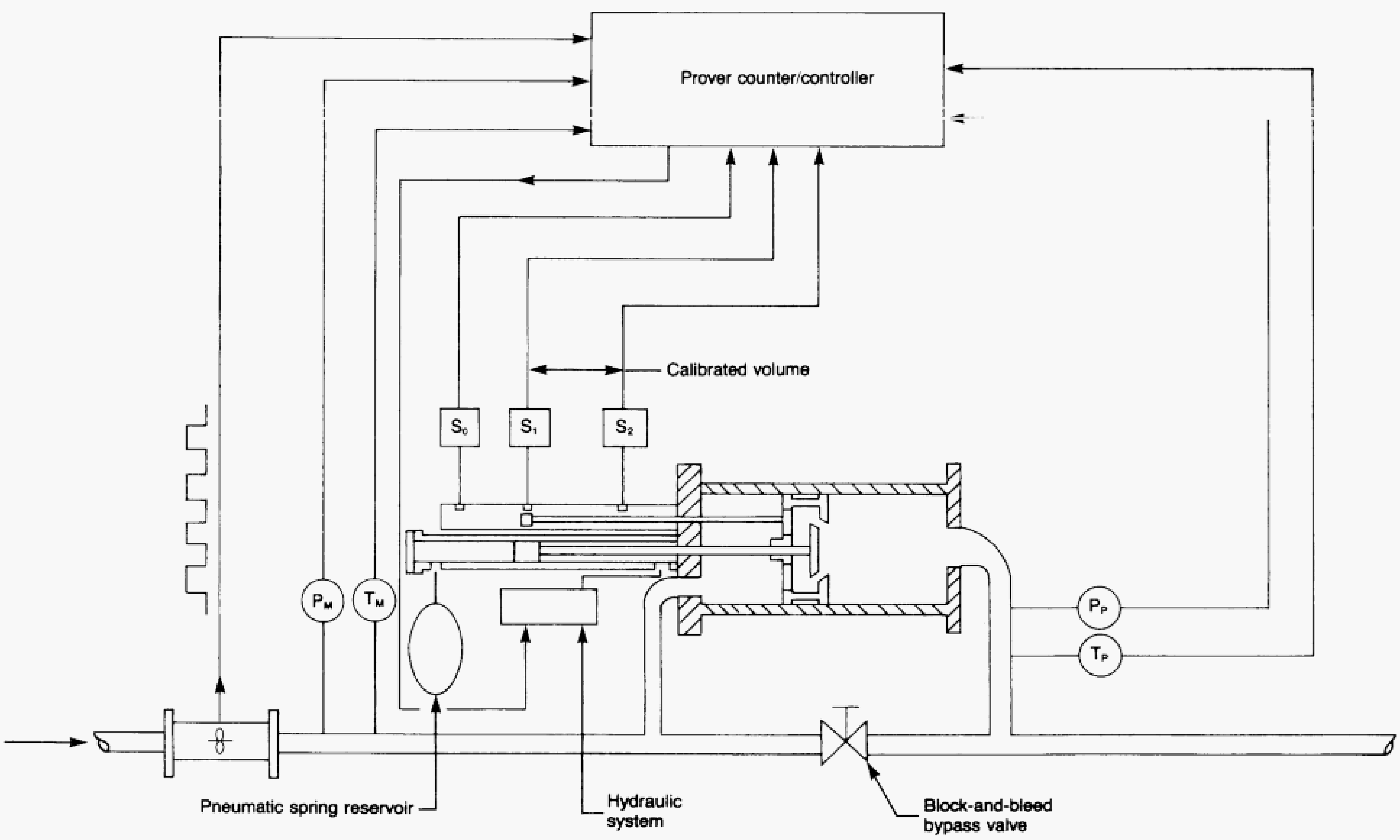

Figure 2—Piston Type Prover with Shaft and Optical Switches

3.11.2 Flow Tube

Unidirectional piston provers must utilize a precision flow tube normally honed and polished to provide a seamless and smooth finish. There shall be no obstructions or intrusions within the calibrated section of the tube. Coating materials such as hard chrome or nickel may be used to provide abrasion resistance. Flanges or other provisions should be included for access to the inside surfaces of the calibrated and pre-run sections. Care should be exercised to ensure and maintain proper alignment and concentricity of pipe joints.

3.11.3 Externally Mounted Detectors

Detectors are high precision, highly repeatable optical type switches mounted externally to the flow media. These switches are often mounted on material having an extremely low coefficient of thermal expansion characteristic. This minimizes the change in distance between the detector switches due to temperature variation. Any linear movement must be accounted for, as this will impact the calibrated volume of the prover. Detectors must indicate the position of the displacer within 0.01% of the linear distance between the detectors. The activation of the detector switches must correspond to the position of the piston displacer, which is normally achieved with a shaft connected directly to the piston displacer.

3.11.4 Piston Launch

Under proving conditions, the piston displacer must be set into motion from a stopped position and come to equilibrium velocity as the fluid traveling inside the flow tube prior to entering the calibrated section. The systems used to launch the piston can utilize the force of the fluid traveling through the prover, or an external system to apply a positive force such as compressed gas or springs. The prover design must allow sufficient length before the calibrated section to allow the piston to be launched and achieve equilibrium velocity prior to activating the first detector switch. Provers utilizing a bypass (poppet) design must ensure the poppet valve remain seated throughout the prover pass. This can be accomplished with the use of force from an external source (e.g., compressed gas or springs).

3.11.5 Piston Retraction

Inversely to the launching system, the prover must provide for retraction of the piston to its proving position. This can be accomplished with a hydraulic system or a mechanical drive. The retraction system must be designed such that it returns the piston to its original starting position. To accomplish this, fluid bypass (poppet) must be designed to allow retraction of the piston without blocking the flow stream. It must also be designed to minimize the pressure loss through the prover. Once in the original starting position, the prover is ready for another pass.

3.12 BIDIRECTIONAL SPHERE PROVERS

3.12.1 General

Typical bidirectional sphere provers (see Figure 3) have a length of pipe through which the displacer travels back and forth, actuating a detector at each end of the calibrated section. Suitable supplementary piping and a reversing valve or valve assembly that is either manually or automatically operated make possible the reversal of the flow through the prover. The main body of the prover is often a straight piece of pipe, but it may be contoured or folded to fit in a limited space or to make it more readily mobile.

These provers typically use mechanical detector switches.

3.12.2 Launching/Receiver Chambers

The launching/receiving chambers of bidirectional sphere provers are designed to pass liquids while restraining the displacer. The chambers should be at least two pipe sizes larger than the nominal size of the calibrated section. Inlets and outlets to the 4-way diverter valve shall have an area sufficient to avoid excessive pressure loss, and shall have a means to prevent entry of the displacer. The launching/receiving chambers must have an incline or ramp to facilitate launching of the sphere. The transition from the chamber to the pre-run needs to be a concentric reducer for a vertical chamber orientation and an eccentric reducer for all other orientations. All internal surfaces shall be de-burred to prevent damage to the sphere.

3.12.3 Flow Reversal

A single multi-port valve is commonly used for reversing the direction of the flow through the prover. Other means of flow reversal may also be used. All valves must be leak-free and allow continuous flow through the meter during proving. A method of checking for seal leakage during a proving pass shall be provided for all valves. The valve size and actuator shall be selected to limit hydraulic shock.

3.13 BIDIRECTIONAL PISTON PROVERS

3.13.1 General

Bidirectional piston provers (see Figure 4) have a straight length of pipe through which the displacer travels back and forth, actuating a detector at each end of the calibrated section. Suitable supplementary piping and a 4-way reversing valve or valve assembly that is either manually or automatically operated make possible the reversal of the flow through the prover.

3.13.2 Flow Reversal

A 4-way valve is typically used to reverse the flow in a piston prover. In many cases, check valves on the outlet piping are used to divert the flow in order to slow the piston down before it reaches the end of the prover. Other means of flow

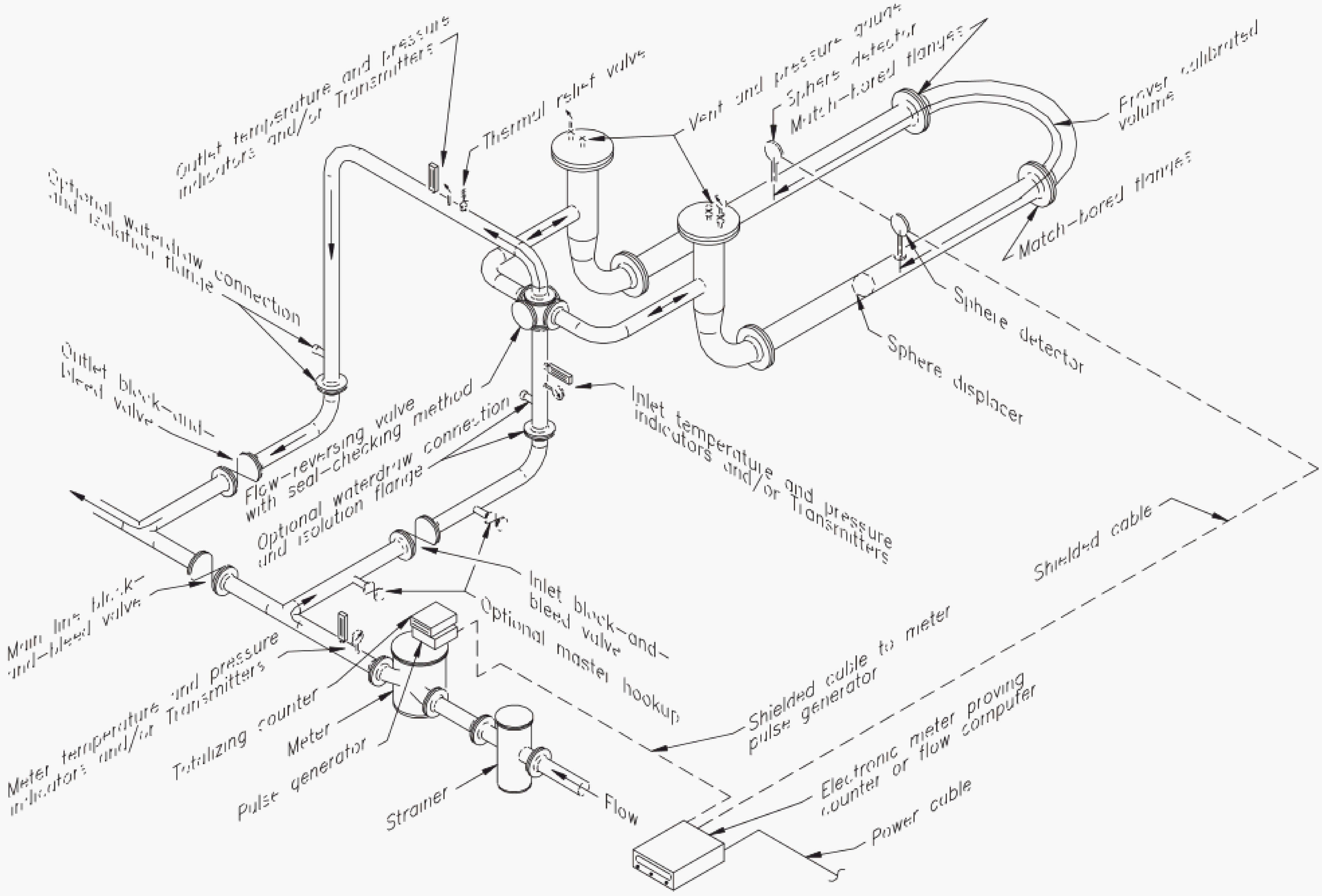

Figure 3—Typical Bidirectional U-type Sphere Prover System

reversal may also be used. However, all valves and flow reversal devices must be leak-free and allow continuous flow through the meter during proving. A method of checking for seal leakage during a proving pass shall be provided for all valves. The valve size and actuator shall be selected to limit hydraulic shock.

3.13.3 Inlets/Outlets

Each end of a bidirectional piston prover has separate inlet and outlet connections, typically of smaller diameter than the calibrated section piping. The inlets/outlets of bidirectional piston provers are designed to pass liquids while restraining the piston displacer in the prerun section of the prover. There are 2 sets of inlets and 2 sets of outlets in a bidirectional piston prover. Each end of the prover has an adjacent inlet and outlet, which connects to common piping of the flow-reversing valve.

The connections farthest from the calibrated section are referred to as the inlet connections, which allow flow to enter into the prover pipe, behind the displacer, at the beginning of a prover pass.

The connections nearest to the calibrated section are referred to as the outlet connections, which allows flow to exit the prover pipe during and after a prover pass. Since the inlet and outlet piping are connected to common piping of the reversing valve, a check valve must be installed on the outlet piping to block flow into the outlet and allow the displacer to move at the start of a prover pass.

The openings shall be designed to allow the piston to pass across the opening without damage to the seals. Openings shall be de-burred. Inlets and outlets to the 4-way reversing valve shall have an area sufficient to avoid excessive pressure loss, and shall have a means to prevent entry of the displacer.

3.13.4 Displacer Restrictions

The closure or end flange of a bidirectional piston prover must have a method of restricting the displacer in its resting position between the inlet and outlet connections. This restrictor insures the piston will completely de-accelerate before entering the edge of the inlet connection opening. Failure to de-accelerate the piston before it reaches the prover

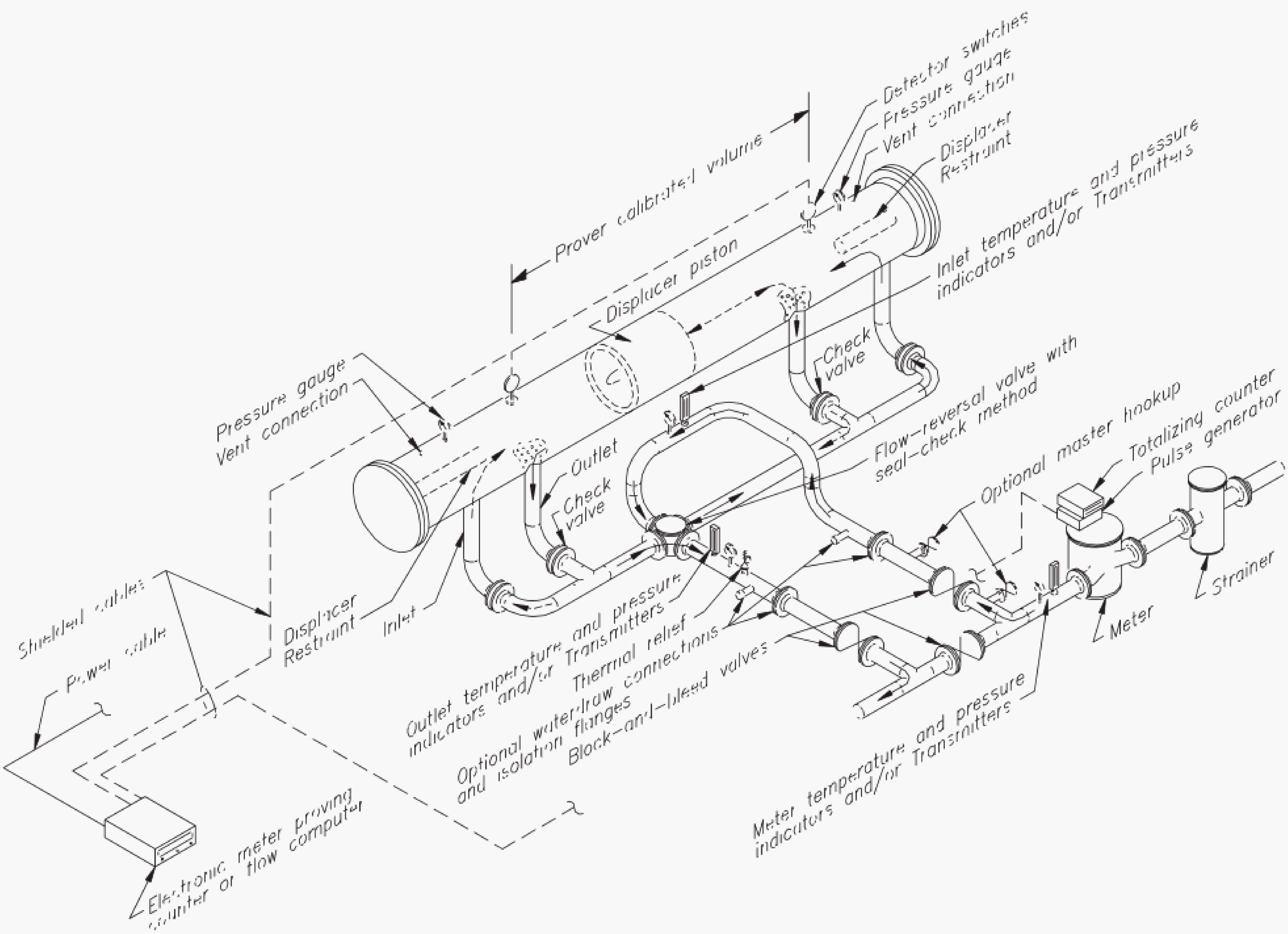

Figure 4—Typical Bidirectional Straight-type Piston Prover System

door could cause damage to the sphere and/or prover. If the piston covers the inlet opening at the end of a prover pass, it may not allow the piston to move in the opposite direction upon flow reversal.

4 Design of Displacement Provers

4.1 INITIAL CONSIDERATIONS

Before a displacement prover is designed or selected, it is necessary to establish the type of prover required for the application and the manner in which it will be connected with the meter piping. Based on the application, intended use, and space limitations, the following should be established. A typical data sheet is shown is Appendix D.

a. If the prover is stationary, determine:
   1. Whether it will be dedicated (on line) or used as part of a central system.
   2. Whether it will be kept in service continuously or isolated from the metered stream when it is not being used to prove a meter.
   3. What portions, if any, are desired below ground.
   4. What foundation and/or support requirements are needed.

b. If the prover is mobile, determine:
   1. Whether leveling devices are required.
   2. Hose compatibility with liquids.
   3. Whether hoses or arms are required.

c. The ranges of temperature and pressure that will be encountered.

d. The maximum and minimum flow rates expected.

e. The flow rate stability.

f. The maximum pressure drop allowable across the prover.

g. The physical properties of the fluids to be handled.

h. The degree of automation to be incorporated in the proving operation.

i. The disposal requirements for the fluid.

j. Available utilities.

k. Volume requirements of the prover.

l. Whether or not pulse interpolation will be used.

4.2 DESIGN ACCURACY REQUIREMENTS

4.2.1 General Considerations

The ultimate requirement for a prover is that it prove meters accurately; however, accuracy cannot be established directly because it depends on the repeatability of the meters, the accuracy of the instrumentation, and the uncertainty of the prover's base volume. The accuracy of any prover/meter combination can be determined by carrying out a series of measurements under carefully controlled conditions and analyzing the results statistically. Appendix C provides one method of calculating this.

The nature of physical measurements makes it impossible to measure a physical variable without error. Absolute accuracy is only achievable when it is possible to count the objects or events; even then, when large numbers are involved, it may be necessary to approximate. Of the three basic types of error (spurious errors, systematic errors, and random errors), only random error can be estimated through statistical methods.

For applications of statistics to custody measurement, the 95% confidence level is traditionally used for analyzing and reporting uncertainties in measured values. The limit of random uncertainty calculated from estimated standard deviation is based on a value known as Student's *t*. For the purpose of this document, all statistical data presented in this section will use:

a. A 95% confidence level.
b. Degree of freedom ($n - 1$ for n measurements).
c. Student's *t* distribution.

Appendix C provides tables to convert range to standard deviation (see Table C-1) and Student's *t* distribution values for 95% probability (see Table C-2). For further information concerning statistical analysis, see API *MPMS* Ch. 13.

4.2.2 Displacer Detectors

The minimum distance between detector switches depends on the detector's ability to consistently locate the position of the displacer. The performance of the detectors and the displacer affects both prover calibration and meter proving operations. The total uncertainty of the detectors and displacer at the 95% confidence level shall be limited to ± 0.01% of the length of the calibrated section. The prover or detector's manufacturer or the prover's designer is responsible for demonstrating, through testing and technical analysis, that the displacer's detection system meets the stated performance requirement. For additional information on displacer position calculations, see Appendix A.

4.2.3 Pulse Count Resolution

If Pulse Interpolation is not used during a single prover pass, a meter pulse counter can potentially add or lose a pulse at both the beginning and end of a pass. The indicated pulse count of a perfectly uniform pulse train has a potential error of ± 1 pulse during a single prover pass. The potential error in pulse count of a perfectly uniform pulse train is determined as follows:

$$a(N_m) = \frac{\pm 1 \text{ pulse}}{N_m} \times 100\% \qquad (1)$$

where

$a(N_m)$ = potential error of the recorded pulse count during a prover pass, ± % pulse,

N_m = number of whole meter pulses collected during a prover pass.

The error in the average pulse count of a series of prover passes can be estimated as follows:

$$a(N_m)' = \frac{a(N_m)}{np} \qquad (2)$$

where

$a(N_m)'$ = error in the average pulse count for a series of prover passes, ± % pluses,

np = number of prover passes.

4.2.4 Metering Pulse Train Variation

The output from the primary flow element of displacement and turbine meters, or other types of meters, can exhibit variations even when flow rate through the meter is constant. These variations are caused by imperfections and/or wear in bearings, blades, sensory plugs and other moving parts. Gears, universal joints, clutches and other mechanical devices that compensate, calibrate and transmit the output of the primary flow element can cause variations in the indicated flow rate signal that are greater than those caused by the primary flow element.

Three types of pulse train variations are: interpulse deviation, which refers to random variation between consecutive pulses; pulse rate modulation, which refers to a pattern of variation in pulse rate or *K* factor; and pulse burst variation which refers to meters that do not have a frequency output proportional to flow and where the pulses are transmitted intermittently (see Figure 5). These variations occur even when the flow rate through the meter is constant. They also affect the meter pulse count during a proving run and the error in the meter pulse count.

4.2.5 Base Prover Volume Variation

The procedural uncertainty (at the 95% confidence level) in the average of three calibration runs that agree within a

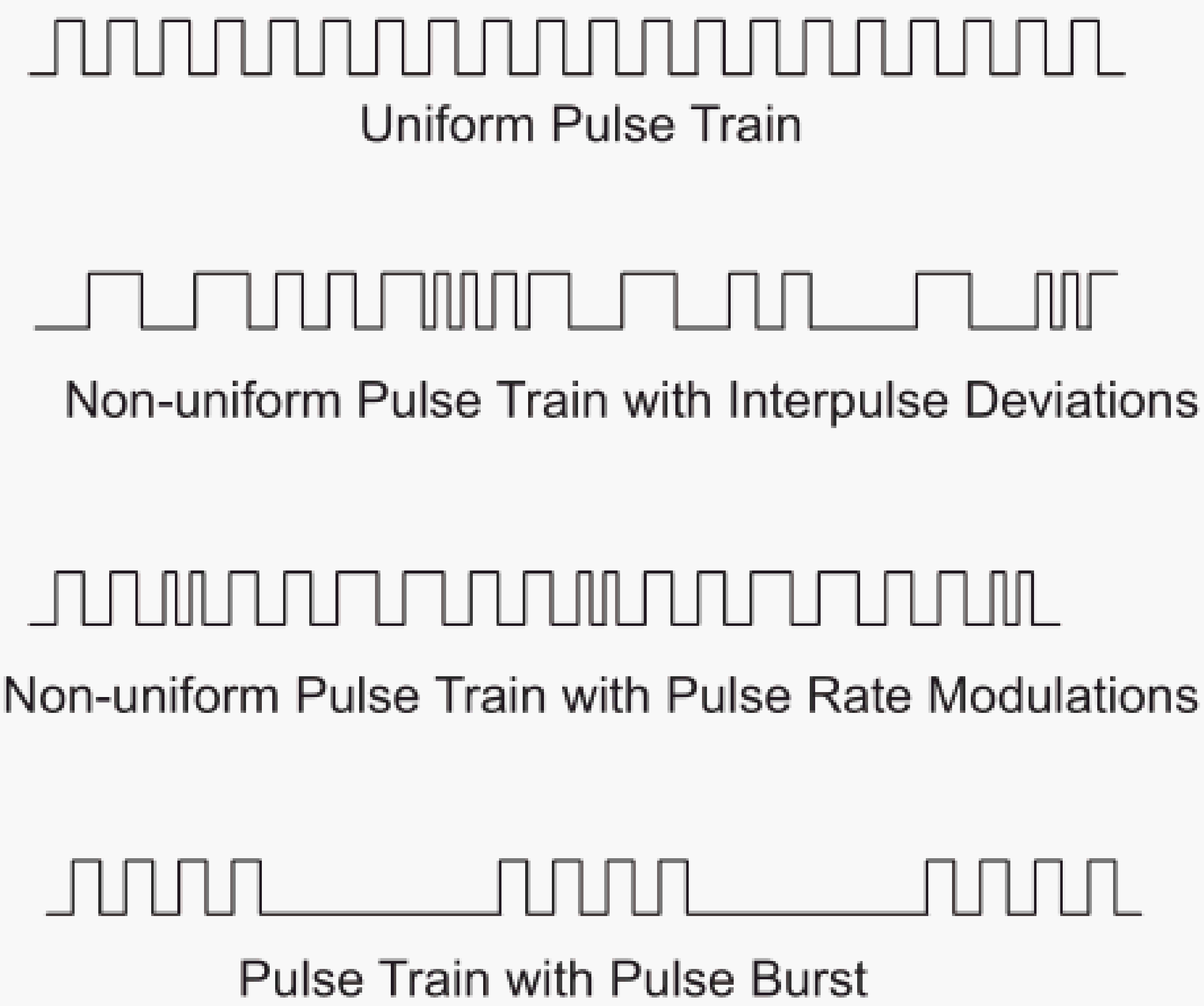

Figure 5—Pulse Train Types

range of 0.02% is ± 0.029% (see API *MPMS* Ch. 4.9). This means that there is a 95% probability that the true prover volume lies inside the range described by 0.029% of the calculated base volume. Conversely, there is only a 5% probability that the true prover base volume lies outside the range described by ± 0.029% of the calculated base volume.

4.3 DIMENSIONS OF A DISPLACEMENT PROVER

4.3.1 General Considerations

To achieve the desired accuracy of the proving system, the following items shall be considered by the designer in determining the dimensions of a prover:

a. The repeatability of the detectors.

b. The number of meter pulses per unit volume (i.e., *K* factor).

Note: The actual pulses per unit volume can vary considerably from the nominal number supplied by the meter manufacturer because of influences such as flow rate, rangeability, hydrocarbon being measured, and wear over time. Similar meters (same size and manufacturer) can and will be different.

c. The maximum and minimum flowrates of the metering systems.

d. The type of meter(s) to be proved, potential variations in the meter's pulse train.

e. Whether prover is bidirectional or unidirectional.

f. The type of displacer and the velocity limitations of the displacer.

g. The prerun and post-run requirements.

h. Wall thickness and internal diameter of piping and fitting components to meet operating requirements.

i. The physical space and weight limitations.

j. The cycle time and velocity limitations of the flow reversal valve or interchange.

The dimensions selected for provers are a compromise between displacer velocity limits and uncertainty limits on detection of the displacer's position and error in the meter pulse count. Decreasing the diameter of the prover pipe increases the length between detectors for a given volume and reduces the uncertainty on positions of the displacers. Decreasing the pipe diameter also increases displacer velocity, which may become a limiting factor. Increasing the diameter of the prover pipe has the opposite effect; the velocity of the displacer is reduced, but the resulting decrease in length increases uncertainty in positions of the displacer and thus may become a limiting factor. Examples of prover sizing can be found in Appendix B.

4.3.2 Minimum Number of Meter Pulses

In order to design a prover the first requirement is to determine the number of meter pulses that must be accumulated to meet the desired accuracy requirement (± 0.01%). For provers not using pulse interpolation the number of pulses required is determined by the pulse resolution and uncertainty as discussed in 4.3.2.1. For provers using pulse interpolation the number of meter pulses required is determined by the potential error in the timer and the meter pulse train variation as discussed in 4.3.2.2.

4.3.2.1 Provers without Pulse Interpolation

When proving a meter without pulse interpolation the number of meter pulses required, achieving an accuracy of ± 0.01% can be determined from Eq. (1) by solving for N_m.

$$N_m = \frac{\pm 1 \text{ pulse}}{a(N_m)} \times 100\%$$

where

$a(N_m)$ = potential error of the recorded pulse count during a prover pass, ±% pulse,

N_m = number of whole meter pulses collected during a prover pass.

$$N_m = \frac{\pm 1 \text{ pulse}}{0.01} \times 100\% = 10,000 \text{ pulses}$$

Therefore, a minimum of 10,000 meter pulses will be required without the use of pulse interpolation.

4.3.2.2 Provers with Pulse Interpolation

For provers using pulse interpolation the number of meter pulses required to achieve an accuracy of ± 0.01% is determined by the potential error in the double-chronometry timers and the meter pulse train variation.

P_s is utilized in Eqs. (8) and (10) in 4.3.2.2.2 to estimate the minimum number of pulses (N_m) needed for calculating the volume between detector switches for provers collecting less than 10,000 whole, unaltered pulses.

P_s will vary. It is influenced by a number of factors such as:

a. Type of meter.
b. Condition of meter.
c. Installation effects.
d. Flow rate and other flow conditions.
e. Pulse generating device.
f. Fluid properties.
g. Wiring.

As a result, the P_s obtained at the manufacturing facility may not be representative of the P_s obtained in the field.

Typically, manufacturer's P_s for turbine meters and direct drive positive displacement (PD) meters is in the range of 0.006 – 0.015, while PD meters with gear trains are typically in excess of 0.04. For any particular meter application, the meter manufacturer should be consulted for the P_s value of the meter (see Appendix E for procedures for developing P_s).

4.3.2.2.1 Estimated Error of Double Chronometry Timers During Prover Pass

The estimated error due to the resolution of double-chronometry timers during a prover pass can be calculated as follows:

$$U_t = \pm\sqrt{2}/N_c \qquad (3)$$

where

U_t = estimated error in time accumulated by two timers (one that times meter pulse output and one that times prover displacement), expressed as a plus/minus fraction of a pulse,

2 = number of timers,

N_c = number of clock pulses accumulated during a prover pass.

The number of clock pulses accumulated during a prover pass is calculated as follows:

$$N_c = T_2 F_c \qquad (4)$$

where

T_2 = clock operating time during a prover pass, in sec.,

F_c = clock frequency, in hertz (Hz).

The clock operating time during a prover pass is calculated as follows:

$$T_2 = N_m/F_m \qquad (5)$$

where

N_m = number of meter pulses during a prover pass, in pulses,

F_m = meter pulse frequency, in Hz.

Eqs. (3), (4) and (5) can be combined to express the error of the timers in terms of meter output and timer frequency:

$$U_t = \pm\sqrt{2}F_m/N_m F_c \qquad (6)$$

The meter pulse frequency is calculated as follows:

$$F_m = Q_m k/3600 \qquad (7)$$

where

Q_m = meter flow rate,

k = meter pulses per unit volume or mass, in pulses per barrel,

3600 = number of sec. per hour.

4.3.2.2.2 Estimated Error Due to Non-uniform Meter Interpulse Spacing

The estimated error due to non-uniform meter interpulse spacing at the start and end of a prover pass is calculated as follows:

$$U_m = \sqrt{N_{\text{Det}}}(\pm P_s)/N_m \qquad (8)$$

where

U_m = estimated error due to non-uniform meter interpulse spacing during a prover pass, expressed as a plus/minus fraction,

N_{Det} = number of times a detector is actuated for a proving run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

$$P_s = \text{pulse stability} = \frac{\text{standard deviation of pulse period}}{\text{mean of pulse period}}$$

$$P_s = \frac{N_\sigma \cdot \sigma_{\text{normalized}}}{N_{PR}/N_S}$$

where

N_σ = the number to capture possible pulse fluctuation events,

N_σ of 2 have 95% confidence level,

N_σ of 6 will include all possible intra-pulse variations,

N_{PR} = number of pulses per revolution (cycle) of the primary element of meter,

N_S = number of possible pulse triggers per prover run,

N_S = 4 for prover using double chronometry (2 detector switches and 2 time triggers),

N_S = 2 for provers using single timer method.

For a procedure to develop the P_s for a meter see Appendix E. Typically, P_s for turbine meters and direct drive PD meters is in the range of 0.006 – 0.015. For PD meters with gear trains the P_s is in excess of 0.04. For your particular meter application, check with the meter manufacturer.

4.3.2.2.3 Total Uncertainty in the Number of Meter Pulses

The combined meter output uncertainty at the start and end of a prover pass can be estimated by combining Eqs. (6) and (8) as follows:

$$a(N_m) = \sqrt{U_t^2 + U_m^2} = \sqrt{(\pm\sqrt{2}F_m/N_mF_c)^2 + (\sqrt{N_{\text{Det}}}(\pm P_s)/N_m)^2} \quad (9)$$

If $a(N_m)$ equals an uncertainty of 0.01%, then solving the equation above for N_m yields the following:

$$N_m = 10,000\sqrt{N_{\text{Det}}}\sqrt{\left(\frac{F_m}{F_c}\right)^2 + P_s^2} \quad (10)$$

where

N_{Det} = number of times a detector is actuated for a proving run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

F_m = meter pulse frequency, in Hz,

F_c = clock frequency, in Hz,

$$P_s = \text{pulse stability} = \frac{\text{standard deviation of pulse period}}{\text{mean of pulse period}}$$

$$P_s = \frac{N_\sigma \cdot \sigma_{\text{normalized}}}{N_{PR}/N_s}$$

where

N_σ = the number to capture possible pulse fluctuation events,

N_σ of 2 have 95% confidence level,

N_σ of 6 will include all possible intra-pulse variations,

N_{PR} = number of pulses per revolution (cycle) of the primary element of meter,

N_S = number of possible pulse triggers per prover run,

N_S = 4 for prover using double chronometry (2 detector switches and 2 time triggers),

N_S = 2 for provers using single timer method.

4.3.3 Volume

For a prover the minimum volume of the calibrated prover pass (between detector switches) is:

$$V_p \geq \frac{N_m}{k} \quad (11)$$

where

V_p = volume of prover pass, barrels,

N_m = number of meter pulses during a prover pass, in pulses,

k = K factor for meter, pulses per barrel.

For example, if k = 1000 pulses per barrel for a meter and a prover does not use pulse interpolation (where N_m equals 10,000 pulses), V_p is:

$$V_p \geq \frac{10{,}000 \text{ pulses}}{1000 \text{ pulses/barrel}} = 10 \text{ barrels}$$

After designing a meter prover for a specific application, the volume of the prover should be adjusted up to accommodate a minimum number of test measures used during a water-draw calibration. The least number of test measures used will reduce the overall uncertainty of the calibration procedure.

Example:

If the original design requirements call for 92 gallons between detector switches, the minimum test measures required would be:

1 – 50 gallon test measure
1 – 25 gallon test measure
1 – 10 gallon test measure
1 – 5 gallon test measure
2 – 1 gallon test measures

This would require six scale and temperature readings, six calculations, and would take a considerable amount of time to fill and drain the six test measures.

If the prover volume would be adjusted up to 100 gallons between the switches, the calibration would require only one 100 gallon test measure. This will reduce the calibration time and uncertainty.

Other things to consider that may increase the volume required include:

a. The variance of the actual *K* factor from the manufacturer's typical published *K* factor for turbine meters may result in less than 10,000 pulses.

b. For small displacement meters, generally less than 4 in., which use mechanical gearing in their pulse generation train, the volume may need to be increased to the next whole unit of volume per revolution of the meter to avoid the cyclical effects of the clutch calibrator. For example, 5 gallon increments on 5 – 1 gallon-geared meters.

4.3.4 Displacer Velocities

Some practical limit to the maximum velocity of a displacer must be established to prevent damage to the displacer and the detectors. Nevertheless, the developing state of the art advises against setting a firm limit to displacer velocity as a criterion for design. Demonstrated results are better to use as a criterion. The results are manifested in the repeatability and reproducibility of *MF*s using the prover in question. Other considerations include consistency of the prover diameter and prover surfaces along with the friction between the prover and displacer's sealing surfaces.

4.3.4.1 Maximum Displacer Velocities

For sphere displacers, most operators and designers agree that 10 ft/sec. is a typical design specification for unidirectional provers, whereas velocities up to 5 ft/sec. are typical in bidirectional provers.

For piston displacers, a maximum velocity of 3ft/sec. – 5 ft/sec. is recommended, depending on the design.

Higher velocities may be possible if the design incorporates a means of limiting mechanical and hydraulic shock as the displacer completes its pass.

4.3.4.2 Minimum Displacer Velocities

Minimum displacer velocity must also be considered, especially for proving meters in a liquid that has little or no lubricating ability, such as gasoline that contains high proportions of aromatics or liquefied petroleum gas. The displacer should move at a uniform velocity between detectors. At low velocities when the lubricating ability is poor, the sealing friction is high, and/or the prover surface is rough, the displacer may chatter.

Typical minimum sphere displacer velocities for lubricating fluids are 0.5 ft/sec. – 1.0 ft/sec. For non-lubricating fluids such as LPGs and NGLs higher minimum velocities will be necessary for sphere type displacers. Minimum sphere displacer velocities can be decreased by using low friction spheres (e.g., Teflon® blends, etc.), or by honing and polishing the inside of the prover.

Typical minimum piston displacer velocities are 0.25 ft/sec. – 0.5 ft/sec. for piston elastomer cup seals and 0.1 ft/sec. or less for piston spring loaded plastic cup seals. Minimum velocities to ð 0.005 ft/sec. may be attainable by honing and polishing the inside of the prover.

4.3.4.3 Displacer Velocity Calculations

The velocity of the displacer is dependent upon the internal diameter of the prover pipe and the maximum and minimum flow rates of the meters to be proved.

The velocity of the displacer can be calculated as follows:

$$\text{velocity} = \frac{\text{flow rate}}{\text{area of the pipe}}$$

$$V_d = \frac{Q}{\frac{\pi}{4}D_p^{\,2}}$$

$$V_d = \frac{4 \times 42 \text{ gallons/barrel} \times 231 \text{ in.}^3\text{/gallon} \times Q}{\pi \times 12 \text{ in./ft} \times 3600 \text{ sec./h} \times D_p^{\,2}}$$

$$V_d = \frac{0.286 \times Q}{D_p^{\,2}} \tag{12}$$

where

Q = flow rate, barrels per hour (bbl/h),

D_p = inside diameter of the prover, in.,

V_d = displacer velocity, ft/sec.

This standard is not intended to limit the velocity of displacers. Provided that acceptable performance can be assured, no arbitrary limit is imposed on velocity.

4.3.5 Prover Diameter

The prover diameter depends on the minimum and maximum flow rates and the minimum and maximum displacer velocities. The prover diameter to meet a prescribed velocity limit is determined using Eq. (5) and is repeated as follows:

$$D_p = \sqrt{\frac{0.286Q}{V_d}} \tag{13}$$

where

D_p = inside diameter of prover, in.,

Q = flow rate, bbl/h,

V_d = displacer velocity, ft/sec.

For example, if the maximum flow rate for a meter is 2300 bbl/h and a bidirectional prover will be used, D_p is:

$$D_p = \sqrt{\frac{0.286 \times 2300}{5}} = 11.47 \text{ in.}$$

If the minimum flow rate for the same meter is 473 bbl/h, the V_d from Eq. (4) is:

$$V_d = \frac{0.286 \times 473}{11.47^2} = 1.03 \text{ ft/sec.}$$

From this example the prover diameter of 11.47 in. would satisfy both the maximum and minimum velocity recommendations for a bidirectional prover.

The final design diameter should be based upon a nominal pipe size that meets the design operating pressure requirements of the system.

4.3.6 Minimum Calibrated Section Length

Two calculations are required to determine the length of the calibrated section of the prover. The length shall be dependent upon the greater of:

a. the length of the calibrated section based on the minimum required volume, or
b. the length required to meet the accuracy of the detectors.

The calculation for the calibrated section length based upon the minimum required volume is:

$$\text{minimum calibrated section length} = \frac{\text{minimum volume of the prover}}{\text{area of the prover pipe}}$$

$$L_{\min_v} = \frac{4 \times 42 \text{ gallons/barrel} \times 231 \text{ in.}^3\text{/gallon} \times V_p}{\pi \times 12 \text{ in./ft} \times D_p^2}$$

$$L_{\min_v} = \frac{1029.41 \times V_p}{D_p^2} \tag{14}$$

where

$L_{\min_v}$ = minimum calibrated section length based on volume (ft),

V_p = volume of calibrated section (barrels),

D_p = prover inside diameter (in.).

For example, if the volume of the calibrated section is 10 barrels, as calculated in Eq. (11), and the prover inside diameter is 11.47 in. as calculated in Eq. (13), $L_{\min_v}$ is:

$$L_{\min_v} = \frac{1029.41 \times 10}{11.47^2} = 78.24 \text{ ft}$$

The minimum calibrated length between detector switches depends on the accuracy with which the detector switch can repeatedly determine the position of the displacer and the desired discrimination of the prover system during calibration. The span of repeatability for determining the position of the displacer during a prover run is limited to ± 0.01% (± 0.0001 or 0.0002 range) of the length of the prover run. Minimum length of the prover run based on the accuracy of the detectors is determined as follows:

Note: Generally accepted statistical methods use the square root of the number of events to arrive at the 95% confidence level.

$$\text{minimum calibrated section length} = \frac{\text{displacer position repeatability (detector actuations)}^{0.5}}{\text{desired prover accuracy}}$$

$$L_{\min_{\text{Det}}} = \frac{\Delta X \sqrt{N_{\text{Det}}}}{P_a} \tag{15}$$

where

$L_{\min_{\text{Det}}}$ = minimum calibrated section length of a prover run based upon the prover detectors,

ΔX = displacer position repeatability resulting from detector uncertainty during a prover pass (in.). The ΔX of a sphere displacer must be determined using Appendix A. For piston displacers, consult the manufacturer,

N_{Det} = number of times a detector is actuated for a calibration run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

P_a = desired prover accuracy.

For example, if $\Delta X = \pm\ 0.030$ in. (0.060 in. total) and the desired accuracy is 0.02%, $L_{\min_{Det}}$ for a bidirectional prover becomes at least:

$$L_{\min_{Det}} = \frac{0.060 \text{ in.} \times \sqrt{4}}{0.0002 \times 12 \text{ in./ft}} = 50 \text{ ft per run}$$

$$= 25.0 \text{ ft per pass}$$

For a bidirectional prover, a prover run consists of two passes. Since 78.24 ft (from $L_{\min_v}$) is greater than 25.0 ft (from $L_{\min_{Det}}$) the calibrated section of the prover must be at least 78.24 ft long.

4.3.7 Prerun

Prover prerun is the length of pipe required for the displacer to travel from its holding or resting location to the first detector. The minimum prerun length must allow for sufficient time to bring the displacer up to maximum stable velocity before reaching the calibrated section of the prover. It also must provide sufficient time for the interchange or flow reversing valve (e.g., 4-way valve) to cycle and seal.

The valve and interchange manufacturer should be consulted to establish minimum travel and seal times, and maximum allowable velocity. Consideration should be given to installation of a valve or interchange seal detector so that the proving controls can determine that a seal has been established before the displacer reaches the first detector of the calibrated section.

Methods used to shorten this prerun, such as faster operation of the valve or delay of the displacer launching, require that caution be exercised in the design so that hydraulic shock or additional undesired pressure drop is not introduced. If more than one flow-directing valve is used, they should be sequenced to prevent shock.

The prerun length is calculated as follows:

$$\text{minimum prerun length} = (\text{cycle time}) \times (\text{maximum velocity}) \times (\text{stabilization factor})$$

$$L_{pr} = T_{pr} \times V_{d\ \max} \times SF \qquad (16)$$

where

L_{pr} = minimum prerun length (ft),

T_{pr} = cycle time (sec.),

$V_{d\ \max}$ = the maximum velocity of displacer (ft/sec.),

SF = stabilization factor determined by the manufacturer or designer.

Note: The stabilization factor is essentially a safety factor to ensure that enough time is provided to stabilize the flow before the displacer hits the first detector. This is typically 1.25.

Cycle Time:

a. For a bidirectional prover, total cycle time is defined as the time required to reverse the flow including unseating the valve(s), changing valve positions, and reseating the valve(s). The movement of the sphere starts at the mid travel point of the valves, therefore, only one half of the total cycle time is used in the calculation.

b. For a unidirectional sphere prover, total cycle time is defined as the time when the interchange actually launches the sphere into the flow stream, to the point when the interchange plunger or valve seals.

c. For a unidirectional piston prover, total cycle time is defined as the total time required to close the poppet valve in the piston or the external bypass valve.

For example, given a 4-way valve cycle time of 8 sec., a displacer maximum velocity of 5 ft/sec., and an assumed stabilization factor of 1.25, L_{pr} is calculated as:

$$L_{pr} = \frac{8}{2} \times 5 \times 1.25 = 25 \text{ ft}$$

5 Installation

5.1 GENERAL CONSIDERATIONS

All components of the prover installation, including electrical, piping, valves, and manifolds, shall be in accordance with applicable codes. Once the prover is in service, it becomes a part of the pressure piping system.

The proving section and related components shall have suitable hangers and supports prescribed by applicable codes and good engineering principles. When proving systems are designed and installed, precautions should be taken to cope with expansion, contraction, vibration, pressure surges, and other conditions that may affect piping and related equipment.

Adequate access to all equipment and parts of the prover system for maintenance purposes, meter proving activities and prover calibration requirements shall be provided. This may include walkways, space for field standard installation, and truck access.

Valving to isolate the prover unit from line pressure when it is not on stream (e.g., during maintenance or removal of the displacer) must be provided.

All units shall be equipped with vent and drain connections. Vent valves should be installed on the topmost portion of the pipe and should be located where all air is vented from dead spaces that are not swept by the displacer. Provisions should be made for the disposal of liquids or vapors that are drained or vented from the prover. This may be accomplished by pumping liquids or vapors back into the system or by diverting them to a collection point.

Temperature sensors in accordance with 3.3 and pressure gauges in accordance with 3.4 should be installed in suitable locations to determine the temperatures and pressures of the prover's calibrated section.

Note: Temperature sensors and pressure gauges should also be installed in suitable locations near the meter.

In most instances, these are installed at the outlet of the prover. Where differences in temperatures and pressures normally exist, install sensors at both inlet and outlet locations.

Blind flange or valve connections should be provided on either side of a leak-free block valve in the piping system to serve as a connection for proving portable meters or as a means for calibrating the prover by the master-meter method. Connections at the inlet and outlet should be provided for calibration by the waterdraw method. Examples of suitable connections are shown in Figures 1, 3 and 4.

Pressure relief valves with discharge piping and leak-detection facilities are usually installed to control thermal expansion of the liquid in the prover while it is isolated from the mainstream. These devices should be positioned to avoid being located between the meter and the far most detector of the prover. For example, if the meter prover system is designed with the meter before the prover, the pressure relief should be located after the second detector. If the prover is located ahead of the meter, the pressure device should be installed before the first detector. Pressure relief valves should be avoided between the meter and the prover.

Power and remote controls should be suitably protected with lockout switches, circuits, or both, between remote and local panel locations to prevent accidental remote operation while a unit is being controlled locally. Suitable safety devices and locks or seals should be installed to prevent inadvertent operation of, or unauthorized tampering with, equipment. All wiring and controls shall conform to applicable codes. Components shall conform to the class and group appropriate to the location and operation. All electrical controls and components should be placed in a location convenient for operation and maintenance. Manufacturers' instructions should be strictly followed during the installation and grounding of electronic counters, controls, power units, and signal cables.

Where applicable, provers and metering equipment should be protected by strainers or filters.

5.2 PROVER LOCATION

Displacement provers may be either mobile (portable) or stationary. When in service, they should be located as near to the meters as practical. Because of space limitations, some provers are buried during installation while others are positioned above ground and skid mounted or otherwise supported.

5.2.1 Mobile Prover

A mobile prover is normally mounted on a road vehicle or trailer so that it can be taken to various sites for proving of meters in their installed positions while they are in normal operation. Mobile provers are occasionally housed in containers or mounted on self-contained skids so that they may be transported by road, rail, or sea. Mobile provers are always provided with a means of safely and conveniently connecting them to the metering system. Mobile provers are designed to operate in the meter's environment. Provisions must be made to electrically ground the prover.

Portable meter provers mounted on a truck or trailer fall within the purview of the DOT *Code of Federal Regulations* (*CFR*) for the transportation of hazardous materials. The code is applicable when portable meter provers are moved on public roads and contain flammable or combustible liquids or are empty but not gas free. The most recent edition of 49 *CFR* Parts 171 – 177 (Subchapter C, "Hazardous Materials Regulations") and 390 – 397 (Subchapter B, "Federal Motor Carrier Safety Regulations") should be consulted (see specifically Sections 172.500, 172.503, 172.504, 172.506, 172.507, 173, 177.817, 177.823, 391.11(a)(7), 391.41.49, and 393.86). The DOT provides an exemption from 173.119, 173.304, and 173.315 for portable meter provers.

When flexible hoses are used to connect a portable prover to a metering system, caution must be taken to ensure that the hoses are in good physical condition, the working and burst pressures of the hoses are adequate for the procedure, and the material of construction is compatible with the liquid to be used in proving.

5.2.2 Stationary Prover

A stationary prover is fixed at one site and is connected by a system of pipes and valves to the meter(s) at or near that site. It is used to prove the meters independently, or in combination, at the required time intervals.

5.2.3 Central Prover

A central prover is a stationary prover installed at a location where pumping facilities and a supply of liquid are available. It is used to prove meters that are periodically brought to the prover and temporarily connected. The following precautions should be taken to ensure performance similar to what would be expected if the meter was proved at its normal operating location:

a. Meters should be proved on liquids similar to those under normal operating conditions.
b. The meter should be operated at a flow rate typical to operating flow rates.
c. Meters should be handled with care during transportation, storage and installation, so that their performance will not change when they are reinstalled at their operating location.

APPENDIX A—ANALYSIS OF SPHERE POSITION REPEATABILITY

A.1 General Information

The equation discussed in this appendix is used to determine the change in linear position of a sphere displacer relative to the mechanical and electrical actuation of a prover detector. As the mechanical tolerance and electrical switch timing of the detector varies, so does the linear position of the sphere and the prover volume. Because of this relationship, the potential impact on accuracy of a prover can be determined from the actuation tolerance of the sphere detector and the variance of electrical switch timing. This includes all the electrical components that are connected between the detector electrical switch and the electronic device being actuated. The equation may also be used to determine the minimum length of a prover if the detector tolerance, electrical switch timing, and required repeatability of the proving system are known. The detector switch and electrical timing tolerance represent the random error associated with a typical detector switch.

Other effects can and do have an impact on the evaluation techniques recounted herein, including sphere selection. Prover spheres are available in a selection of durometer ranges and equipped with and without an internal bladder. Too many combinations of switches, sphere type, sphere material and internal construction are available to offer precise guidance. This appendix is intended to inform the reader regarding those considerations that may materially affect the accurate performance of the prover with respect to both mechanical and electrical switch hysteresis.

A.2 Mathematical Explanation of Sphere Position Repeatability

The relationship between sphere position repeatability and the detector actuation tolerance is described below and is illustrated in Figure A-1. If the insertion depth (or actuation depth) of the detector changes on the vertical axis (y), the position of the sphere changes on the horizontal axis (x). When errors due to mechanical tolerances in the detector switch are known, they can be used to determine the change in actuation depth. This change in insertion depth results in a change in position of the sphere.

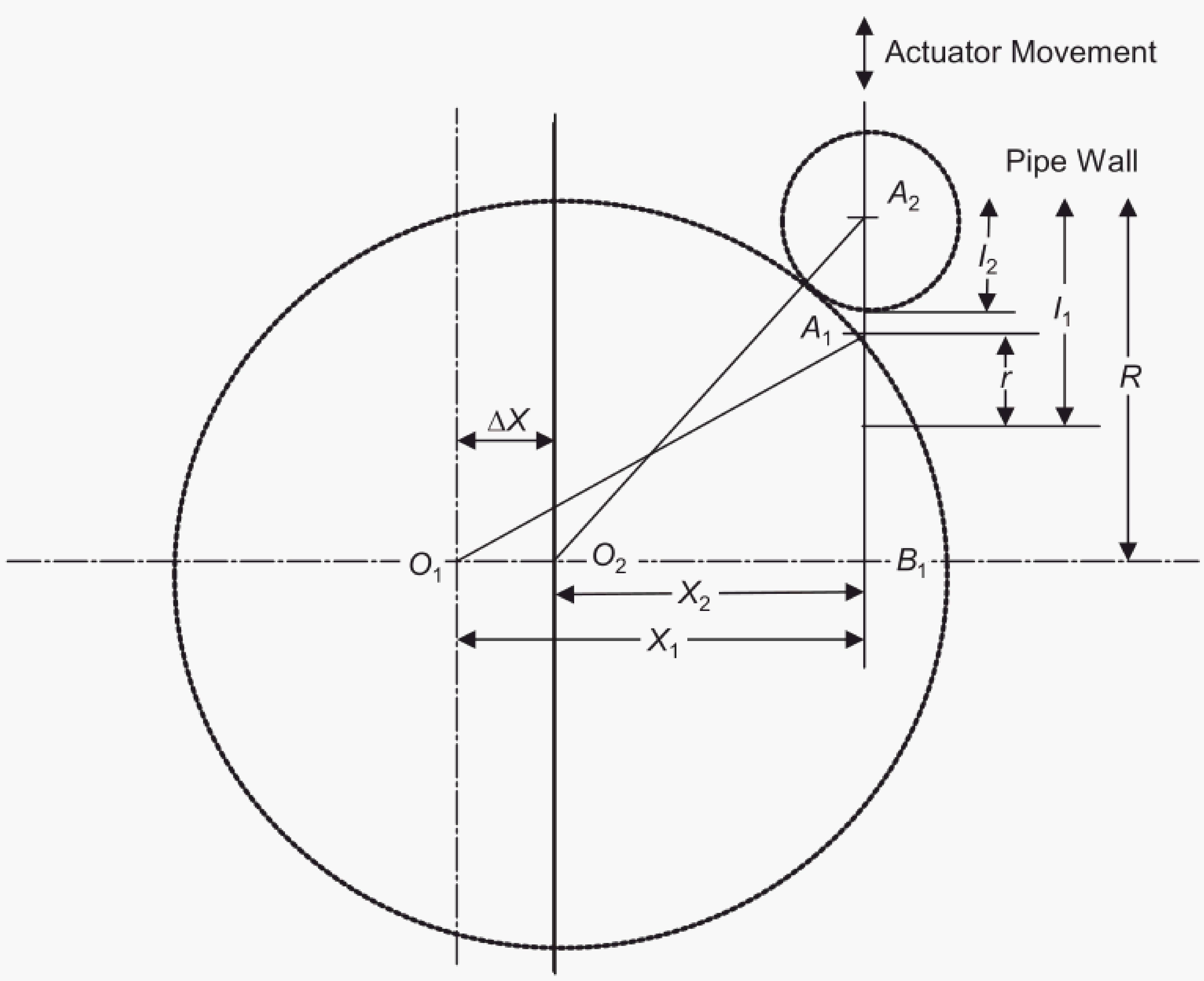

Figure A-1—Diagram Showing the Relationship Between Sphere Position Repeatability and Mechanical Detector Actuation Repeatability

A.2.1 DETECTOR MOVEMENT IN THE *Y* DIRECTION

The equation below determines the movement of the sphere due to movement of the detector switch, in the vertical direction (y).

where

R = radius of the sphere,

D = diameter of sphere or inside diameter of the displacement prover,

r = radius of the actuator detector probe,

d = diameter of actuator detector probe,

I_1 = maximum detector actuation depth,

I_2 = minimum detector actuation depth,

$I_1 - I_2$ = range of detector actuation or mechanical repeatability (total error along the y axis,

X_1 = center of the sphere from actuator axis for maximum insertion depth for switch activation,

X_2 = center of the sphere from actuator axis for minimum insertion depth for switch activation,

ΔX_y = Movement of sphere due to mechanical repeatability of one detector switch on the y axis.

Subscript 1 and 2 are the switch activation limits of the maximum and minimum insertion depth of the actuator, respectively. Distance X_1 and X_2 are the distances of the center of the sphere from the center of the actuator, for the maximum and minimum insertion depth limits of actuation.

Using the Pythagorean theorem for triangle $O_1A_1B_1$:

$$X_1 = \sqrt{O_1A_1^{\,2} - A_1B_1^{\,2}}$$

$$= \sqrt{(R+r)^2 - (R - I_1 + r)^2}$$

$$= \sqrt{(R+r^2) - (R+r^2) + 2 \times (R+r) \times I_1 - I_1^2}$$

$$= \sqrt{(D+d) \times I_1 - I_1^2}$$

Using the same logic for triangle $O_2A_2B_1$:

$$X_2 = \sqrt{(D+d) \times I_1 - I_1^2}$$

Therefore, the sphere travel repeatability for the mechanical actuation of the switch is:

$$\Delta X_y = X_1 - X_2$$

$$\Delta X_y = \sqrt{(D+d)(I_1) - I_1^{\,2}} - \sqrt{(D+d)(I_2) - I_2^{\,2}} \qquad \text{(A.1)}$$

A.2.2 DETECTOR MOVEMENT IN THE *X* DIRECTION

Movement (or mechanical repeatability) of the detector along the x axis is equal to movement of the sphere down the pipe by the same amount since both are moving along the same axis. For this reason no formula is needed to calculate ΔDX_x.

A.2.3 DETECTOR MOVEMENT IN THE *Z* DIRECTION

Movement of the detector along the z axis causes the detector to move perpendicular to the pipe along the top of the detector base. This causes the actuation point to move off the sphere in the z direction. In order for the sphere to contact the new actuation point, the sphere has to move forward along the x axis to reach the new actuation point. A sensitivity analysis was conducted to determine the significance of the error in X with the movement of the detector in the Z direction. In the worst case the error was approximately 0.0001 %. For this reason the movement of the detector in the Z direction will not be considered.

A.2.4 TOTAL SPHERE MOVEMENT IN THE *X* DIRECTION

So the total mechanical movement of the switch would be,

$$\Delta X_m = \Delta X_x + \Delta X_y \qquad \text{(A.2)}$$

Table A.3 gives examples of detector movement on each axis and the total volume change it causes. In many cases the detector is mounted in a circular base that restricts movement. With a circular base, if the sphere position is at maximum x, then the z movement would be zero. Similarly, if the sphere position is at maximum z, then the x movement would be zero. In this case the maximum sphere movement would be caused by changes in detector position in the y coordinate and either x or z coordinates.

A.3 Sphere Position Change Due to Switch Electrical Tolerance

If high-speed electronics are connected directly to the detector, the electronic actuation time of the prover detector switch will have minimal impact on the prover volume. However, if there are additional electrical components, such as relays and/or heavy-duty electrical/mechanical switches connected in the circuit, the electrical timing tolerance of the circuit will have an impact on the minimum prover volume. Therefore, the total electrical timing tolerance (ΔT) of all the electrical components in one switch should be accounted for as shown below.

$$(\Delta T) = \sqrt{\Delta t_1^2 + \Delta t_2^2 + \Delta t_3^2} \qquad \text{(A.3)}$$

where

ΔT = total electrical timing tolerance in unit of time,

Δt_1, Δt_2, Δt_3, etc. = timing tolerance of individual components in units of time.

In order to determine the timing tolerance of an electronic component, a digital frequency meter is connected to frequency generator with the electrical component being tested connected in-between. The electrical component must be a double throw design with normally open and normally closed contact positions. The circuit is wired by connecting one leg of the frequency generator signal wire to the normally open and normally closed contacts of the electrical device and then connected to the frequency counter. The other leg of circuit is connected from the frequency generator, to the common contact of the electrical device and then to the frequency counter. The signal generator should then be turned on to a frequency of 30,000 to 50,000 Hz. Although the generator is running, no counts will be registered because the electronic device is wired to both the normally open and normally closed connection causing a closed loop circuit. However, when the electronic device is activated, the frequency counter will record pulses as the switch in the electronic device travels from normally closed to normally open. This short burst of pulses can then be divided by the pulse output of the frequency generator to determine the time component for this device. The frequency counter should be zeroed each time the device is reset. This procedure should be repeated several times to determine an average time component.

This procedure should be conducted on several different units of the same type of device. From that, a high and low value of the time component can be established. The difference in the high and low value is ΔT.

In order to determine the variance in prover sphere position due to the electrical components, the following equation may be used.

$$\Delta X_e = \Delta T \times V_p \qquad \text{(A.4)}$$

where

ΔX_e = sphere position tolerance due to electrical components,

V_p = velocity of prover sphere.

If the prover electronic switch timing is changed due to component modifications, the change may affect the prover volume. For example, if the electrical switch speed is increased (quicker response) on the second detector, the detector will actuate sooner. The second detector switch actuating at an earlier point in the prover sphere's travel will make the prover volume smaller.

A.4 Total Detector Switch Repeatability

Once the mechanical repeatability (ΔX_m) and the electrical repeatability (ΔX_e) of the detector switch have been determined, the Total Repeatability of the switch (ΔX) can be determined as follows:

$$\Delta X = \sqrt{(\Delta X_e)^2 + (\Delta X_m)^2} \qquad \text{(A.5)}$$

where

ΔX = displacer position repeatability,

ΔX_m = mechanical repeatability of the detector switch components,

ΔX_e = electrical repeatability of the detector switch components.

A.5 Prover Accuracy

Once the linear accuracy of the displacer with respect to the detector and the electrical component timing tolerance are known, the accuracy of a prover can be determined from the equation:

$$P_a = \frac{\Delta X \sqrt{N_{\mathrm{Det}}}}{L} \qquad \text{(A.6)}$$

where

P_a = prover accuracy,

N_{Det} = number of times a detector is actuated during a calibration run (unidirectional = 2 for a single pass, bi-directional = 4 for two passes),

L = length of the calibrated section of the prover,

ΔX = displacer position repeatability.

Conversely, if the desired prover accuracy is known, the minimum prover length for a given detector accuracy can be determined by:

$$L_{\mathrm{min}_{\mathrm{Det}}} = \frac{\Delta X \sqrt{N_{\mathrm{Det}}}}{P_a} \qquad \text{(A.7)}$$

where

$L_{min_{Det}}$ = minimum calibrated section length based upon the prover detectors.

Due to the mathematical relationship between the sphere and the detector, the following points should be noted when designing a prover or troubleshooting prover problems.

a. Sphere position repeatability is several magnitudes greater than the detector actuation repeatability. With most provers this can range between 3 to 6 times greater. (See Figure A-2 and Figure A-3.)
b. To minimize proving error caused by detector uncertainty, the detector actuation depth should be as long as practicable. (See Figure A-2 and Figure A-3.)

A.6 Examples

A.6.1 EXAMPLE 1—MECHANICAL TOLERANCE ONLY

If the effect of only the detector mechanical tolerance is needed equation A.1 can be used to determine the change in sphere position. For example, assume the following values:

D = 13.250 in. (the internal diameter of 14 in., 0.375 wall pipe),

d = 1.0 in. (the diameter of the detector probe end),

I_1 = 0.1875 in. (the actuation insertion depth of the detector),

I_2 = 0.1625 in. = I_1 – 0.0250 in. (the detector repeatability of 0.0250 in.).

$$\Delta X = \sqrt{(13.250 + 1.0)(0.1875) - 0.1875^2} - \sqrt{(13.250 + 1.0)(0.1625) - 0.1625^2}$$

$$\Delta X_m = 0.111 \text{ in.}$$

Based on equation A.1, ΔX_m = 0.111 in. This means that in this example the sphere position repeatability as signaled (ΔX_m) is 4.44 times as great as the detector repeatability (0.0250 in.).

Using this example, if the desired overall system repeatability using a unidirectional prover is (0.02 %), the minimum prover length due to the detector mechanical tolerance can be determined as follows:

P_a = 0.02 %,

ΔX_m = 0.111 in.,

N_{Det} = 2 (since a unidirectional prover is used in the example).

$$L_{min_{Det}} = \frac{0.111 \times \sqrt{2}}{0.0002 \times 12 \text{ in./ft}} = 65.40 \text{ ft}$$

A.6.2 EXAMPLE 2—ELECTRICAL TOLERANCE ONLY

If the effect of only the detector electrical tolerance is needed equation A.3 can be used to determine the change in sphere position. For example, assume the following values:

50 pulse variation between maximum and minimum pulses during device testing,

30,000 Hz frequency generator used for testing,

V_p = 10 feet per second prover sphere velocity,

50 pulses/30,000 pulses per second = 0.00167 seconds.

Using equation A.3: $\Delta X_e = \Delta T \times V_p$

ΔX_e = 0.00167 x 10 fps x 12 in./ft

ΔX_e = 0.20 in.

A.6.3 EXAMPLE 3—BOTH MECHANICAL AND ELECTRICAL TOLERANCE

From the data in Example 1 and Example 2, the minimum prover length using both mechanical and electrical tolerance can be determined by using equations A.4 and A.6.

$$\Delta X = \sqrt{(\Delta X_e)^2 + (X_m)^2}$$

$$\Delta X = \sqrt{(0.20)^2 + (0.111)^2} = 0.228 \text{ in.}$$

Using two detectors on a unidirectional prover, the minimum length would be:

$$L_{min_{Det}} = \frac{0.228 \times \sqrt{2}}{0.0002 \times 12 \text{ in./ft}} = 134.79 \text{ ft}$$

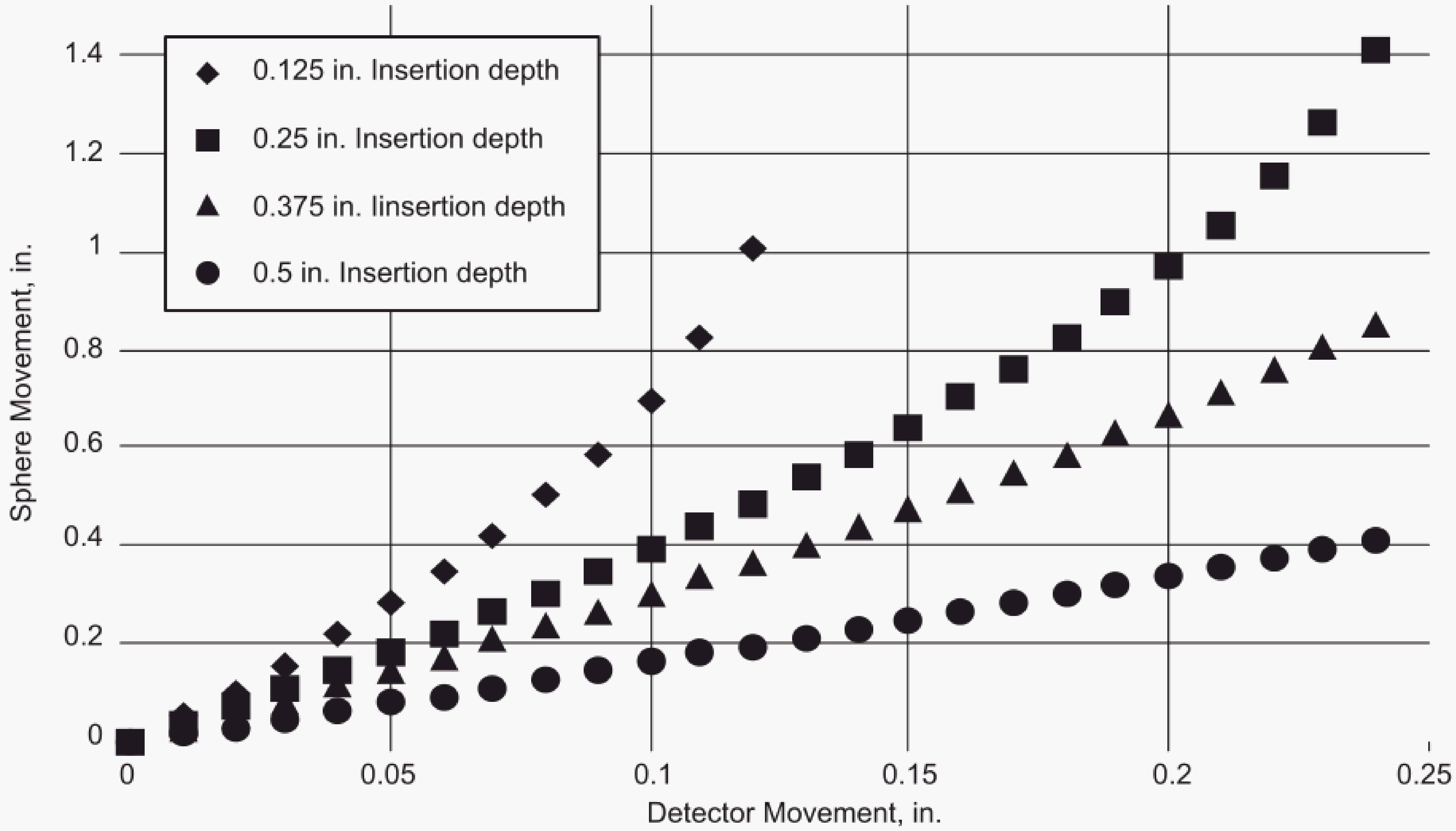

Figure A-2—Sphere versus Detector Relationship at Various Insertion Depths for a 12 in. Prover with a 0.75 in. Diameter Detector Ball

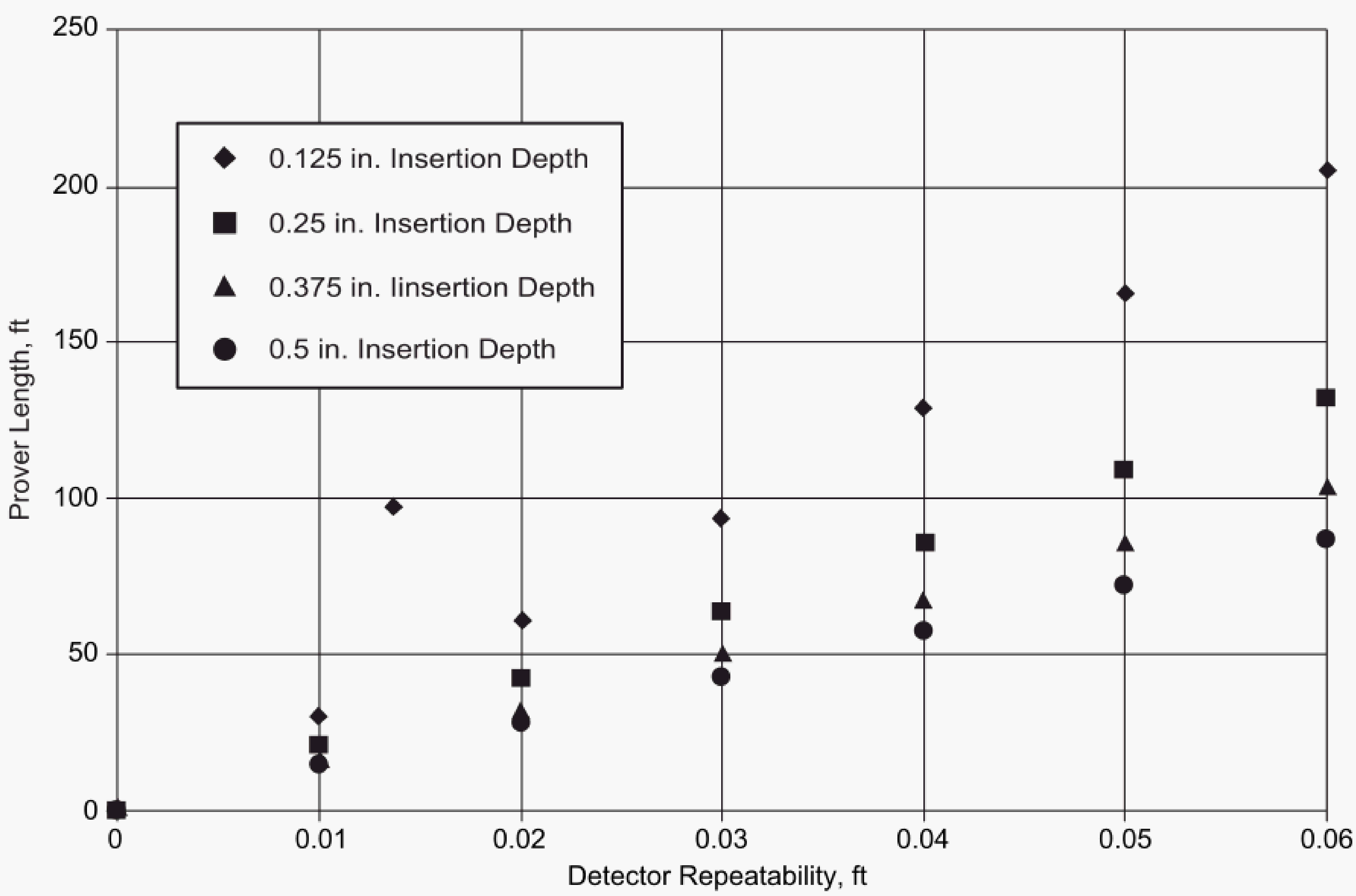

Figure A-3—Prover Length versus Detector Repeatability at Various Insertion Depths for a 12 in. Unidirectional Prover with a 0.75 in. Diameter Detector Ball

APPENDIX B—EXAMPLES OF PROVER SIZING

B.1 General

The following are two examples of typical prover sizing determinations. The choices of meter and prover combinations are for illustrative purpose only.

B.2 Bidirectional Prover Example (Accumulating at Least 10,000 Pulses)

Given: Batching operation of diesel, gasoline, and jet fuel with a bank of 4-in. turbine meters (1,000 pulses/BBL), 1,800 bbl/h normal flow rate through each meter (maximum flow rate expected 2,100 bbl/h – minimum flow rate expected 800 bbl/h), 12 in. piping, gasoline service, bidirectional sphere prover.

Step 1: Determine minimum volume between detector switches to achieve at least 10,000 pulses per proving pass.

a. Using Eq. (11) from 4.3.3:

$$V_p \geq \frac{10{,}000 \text{ pulses}}{k}$$

$$= \frac{10{,}000 \text{ pulses}}{1{,}000 \text{ pulses per barrel}}$$

$$= 10 \text{ barrels}$$

Step 2: Determine displacer velocity.

a. Using Eq. (12) from 4.3.4.3:

$$V_d = \frac{0.286 \times Q}{D_p^2}$$

$$= \frac{0.286 \times 1{,}800 \text{ bbl/h}}{12^2}$$

$$= \frac{514.8}{144}$$

$$= 3.575 \text{ fps}$$

This velocity falls within the "typical accepted" range of 1 fps – 5 fps for bidirectional sphere provers.

b. Test against max and min expected flow rates:

1. Max:

$$V_d = \frac{0.286 \times 2{,}100 \text{ bbl/h}}{12^2}$$

$$= \frac{600.6}{144}$$

$$= 4.17 \text{ fps (okay)}$$

2. Min:

$$V_d = \frac{0.286 \times 800 \text{ bbl/h}}{12^2}$$

$$= \frac{228.8}{144}$$

$$= 1.59 \text{ fps (okay)}$$

Notes: There are a couple of options when considering flow rates in design calculations. One is to consider the normal, maximum and minimum flow rates that are expected for the metering system and operations (used in this example). Another is to consider the meter manufacturer's specifications for maximum and minimum, or extended maximum flow rates. Additionally, the fluid properties being metered should be considered.

Step 3: Determine the prover pipe diameter.

a. Using the maximum expected flow rate (Eq. [13], 4.3.5):

$$D_p = \sqrt{\frac{0.286Q}{V_d}}$$

$$= \sqrt{\frac{0.286 \times 2{,}100 \text{ bbl/h}}{4.17 \text{ fps}}}$$

$$= \sqrt{\frac{600.6}{4.17}}$$

$$= \sqrt{144.029}$$

$$= 12.001 \text{ in.} \Rightarrow \text{use 12 in. nominal}$$

b. Using the minimum expected flow rate (Eq. [13], 4.3.5):

$$D_p = \sqrt{\frac{0.286Q}{V_d}}$$

$$= \sqrt{\frac{0.286 \times 800 \text{ bbl/h}}{1.59 \text{ fps}}}$$

$$= \sqrt{\frac{228.8}{1.59}}$$

$$= \sqrt{143.899}$$

$$= 11.996 \text{ in.} \Rightarrow \text{use 12 in. nominal}$$

Step 4: Determine the minimum calibrated section length.

a. Using Eq. (14) from 4.3.6:

$$L_{\min_v} = \frac{1{,}029.41\,V_p}{D_p^{\,2}}$$

$$= \frac{1{,}029.41 \times 10}{12^2}$$

$$= \frac{10{,}294.1}{144}$$

$$= 71.49 \text{ ft} \Rightarrow 72 \text{ ft}$$

b. Using Eq. (15) from 4.3.6. If detector repeatability is ± 0.030 and desired accuracy is 0.02%, then:

$$L_{\min_{\mathrm{Det}}} = \frac{\Delta X \sqrt{N_{\mathrm{Det}}}}{P_a}$$

$$= \frac{0.06\sqrt{4}}{0.0002 \times 12 \text{ in./ft}}$$

$$= \frac{0.12}{0.0024}$$

= 50 ft for a run
(= 25 ft for a pass)

Since $L_{\min_v}$ Š $L_{\min_{\mathrm{Det}}}$ the minimum length of the calibrated section must be at least 72 ft long.

Step 5: Determine the prerun length.

The cycling characteristics of the 4-way valve or other switching equipment must be known. Assume a cycle time of 8 sec. for this example. Remember that the flow of the sphere starts at the mid-travel point (only 1/2 the travel time is used in the calculation).

a. Using Eq. (16) from 4.3.7:

$$L_{pr} = T_{pr} \times V_{d\ \max} \times SF$$

$$= \frac{8 \text{ sec.}}{2} \times 4.17 \text{ fps} \times 1.25$$

$$= 20.85 \Rightarrow 21 \text{ ft}$$

where

SF = manufacturer's safety factor (for the purpose of this example it is assumed $SF = 1.25$)

Step 6: Review the calculated results.

a. Prover volume: = 10 barrels
b. Prover diameter: = 12 in.
c. Calibrated section: = 72 ft
d. Prerun: = 21 ft

Compare the calculated results to the known quantities (e.g., nominal pipe sizes; standard test measures) and space limitations.

Step 7: Adjust for space limitations, calibrated volumes to match standard test measure volumes, nominal pipe sizes, etc. and rework the formulae to determine the final sizing.

B.3 Unidirectional Prover Example (Accumulating at Least 10,000 Pulses)

Given: 4,200 bbl/h normal flow rate (maximum flow rate expected 4,600 bbl/h – minimum flow rate expected 600 bbl/h), 16 in. piping, crude oil service, unidirectional sphere prover, 10 in. PD meters with pulse rate of 8,400 pulses/barrel.

Step 1: Determine minimum volume between detector switches to achieve at least 10,000 pulses per proving pass.

a. Use Eq. (11) from 4.3.3:

$$V_p \geq \frac{10{,}000 \text{ pulses}}{k}$$

$$= \frac{10{,}000 \text{ pulses}}{8{,}400 \text{ pulses per barrel}}$$

$$= 1.19 \text{ barrels}$$

Step 2: Determine displacer velocity.

a. Using Eq. (12) from 4.3.4.3:

$$V_d = \frac{0.286 \times Q}{D_p^{\,2}}$$

$$= \frac{0.286 \times 4{,}200 \text{ bbl/h}}{16^2}$$

$$= \frac{1{,}201.2}{256}$$

$$= 4.69 \text{ fps}$$

This velocity falls within the "typical accepted" range of 0.5 fps – 10 fps for unidirectional provers.

b. Test against max and min expected flow rates:

1. Max:

$$V_d = \frac{0.286 \times 4,000 \text{ bbl/h}}{16^2}$$
$$= \frac{1,315.6}{256}$$
$$= 5.14 \text{ fps (okay)}$$

2. Min:

$$V_d = \frac{0.286 \times 600 \text{ bbl/h}}{16^2}$$
$$= \frac{171.6}{256}$$
$$= 0.67 \text{ fps (okay)}$$

Notes: There are a couple of options when considering flow rates in design calculations. One is to consider the normal, maximum and minimum flow rates that are expected for the metering system and operations (used in this example). Another is to consider the meter manufacturer's specifications for maximum and minimum, or extended maximum flow rates. Additionally, the fluid properties being metered should be considered.

Step 3: Determine the prover diameter.

a. Using the maximum expected flow rate (Eq. [13], 4.3.5):

$$D_p = \sqrt{\frac{0.286Q}{V_d}}$$
$$= \sqrt{\frac{0.286 \times 4,600 \text{ bbl/h}}{5.14 \text{ fps}}}$$
$$= \sqrt{\frac{1,315.6}{5.14}}$$
$$= \sqrt{255.95}$$
$$= 15.998 \text{ in.} \Rightarrow \text{use 16 in.nominal}$$

b. Using the minimum expected flow rate (Eq. [13], 4.3.5):

$$D_p = \sqrt{\frac{0.286Q}{V_d}}$$
$$= \sqrt{\frac{0.286 \times 600 \text{ bbl/h}}{0.67 \text{ fps}}}$$
$$= \sqrt{\frac{171.6}{0.67}}$$
$$= \sqrt{256.12}$$
$$= 16.004 \text{ in.} \Rightarrow \text{use 16 in.nominal}$$

Step 4: Determine the minimum calibrated section length.

a. Using Eq. (14) from 4.3.6:

$$L_{\min_v} = \frac{1,029.41 V_p}{{D_p}^2}$$
$$= \frac{1,029.41 \times 1.19}{16^2}$$
$$= \frac{1,225.00}{256}$$
$$= 4.79 \text{ ft} \Rightarrow 5 \text{ ft}$$

b. Using Eq. (15) from 4.3.6. If detector repeatability is ± 0.030 and desired accuracy is 0.02%, then:

$$L_{\min_{\text{Det}}} = \frac{\Delta X \sqrt{N_{\text{Det}}}}{P_a}$$
$$= \frac{0.06\sqrt{2}}{0.0002 \times 12 \text{ in./ft}}$$
$$= \frac{0.085}{0.0024}$$
$$= 35.36 \text{ ft for a pass} \Rightarrow \text{ use 36 ft}$$

Since $L_{\min_{\text{Det}}} > L_{\min_v}$ the minimum length of the calibrated section must be at least 36 ft long.

Step 5: Determine the prerun length.

You must know the cycling characteristics of your sphere interchange mechanism. Assume a cycle time of 4 sec. for this example.

a. Using Eq. (16) from 4.3.7:

$$L_{pr} = T_{pr} \times V_{d \max} \times SF$$
$$= 4 \text{ sec.} \times 5.14 \text{ fps} \times SF$$
$$= 25.7 \Rightarrow 26 \text{ ft}$$

where

SF = manufacturer's safety factor (for the purpose of this example it is assumed $SF = 1.25$).

Step 6: Recalculate prover volume.

Given:

L = 36 ft

D_p = 16 in.

$$V_P = \frac{L \times D_P^2}{1029.41}$$

$$V_P = \frac{36 \times (16)^2}{1029.41}$$

$$V_p = 8.95 \text{ bbls}$$

Step 7: Review the calculated results.

a. Prover volume: = 8.95 barrels
b. Prover diameter: = 16 in.
c. Calibrated section: = 36 ft
d. Prerun: = 26 ft

Compare the calculated results to the known quantities (e.g., nominal pipe sizes; standard test measures and space limitations).

Step 8: Adjust for space limitations, calibrated volumes to match standard test measure volumes, nominal pipe sizes, etc. and rework the formulae to determine the final sizing.

B.4 Prover Examples (Accumulating Less Than 10,000 Pulses)

B.4.1 EXAMPLE 1 BIDIRECTIONAL PROVER

Given: The maximum flow rate of the meter to be proved is 1715 bbl/h. The minimum flow rate is 343 bbl/h. The meter is a 6-in. displacement meter with a K factor of 8400 pulses per barrel. The P_s is equal to 0.10. The pulse interpolation is performed by the double-chronometry method using one clock with a frequency of 1,000,000 Hz. The prover displacer-position detectors have a repeatability range of 0.011 in. The maximum displacer velocity is 3.5 ft/sec. The minimum displacer velocity is 0.5 ft/sec.

The required design data is the minimum volume, minimum diameter, and minimum length of the prover.

Step 1: Determine the meter pulse frequency.

a. Using Eq. (7) from 4.3.2.2.1:

$$F_{m\ max} = (1715)(8400)/3600 = 4002 \text{ Hz}$$

Step 2: Solve for N_m (minimum meter pulses) using Eq. (10) from 4.3.2.2.3.

where

N_{Det} = number of times a detector is actuated for a proving run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

F_m = meter pulse frequency, in Hz,

F_c = prover clock frequency, in Hz,

P_s = pulse stability.

$$N_m = 10,000\sqrt{N_{Det}}\sqrt{\left(\frac{F_m}{F_c}\right)^2 + P_s^2}$$

Given:

N_{Det} = 4 per run,

F_m = 4002,

P_s = 0.10,

$$N_m = 10,000\sqrt{4}\sqrt{\left(\frac{4002}{1000000}\right)^2 + 0.10^2}$$

N_m = 2001.6 per run (1000.8 per pass).

Step 3: Determine the minimum prover volume V_p based upon the minimum number of pulses using Eq. (11) from 4.3.3.

where

V_p = volume of prover pass, barrels,

N_m = number of meter pulses during a prover pass, in pulses,

k = K factor for meter, pulses per barrel.

$$V_p \geq \frac{N_m}{k}$$

Given:

N_m = 1000.8 pulses per pass,

k = 8400 pulses/barrel.

$$V_p \geq \frac{1000.8 \text{ pulses}}{8400 \text{ pulses/barrel}} = 0.1191 \text{ barrels}$$

Step 4: Determine the minimum internal diameter of the prover's calibrated section.

a. Using the maximum expected flow rate (Eq. [13] from 4.3.5):

$$D_p = \sqrt{\frac{0.286Q}{V_d}}$$
$$= \sqrt{\frac{0.286 \times 1715 \text{ bbl/h}}{3.5 \text{ fps}}}$$
$$= \sqrt{\frac{490.49}{3.5}}$$
$$= \sqrt{140.14}$$
$$= 11.83 \text{ in.}$$

Step 5: Determine the displacer velocity at the minimum flow rate, using the diameter obtained above.

a. Using the minimum expected flow rate and Eq. (12) from 4.3.4.3:

$$V_d = \frac{0.286 \times 343 \text{ bbl/h}}{11.83^2}$$
$$= \frac{98.098}{139.9489}$$
$$= 0.7 \text{ fps (okay)}$$

Since the minimum calculated displacer velocity of 0.7 ft/sec. (0.213 m/sec.) is more than the design limit of 0.5 ft/sec. (0.15 m/sec.), the diameter of 11.83 in. (30.05 centimeters) is satisfactory.

Step 6: Determine the minimum calibrated section length.

$$L_{\min_v} = \frac{1,029.41 V_p}{D_p^2}$$
$$= \frac{1029.41 \times 0.1191}{11.83^2}$$
$$= \frac{122.6027}{139.9489}$$
$$= 0.8761 \text{ ft}$$

a. Solve for $L_{\min_v}$ (minimum calibrated length based on the minimum required volume) using Eq. (14) from 4.3.6.

b. Solve $L_{\min_{Det}}$ (minimum length between detector switches based upon detector accuracy) using Eq. (15) from 4.3.6.

where

$L_{\min_{Det}}$ = minimum calibrated section length of a prover run based upon the prover detectors,

ýX = displacer position repeatability resulting from detector uncertainty during a prover pass (in.),

N_{Det} = number of times a detector is actuated for a calibration run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

P_a = desired prover accuracy.

$$L_{\min_{Det}} = \frac{\Delta X \sqrt{N_{Det}}}{P_a}$$

Given:

ýX = ± 0.011 in.,

N_{Det} = 4 per run,

P_a = 0.02%.

$$L_{\min_{Det}} = \frac{0.011\sqrt{4}}{0.0002 \times 12 \text{ in./ft}}$$
$$= 9.1667 \text{ ft/run (4.5833 ft/pass)}$$

Since 4.5833 ft (from $L_{\min_{Det}}$) is greater than 0.8761 ft (from $L_{\min_v}$) the calibrated section of the prover must be at least 4.6 ft long.

Step 7: Determine the prerun length.

The cycling characteristics of the 4-way valve or other switching equipment must be known. Assume a cycle time of 8 sec. for this example. Remember that the flow of the sphere starts at the mid-travel point (only 1/2 the travel time is used in the calculation).

a. Using Eq. (16) from 4.3.7:

$$L_{pr} = T_{pr} \times V_{d\ \max} \times SF$$
$$= \frac{8 \text{ sec.}}{2} \times 3.5 \text{ fps} \times 1.25$$
$$= 17.5 \text{ ft}$$

where

SF = manufacturer's safety factor (for the purpose of this example it is assumed SF = 1.25)

Step 8: Recalculate prover volume.

Given:

L = 4.6 ft

D_p = 11.83 in.

$$V_P = \frac{L \times D_P^2}{1029.41}$$

$$V_P = \frac{4.6 \times (11.83)^2}{1029.41}$$

$$V_p = 0.6254 \text{ bbls}$$

Step 9: Review the calculated results.

a. Prover volume: = 0.6254 barrels
b. Prover diameter: = 11.83 in.
c. Calibrated Section: = 4.6 ft
d. Prerun length: = 17.5 ft

This is a good place to step back and take a look at the results, see if they match with known quantities (e.g., nominal pipe sizes; standard test measures) and space limitations.

Step 10: Adjust for space limitations, calibrated volumes to match standard test measure volumes, nominal pipe sizes, etc., and rework the formulae to determine the final sizing.

B.4.2 EXAMPLE 1—UNIDIRECTIONAL PISTON PROVER

Given: The flow meter to be proved is a 6-in., turbine meter with a nominal "*K*" of 1000 pulses per barrel. The flow rate is 1440 bbl/h. The meter frequency is 400 Hz. The P_s is equal to ± 3% per the P_s definition, P_s = 0.03. The pulse interpolation is performed by the double-chronometry method using one clock with a frequency of 1,000,000 Hz. Prover to be used is a commonly manufactured unidirectional piston prover with 2 optical detectors. The detector uncertainty is ± 0.0001 in. The prover has a nominal volume of 0.476 barrels with a 14 in. ID. Prover calibrated section length is 30.012 in.

Step 1: Solve for N_m (minimum meter pulses).

where

N_{Det} = number of times a detector is actuated for a proving run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

F_m = meter pulse frequency, in Hz,

F_c = prover clock frequency, in Hz.

$$P_s = \text{pulse stability} = \frac{\text{standard deviation of pulse period}}{\text{mean of pulse period}}$$

$$N_m = 10,000\sqrt{N_{Det}}\sqrt{\left(\frac{F_m}{F_c}\right)^2 + P_s^2}$$

Given:

N_{Det} = 2

F_m = 400

F_c = 1,000,000

P_s = 0.03

$$N_m = 10,000\sqrt{2}\sqrt{\left(\frac{400}{1000000}\right)^2 + 0.03^2}$$

$$N_m = 424.3$$

Step 2: Solve V_p (minimum prover volume based upon the minimum number of pulses).

where

V_p = volume of prover pass, barrels,

N_m = number of meter pulses during a prover pass, in pulses,

k = K factor for meter, pulses per barrel.

$$V_p \geq \frac{N_m}{k}$$

Given:

N_m = 424.3 pulses,

k = 1000 pulses/barrel.

$$V_p \geq \frac{424.3 \text{ pulses}}{1000 \text{ pulses/barrel}} = 0.4243 \text{ barrels}$$

Step 3: Solve V_d (piston velocity).

where

Q = flow rate, bbl/h,

D_p = inside diameter of the prover, in.,

V_d = displacer velocity, ft/sec.

$$V_d = \frac{0.286 \times Q}{D_p^2}$$

Given:

Q = 1440 bbl/h,

D_p = 14 in.,

V_d = displacer velocity, ft/sec.

$$V_d = \frac{0.286 \times 1440 \text{ bbl/h}}{14^2} = 2.1 \text{ ft/sec.}$$

Step 4: Solve $L_{\min_{Det}}$ (minimum length between detector switches based upon detector accuracy).

where

$L_{\min_{Det}}$ = minimum calibrated section length of a prover run based upon the prover detectors,

ýX = displacer position repeatability resulting from detector uncertainty during a prover pass (in.),

N_{Det} = number of times a detector is actuated for a calibration run (unidirectional = 2 for a single pass, bidirectional = 4 for two passes),

P_a = desired prover accuracy.

$$L_{\min_{Det}} = \frac{\Delta X \sqrt{N_{Det}}}{P_a}$$

Given:

ýX = ± 0.0001 in.,

N_{Det} = 2,

P_a = 0.02%.

$$L_{\min_{Det}} = \frac{0.0001\sqrt{2}}{0.0002} = 0.707 \text{ in.}$$

Conclusion:

Based on the above calculations, the unidirectional piston prover selected exceeds the required volume for minimum number pulses, minimum calibrated section length for detector accuracy and the piston velocity is within desired range. Therefore the prover meets the accuracy requirements for this application.

APPENDIX C—A PROCEDURE FOR CALCULATING MEASUREMENT SYSTEM UNCERTAINTY

C.1 General Considerations

Field proving procedures are covered in API *MPMS* Ch. 4.8. Normally, meter-proving procedures consist of a minimum number of consecutive proving runs that agree within a prescribed range limit. When meters are proved, it is expected that the proving set will consistently meet the range limits. If the range limits are not met, several additional sets of meter proving runs are made. If none of the additional sets of proving runs meet the range limits, the meter proving activity is normally rescheduled resulting in lost time. Therefore, it is desirable that a meter and proving system meet the prescribed proving procedures with a 95% confidence level.

C.2 Evaluation Test Procedure

When experience is limited on the variation of a type of meter pulse train and/or the suitability of specific meter proving procedure to yield an appropriate *MF*, a field test may be performed to calculate the measurement system uncertainty. A test consisting of 15 – 25 prover passes or round trips can be gathered to statistically evaluate the system uncertainty of the existing meter proving procedure. The data set should at least have 15 runs and include as many prover passes as the operator of the metering facility would be willing to perform to prove the meter, but the maximum number of runs should be limited to a maximum of 25 runs.

The procedural uncertainty of any proving procedures can be calculated as follows:

$$(a)MF = \frac{w(MF) \times t(\%, n-1)}{D(n) \cdot \sqrt{n}}$$

where

$a(MF)$ = estimated uncertainty of the average in the meter proving set,

$w(MF)$ = (normalized high value – normalized low value) of n runs in the meter proving set; (i.e., high-low) divided by the average of the data set,

$t(\%, n-1)$ = student "t" factor for converting standard deviation to uncertainty at a prescribed confidence level agreed to by the custody transfer parties (see Table C-2),

$n-1$ = degree of freedom,

$D(n)$ = range to standard deviation conversion factor (see Table C-1),

n = number of proving runs in the data set.

Table C-1—Range to Standard Deviation Conversion Factors

Number of Data Sets or Measurements	Range to Standard Deviation Conversion Factor
n	$D(n)$
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534
7	2.704
8	2.847
9	2.970
10	3.078
11	3.173
12	3.258
13	3.336
14	3.407
15	3.472
16	3.532
17	3.588
18	3.640
19	3.689
20	3.735
21	3.778
22	3.819
23	3.858
24	3.895
25	3.931

For example, the uncertainty at the 95% confidence level of the average of five runs that agree within a range of 0.05% can be calculated as follows:

From Table C-1: $D(5) = 2.326$ and

From Table C-2: $t(\%,4) = 2.776$

$$a(MF) = \frac{(0.05) \times (2.776)}{(2.326) \cdot \sqrt{5}} \approx \pm\ 0.027\%$$

Example of a field test and calculation of System Uncertainty:

Given: Data set of 20 runs has the following K factor values for a meter:

52.324	52.315	<u>52.299</u>	52.304	52.312
52.318	52.311	52.319	52.303	52.313
52.315	52.319	52.306	52.316	52.323
52.322	52.310	52.322	<u>52.325</u>	52.314

Table C-2—Student *t* Distribution Factors for Individual Measurements

Number of Sets or Measurements	Student *t* Distribution Factors for Individual Measurements	Distribution Factor vs. 95% Confidence Level
n	$n-1$	$t(\%, n-1)$
2	1	12.706
3	2	4.303
4	3	3.182
5	4	2.776
6	5	2.571
7	6	2.447
8	7	2.365
9	8	2.306
10	9	2.262
11	10	2.228
12	11	2.201
13	12	2.179
14	13	2.160
15	14	2.145
16	15	2.131
17	16	2.120
18	17	2.110
19	18	2.101
20	19	2.093
21	20	2.086
22	21	2.080
23	22	2.074
24	23	2.069
25	24	2.064
Infinity	Infinity	1.960

The high and low values of the data set are in bold and underlined. The average value of the data set is 52.3145 and the range of high and low of 20 data set is;

$$w(MF) = \frac{(52.325 - 52.299)}{52.3145} = .0497\%$$

For the data set of the example, the uncertainty of the system is calculated as follows:

Number of data for the test is 20.

From Table C-1: $D(20) = 3.735$ and

From Table C-2: $t(\%,19) = 2.093$

$$a(MF) = \frac{(0.0497) \times (2.093)}{(3.735) \cdot \sqrt{20}} \approx \pm\ 0.0062\%$$

For the above example, if the first 15 data are considered;

<u>52.324</u>	52.315	<u>52.299</u>	52.304	52.312
52.318	52.311	52.319	52.303	52.313
52.315	52.319	52.306	52.316	52.323

Table C-3—Estimated Measurement Uncertainty of the System at the 95% Confidence Level for Data That Agree within a Range of 0.05%

Number of Sets or Measurements	Distribution Factor for 95% Confidence Level	Range of Standard Deviation Conversion Factor	$(a)MF = \frac{0.05 \times t(\%,n)}{D(n) \cdot \sqrt{n}}$
n	$t(\%, n-1)$	$D(n)$	$a(MF)$
5	2.776	2.326	± 0.0267%
6	2.571	2.534	± 0.0207%
7	2.447	2.704	± 0.0171%
8	2.365	2.847	± 0.0147%
9	2.306	2.970	± 0.0129%
10	2.262	3.078	± 0.0116%
11	2.228	3.173	± 0.0106%
12	2.201	3.258	± 0.0098%
13	2.179	3.336	± 0.0091%
14	2.160	3.407	± 0.0085%
15	2.145	3.472	± 0.0080%
16	2.131	3.532	± 0.0075%
17	2.120	3.588	± 0.0072%
18	2.110	3.640	± 0.0068%
19	2.101	3.689	± 0.0065%
20	2.093	3.735	± 0.0063%
21	2.086	3.778	± 0.0060%
22	2.080	3.819	± 0.0058%
23	2.074	3.858	± 0.0056%
24	2.069	3.895	± 0.0054%
25	2.064	3.931	± 0.0053%

The average of the set is 52.3131 and the range of high and low is:

$$w(MF) = \frac{(52.324 - 52.299)}{52.3131} = 0.0478\%$$

The system uncertainty would be calculated as follows:

Number of data for the test is 15.

From Table C-1: $D(15) = 3.472$ and

From Table C-2: $t(\%,14) = 2.145$

$$a(MF) = \frac{(0.0478) \times (2.145)}{(3.472) \cdot \sqrt{15}} \approx \pm\ 0.00762\%$$

Using the above calculation method, the Measurement Uncertainty of the System can be calculated for any number of samples for a specific range of high and low values of actual data. Table C-3 shows the Estimated Measurement Uncertainty of the System at the 95% of the confidence level for different number of runs when the range of high and low for the data agree within a range 0.05%. When the actual test results yield a value of $w(MF)$ other than 0.05%, the measurement uncertainty of the system (for 95% confidence level) can be calculated by following the above examples, which will be different from the corresponding value given in Table C-3.

If the proving procedure qualification test data does not consistently meet the requirement for a specified number of proving to agree within a given range limit, the normal practice is to try one or both of the following variations from the normal meter proving operations.

a. Average several provers passes or round trips for each proving run and compare the averages of these groups for acceptance of the proving data.

b. Increase the number of proving runs (passes or round trips) and increase the range limits approximately to control the uncertainty of the average of the moving set of proving runs.

The requirements for acceptance of a proving procedure qualification test data should be more rigorous than normally required for other locations with similar fluids, custody transfer quantities and meter proving intervals. Several methods can be employed to increase the confidence that the proving procedures that meet the qualification requirements will consistently provide a suitable *MF*. These procedures include, but are not limited to the following concepts:

a. Reduce the range limit for a prescribed number of proving runs;

b. Increase the minimum number of proving runs to meet a prescribed range limit;

c. Use a higher statistical confidence level to evaluate the qualification test data than normally used to evaluate measurement procedural uncertainties; or

d. Use the same statistical confidence level to evaluate the qualification test data as normally used to evaluate procedural uncertainties, but reduce the uncertainty limit for the qualification test data to a lower level than normally required for routine sets of meter proving runs.

e. Determine the average range or uncertainty from records with a specific meter proving procedure and require the qualification test data at least meet the average.

APPENDIX D—TYPICAL DISPLACEMENT PROVER DESIGN CHECK LIST

D.1 General

D.1.1 Service: Crude, Refined Products, LPG/NGL, Chemicals____________

D.1.2 Type: Bidirectional-sphere, Bidirectional-piston, Unidirectional-sphere, Unidirectional-piston

D.1.3 Displacer: Sphere, Cup Piston, Precision Seal Piston

D.2 Design Data

D.2.1 Flow Rate: Units: Minimum ________, Normal _________, Maximum ________

D.2.2 Pressure: Units: Normal _________, Maximum __________

D.2.3 Temperature: Units: Normal _________, Maximum __________

D.2.4 Fluid: Relative Density _____________, Viscosity CST CP SSU ___________

D.2.5 Design Considerations: (Corrosive Properties, etc.) _____________________

D.2.6 Meter Type: Turbine, Positive Displacement, Coriolis, Other ___________

D.2.6.1 Manufacturer: ____________, Model: ____________, Size: ___________

D.2.6.2 Nominal Meter "*K*" Factor:_______________

D.3 Valves

D.3.1 Diverter Valve, If Required

D.3.1.1 Manufacturer: ________________, Model: ________________

D.3.1.2 Size: _____________in., ANSI Rating: _______________,

Connection: ________________

D.3.1.3 Material: (Body):_____________, (Elastomers):___________

D.3.1.4 Valve Operator

D.3.1.4.1 Manufacturer: ________________, Model: ____________

D.3.1.4.2 Cycle time: _______ sec., Type: Electric, Hydraulic, Manual

D.3.1.4.3 Electric Data: Voltage: _________, Phase _______, HP _____

D.3.1.4.4 Hydraulic System Press: _________, Fluid: ____________

D.3.2 Drain Valves

D.3.2.1 Manufacturer: _________________, Model: _______________

D.3.2.2 Size: _____________ in., ANSI Rating: ______________,

Connection: ________________

D.3.2.3 Material: (Body)______________, (Elastomer)_____________

D.3.3 Vent Valves

D.3.3.1 Manufacturer: _________________, Model: _______________

D.3.3.2 Size: _____________ in., ANSI Rating: ______________,

Connection: ________________

D.3.3.3 Material: (Body)______________, (Elastomer)_______________

D.3.4 Relief Valves

D.3.4.1 Manufacturer: ___________________, Model: ____________________

D.3.4.2 Size: __________, in., ANSI Rating: ______________,

Set Pressure: ___________ psig,

Quantity: ______________

D.3.4.3 Material: (Body)______________, (Elastomer)_______________

D.4 Piping Details

D.4.1 Piping

D.4.1.1 Prover Nominal Diameter: _________________ Units

D.4.1.2 Pipe OD (Units): _________, ID (Units) ________, WT (Units): __________

D.4.1.3 Material: Carbon Steel, Stainless Steel, Other: _______________

D.4.1.4 Full Length Honing: Yes, No, Final Surface Roughness: _______________

D.4.2 Flanges

D.4.2.1 ANSI Ratings: _____________, Type: _____________

D.4.2.2 Matched Bored and Doweled, Matched Bored and Tongue and Grooved

D.5 Displacer Details

D.5.1 Sphere/Piston Velocity:

D.5.1.1 Minimum ________fps, Maximum _______fps

D.5.2 Sphere/Piston Cup/Seal Material: Polyurethane, Buna®, N, Teflon®, Viton®,

Other (Specify): ________________

D.5.3 Piston Material: Aluminum, Stainless Steel, Other (Specify):_______________

D.5.3.1 Poppet Material (Specify):_______________

D.5.4 Piston Wiper Material (Specify): _______________

D.5.5 Wear Ring Material (Specify): _______________

D.6 Detector Switch Details

D.6.1 Type: Mechanical, Electro-magnetic, Optical, Other: _______________

D.6.2 Number Required: 2, Other (Quantity) _____________

D.6.3 Manufacturer: _________________, Model: _________________

D.7 Coating Details

D.7.1 Internal Coating

D.7.1.1 Baked Epoxy-phenolic; Manufacturer _____________, Type ________,

Thickness _____________ mils

D.7.1.2 Air Dried Epoxy; Manufacturer _______________, Type ___________,

Thickness _____________ mils

D.7.1.3 Plating: Yes, No, Type: _______________

D.7.1.4 None

D.7.2 External Coating

D.7.2.1 Piping, Skid and Supports

D.7.2.1.1 Primer (1st Coat), Manufacturer ____________, Type ________,
Thickness ____________ mils

D.7.2.1.2 Mid-coat (2nd Coat), Manufacturer ____________, Type ________,
Thickness ____________ mils

D.7.2.1.3 Top-coat (3rd Coat), Manufacturer ____________, Type ________,
Thickness ____________ mils

D.7.2.1.4 None

D.7.2.2 Grating: ________________________

D.7.2.3 Stud Bolts and Nuts: __________________

D.8 Insulation

D.8.1 Type: Rigid Fiberglass, None, Other ___________________

D.8.2 Minimum Thickness: _____________________in.

D.8.3 Jacket/Covering: Aluminum, Stainless Steel

D.9 Closures

D.9.1 Type: ___________, Quantity: Two, One, ANSI Rating: ______________

D.9.2 Manufacturer: _______________, Model: ____________________

Note: Quick-opening closures should have a permissive warning device.

D.10 Prover Barrel Dimensions

D.10.1 Design Volume _____________________ (Units)

D.10.2 Dimensions

D.10.2.1 Calibrated Section (Length): __________ (Units)

D.10.2.2 Pre-run Section (Length): ___________ (Units)

D.10.2.3 Launch Chamber Section (Length): __________ (Units)

D.10.2.4 Calibrated Section (ID): ___________ (Units)

D.10.2.5 Launch Chamber (ID): ____________ (Units) (At Least 2 Sizes Larger than Calibrated Section ID)

D.11 Accessory Equipment

D.11.1 Pressure

D.11.1.1 Transmitter (Electronic): Smart Digital, Digital, Smart Analog, Analog, Other
Manufacturer: ________________, Model: ___________________,
Range: __________ Units Connection Size: Type:______________
Quantity: ____________

D.11.1.2 Gauge: Manufacturer: _____________, Model: _____________________,

Range: _________ psig Connection Size:_______________

Quantity: ____________

D.11.2 Temperature

D.11.2.1 Transmitter (Electronic): Smart Digital, Digital, Smart Analog, Analog, Other

Manufacturer: _________________, Model: _____________________,

Sensor: 100 Ohm Platinum RTD, Other (Specify):__________

Range: ___________ °F or °C

Connection Size:______,Type:______

Quantity: ____________

D.11.2.2 Thermometer: Manufacturer: _________________, Model _________________,

Range: ________________ °F or °C

Connection Size:______,Type:______

Quantity: _____________

D.11.2.3 Thermowell: Type: Flanged, Threaded, Van Stone, Other __________

Material: 316SS, Other _____________

Bore Size: _________, OD: __________, Length: ____________

Quantity: ____________

D.12 Sphere Handling

D.12.1 Sphere Sizing Ring:

Diameter: ________________,% Oversize: ______________

D.12.2 Sphere Removal Equipment: Required? Yes No

D.13 Timers/Counters;

D.13.1 Manufacturer: ___________________, Model: ____________________,

Quantity: ____________

Pulse Interpolation Required? Yes, No

D.14 Test(s) and Inspection(s)

D.14.1 Welding Qualifications Tests: Test: Yes, No, Notification: Yes, No

D.14.2 Radiographic testing: Test: Yes, No; 100% Other _______%,

Notification: Yes, No

D.14.3 Hydrostatic Test: Test: Yes, No, Notification: Yes, No

D.14.4 Water Draw Calibration: Test: Yes, No, Notification: Yes, No

D.14.5 Functional/Operational Test: Test: Yes, No, Notification: Yes, No

D.14.6 Surface Preparation (For Coating): Test: Yes, No, Notification: Yes, No

D.14.7 Coating Application: Test: Yes, No, Notification: Yes, No

D.14.8 System Uncertainty Analysis Per API Ch. 4.2, Appendix C: Yes, No

D.14.8.1 Limits of Uncertainty: ____

D.15 Applicable Codes and Regulations (Design, Fabrication/Construction and Testing)

D.15.1 ANSI Piping: B31.3, B31.4

D.15.2 API Classification: RP 500A, RP 500B, RP 500C

D.15.3 Pressure Vessels: ASME Section VIII, Stamp: Yes, No

D.15.4 OSHA Yes, No

D.15.5 National Electric Code Yes, No

D.15.6 DOT 195 Yes, No

D.15.7 Other ______________

D.16 Attachments

D.16.1 Drawings: _________________

D.16.2 Specifications:_________________

APPENDIX E—EVALUATION OF METER PULSE VARIATIONS

E.1 General

The purpose of this appendix is to describe the calculation method for determining the Pulse Stability P_s of a flow meter. P_s is one of the factors necessary to determine the minimum volume of a prover that accumulates less than 10,000 pulses.

E.2 Definitions

Pulse period. The time interval between the leading edge of one pulse to the leading edge of the next pulse

Pulse stability (P_s). The variations of time between meter pulses.

E.3 Equipment

There are several ways to measure the pulse period. These may include digital storage oscilloscopes, flow computers, smart preamps and PC add on cards to measure periods.

The clock speed or time base of the equipment used to measure pulse periods must have a resolution of one part in 10,000, at the maximum frequency of the flowmeter output.

The period measurements may be transferred to a PC spreadsheet for calculation of P_s.

E.4 Test Procedure

E.4.1 STEP 1

Using the limiting factors below, determine the minimum data required for establishing a P_s.

a. Minimum data collection time period of 1 sec.
b. Minimum number instrument cycles of 10 (revolutions, refresh, pulse burst, etc.).
c. Minimum number of meter pulses collected of 1,500.

E.4.2 STEP 2—COLLECT DATA

Collect three sets of data at the minimum, normal, and maximum design flow rates. A data set is defined as the measurement of each pulse period for a minimum number of consecutive pulses as defined in Step 1. Data should be collected at normal operating conditions (do not prove the meter while collecting data).

E.4.3 STEP 3

Calculate P_s for each data set (minimum nine required).

E.4.3.1 Calculate the mean pulse time period using the following equation:

$$T_{mean} = \frac{\sum_{i=1}^{N_D} T_i}{N_D} \quad \text{(E-1)}$$

where

N_D = the total number of pulses in the data set,

T_i = the time period of the i^{th} pulse.

E.4.3.2 Calculate the standard deviation (σ) of the sample population, using the following equation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N_D} (T_i - T_{mean})^2}{N_D - 1}} \quad \text{(E-2)}$$

E.4.3.3 Calculate the P_s using the following equation:

$$P_s = \frac{\sigma_{mp}}{T_{mean}} \quad \text{(E-3)}$$

where

σ = the standard deviation of the meter pulse,

T_{mean} = mean time between meter pulses.

E.4.4 STEP 4—SELECTION OF P_S VALUE

E.4.4.1 Calculate the mean P_s value for each flow rate.

E.4.4.2 Select the mean P_s that has the highest value for the three flow rates of the test. This is the P_s to be used for sizing the prover.

E.4.5 NUMERIC EXAMPLE EXPLAINING THE CALCULATION METHOD

a. Determine the value of the P_s for the following application:
   1. 4 in., liquid turbine meter with 12 blades.
   2. 1,000 pulses per barrel.
   3. Maximum flow rate of 2,000 bbl/h.
b. From E.4.1, the minimum number of pulses is:
   1. In 1 sec. there will be about = 1000 × 2000/3600 = 555.5 pulses/sec.
   2. In 10 revolution there will be 120 pulses.
   3. So, the requirement of 1,500 is the minimum number of pulse count needed per data set.

Following is a numeric example with limited number of pulse periods in the data to show the calculation method.

Reduced data set with ND of 32.

Note: Actual data set should have at least 1,500 samples.

Pulse Period	Pulse Period	Pulse Period	Pulse Period	Pulse Period	Pulse Period	Pulse Period	Pulse Period
23488	23428	22747	22888	22679	22547	23312	23115
23218	23075	22601	23017	22595	23398	23211	23188
23412	22658	22718	23312	23361	22578	23291	23098
22549	23481	22675	22911	22875	23417	23106	22547

a. Using Eq. (E-1), the mean time period of pulse in the data set is 23015.50.

b. Using Eq. (E-2), the standard deviation, σ, of the data set is 328.4606.

c. Using Eq. (E-3):

$$P_s = 328.4606/23015.50 = 0.0143 = 0.0143$$

APPENDIX F—PROVER SPHERE SIZING

Most spheres used in meter proving equipment are hollow. This allows the sphere to be filled with water or other suitable materials. Once the sphere is full, additional material is pumped in to expand the sphere to a larger size. Expanding the sphere insures that a seal will be maintained while it travels through the calibrated section of pipe. Most spheres are inflated to 2% over the pipe internal diameter to obtain a seal. However, even though a seal may initially be obtained against the walls of the pipe, leakage may occur when the sphere passes a detector or other fitting. Because of this, the sphere may need to be increased in size to maintain a seal across the detector or fittings. However, increasing the sphere size too much can cause the sphere to jump or chatter while it is running through the calibrated section of the prover. This can have a detrimental affect on the meter calibration. Therefore it is important to use the minimum sphere size that will maintain a seal across the fitting.

Another point to consider is the speed of the sphere while it is traversing the detector or fitting. If the sphere is traveling at average velocity (5 ft/sec.), the amount of time the sphere spends crossing a 1-in. detector opening is around 0.017 sec. This occurs so quickly that there is almost no time available for product to leak across the opening. However, when the sphere is moving very slowly, as in a water draw when approaching the second detector, enough time is available for product to leak across the opening.

As the sphere size is increased, a larger portion of the sphere remains in contact with the pipe wall around its entire circumference. As the sphere size is further increased, the contact against the pipe wall increases along the length of the pipe. The length of contact along the length of the pipe wall can be determined from the equation below:

$$L = \frac{2}{3}d[(1 + i\%)^3 - 1]$$

where

L = contact length,

d = internal diameter of pipe,

$i\%$ = % increase in sphere diameter and/or circumference (e.g., 2% = 0.02).

For example: A 16 in., prover with 0.375 in., wall thickness, with a sphere at 2% will have a contact length $L = 0.622$ in.

It is important that the detector opening or fitting be smaller that this value or leakage will occur through the opening and around the sphere. Although it may not be noticeable during normal operations, it may be occurring at low flow rates, and also it will be very noticeable during waterdraw calibrations.

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

Additional copies are available online at www.api.org/pubs

Phone Orders:	1-800-854-7179	(Toll-free in the U.S. and Canada)
	303-397-7956	(Local and International)
Fax Orders:	303-397-2740	

Information about API publications, programs and services is available on the web at www.api.org.

Product No. H04023