Manual of Petroleum Measurement Standards
Chapter 4—Proving Systems

Section 3—Small Volume Provers

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Measurement Coordination Department

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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 commonly 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 Bureau of Standards (NBS). 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, "Conventional Pipe Provers"
Section 3, "Small Volume Provers"
Section 4, "Tank Provers"
Section 5, "Master-Meter Provers"
Section 6, "Pulse Interpolation"
Section 7, "Field-Standard Test Measures"

Suggested revisions are invited and should be submitted to the director of the Measurement Coordination Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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SECTION 3—SMALL VOLUME PROVERS

Chapter 4—Proving Systems

SECTION 3—SMALL VOLUME PROVERS

4.3.1 Introduction

The use of small volume provers has been made possible by the availability of high-precision displacer-position detectors used in conjunction with pulse-interpolation techniques (see Chapter 4.6). The small volume prover normally has a smaller base volume than that of conventional pipe provers (see Chapter 4.2) and is usually capable of fast proving passes over a wide range of flow rates.

Small volume provers have a volume between detectors that does not permit a minimum accumulation of 10,000 direct (unaltered) pulses from the meter. Small volume provers require meter pulse discrimination using a pulse-interpolation counter or another technique that increases the resolution (see Chapter 4.6). This may include using provers with both large and small base volumes, depending on the pulse rates of the meters to be proved.

The small volume prover may be used in many applications in which pipe provers or tank provers are commonly used. Small volume provers may be stationary or portable.

The volume required of a small volume prover can be less than that of a conventional pipe prover when high-precision detectors are used in conjunction with pulse-interpolation techniques. Pulse-interpolation methods of counting a series of pulses to fractional parts of a pulse are used to achieve high resolution without counting 10,000 whole meter pulses for a single pass of the displacer between detectors (see Chapter 4.6.)

To achieve the required proving accuracy and repeatability, the minimum volume between detector switches depends on the discrimination of a combination of pulse-interpolation electronics, detectors, and uniform meter pulses, as well as flow rate, pressure, temperature, and meter characteristics.

4.3.1.1 SCOPE

This chapter outlines the essential elements of a small volume prover and provides descriptions of and operating details for the various types of small volume provers that meet acceptable standards of repeatability and accuracy.

4.3.1.2 DEFINITION OF TERMS

Terms used in this chapter are defined in 4.3.1.2.1 through 4.3.1.2.6.

4.3.1.2.1 *Interpulse spacing* refers to variations in the meter pulse width or space, normally expressed in percent.

4.3.1.2.2 *Meter proof* refers to the multiple passes or round trips of the displacer in a prover for purposes of determining a meter factor.

4.3.1.2.3 A *meter prover* is an open or closed vessel of known volume utilized as a volumetric reference standard for the calibration of meters in liquid petroleum service. Such provers are designed, fabricated, and operated within the recommendations of Chapter 4.

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

4.3.1.2.5 A *prover round trip* is the result of the forward and reverse passes in a bidirectional prover.

4.3.1.2.6 A *proving timer/counter* is a high-speed counter used in double chronometry to measure time with a pulsed signal of known frequency.

4.3.1.3 REFERENCED PUBLICATIONS

The current editions of the following standards, codes, and specifications are cited in this chapter:

API

Manual of Petroleum Measurement Standards

Chapter 4, "Proving Systems," Section 2, "Conventional Pipe Provers," Section 6, "Pulse Interpolation," and Section 7, "Field-Standard Test Measures"

Chapter 5, "Metering," Section 2, "Measurement of Liquid Hydrocarbons by Displacement Meters," Section 3, "Measurement of Liquid Hydrocarbons by Turbine Meters," and Section 4, "Accessory Equipment for Liquid Meters"

Chapter 7.2, "Dynamic Temperature Determination"

Chapter 12.2, "Calculation of Liquid Petroleum Quantities Measured by Turbine or Displacement Meters"

NFPA[1]

70 *National Electrical Code*

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

4.3.2 Small Volume Prover Systems

The small volume prover is available in several different configurations that allow a continuous and uniform rate of flow. All types operate on the common principle of the repeatable displacement of a known volume of liquid in the calibrated section of a pipe or tube. A displacer travels through a calibrated section with its limits defined by one or more highly repeatable detectors. The corresponding metered volume simultaneously passes through the meter, and the whole number of pulses is counted. Precise calculations are made using a pulse-interpolation technique (see Chapter 4.6).

The two types of continuous-flow small volume provers are unidirectional and bidirectional. The unidirectional prover allows the displacer to travel and measure in only one direction through the proving section and has a means of returning the displacer to its starting position. The bidirectional prover allows the displacer to travel and measure first in one direction and then in the other and is capable of reversing the flow through the prover section.

Both unidirectional and bidirectional small volume provers must be constructed so that the full flow of the stream passing through the meter being proved will pass through the prover.

4.3.3 Equipment

The small volume prover must be suitable for the intended fluids, pressures, temperatures, and type of installation. The materials used must be compatible with the fluid stream and the location where the prover will be installed.

A small volume prover will normally consist of the following elements:

a. A precision cylinder.
b. A displacer piston, spheroid, or other fluid-separation device.
c. A means of positioning and launching the displacer upstream of the calibrated section.
d. A displacer detector or detectors.
e. A valve arrangement that allows fluid flow while the displacer is traveling from one position to the opposite position.
f. Pressure-measurement devices.
g. Temperature-measurement devices.
h. Instrumentation with timers, counters, and pulse-interpolation capability.

4.3.3.1 MATERIALS AND FABRICATION

The materials selected for a prover shall conform to applicable codes, pressure ratings, corrosion resistance, and area classifications.

The calibrated volume-measurement section of the prover, located between the displacer-position sensors, must be designed to exclude any appurtenances such as vents or drains.

Flanges or other provisions should be included for access to the inside surfaces of the calibrated and prerun sections. Care should be exercised to ensure and maintain proper alignment and concentricity of pipe joints.

Internally coating the prover section with a coating or plating material that will provide a hard, smooth, long-lasting finish will reduce corrosion and prolong the life of the displacer or displacer seals and the prover.

4.3.3.2 TEMPERATURE STABILITY

Temperature stability is necessary to achieve acceptable proving results. Temperature stabilization is normally achieved by continuously circulating liquid through the prover section, with or without insulation. When provers are installed aboveground, the application of thermal insulation will contribute to better temperature stabilization.

4.3.3.3 TEMPERATURE MEASUREMENT

Temperature-measurement sensors should be of suitable range and accuracy and should be graduated by temperature discrimination in fractional degrees to at least 0.5°F (0.25°C). See Chapters 7.2 and 12.2. Temperature-measurement devices shall be installed at appropriate locations to measure temperature at the meter and the prover. Caution must be exercised to ensure that the temperature sensors are located in a position in which they will not be shut off from the liquid path.

4.3.3.4 PRESSURE MEASUREMENT

Pressure-measurement devices of suitable range and accuracy, calibrated to an accuracy of 2 percent full scale or better, shall be installed at appropriate locations to measure pressure at the meter and the prover. (See Figures 1–4 and Chapter 12.2 for further information).

4.3.3.5 DISPLACING DEVICES

One type of displacer is a piston, with seals, connected to a central shaft. A second type of displacer is a free piston that uses seals between the precision cylinder and the piston. A third type is the elastomer sphere filled with liquid under pressure. To provide a seal without excessive friction, the sphere is expanded to a diameter greater than the prover pipe's inside diameter, which is normally 2–4 percent. Insufficient expansion of the sphere can lead to leakage past the sphere and

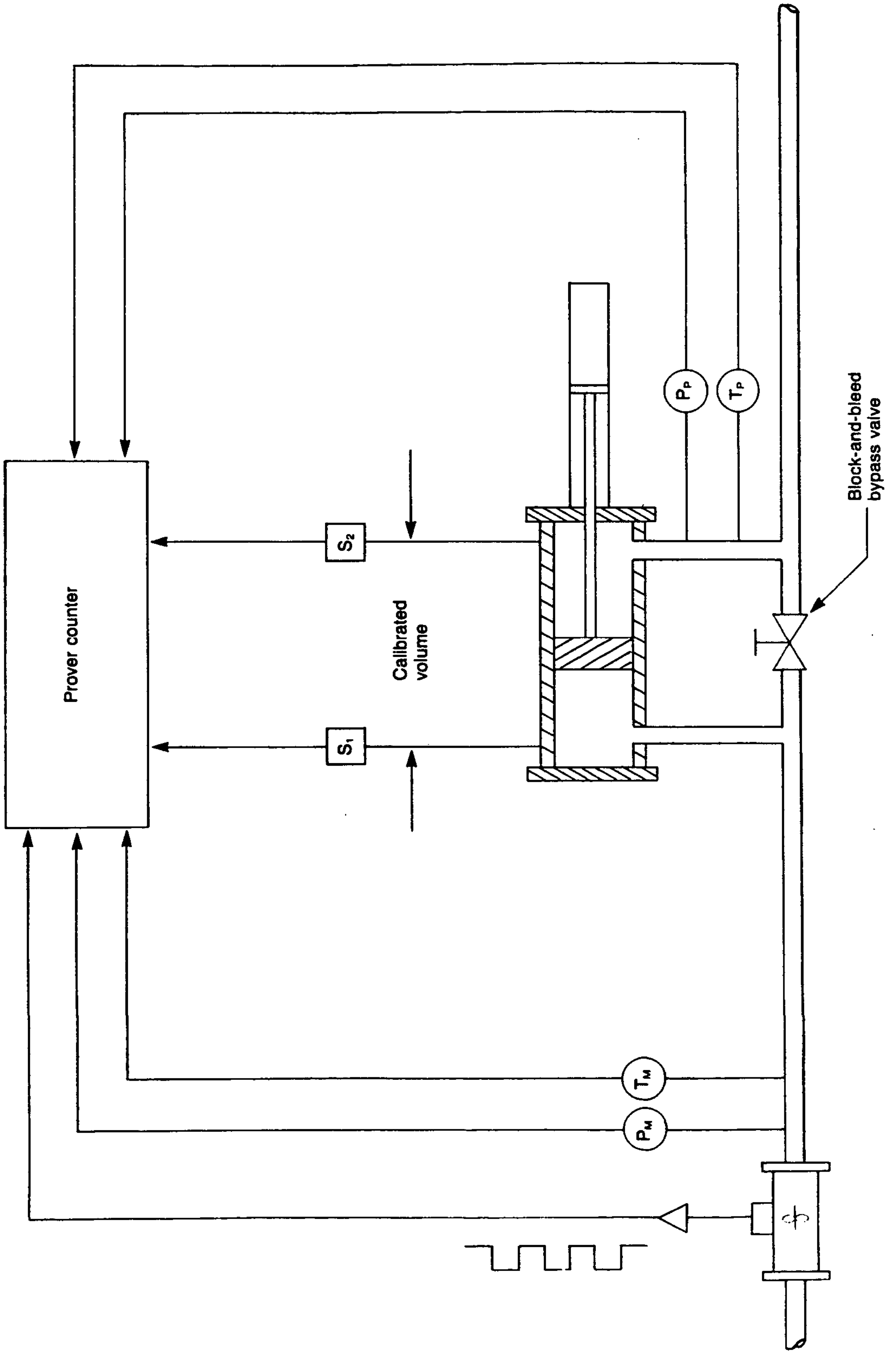

Figure 1—Generalized System Overview

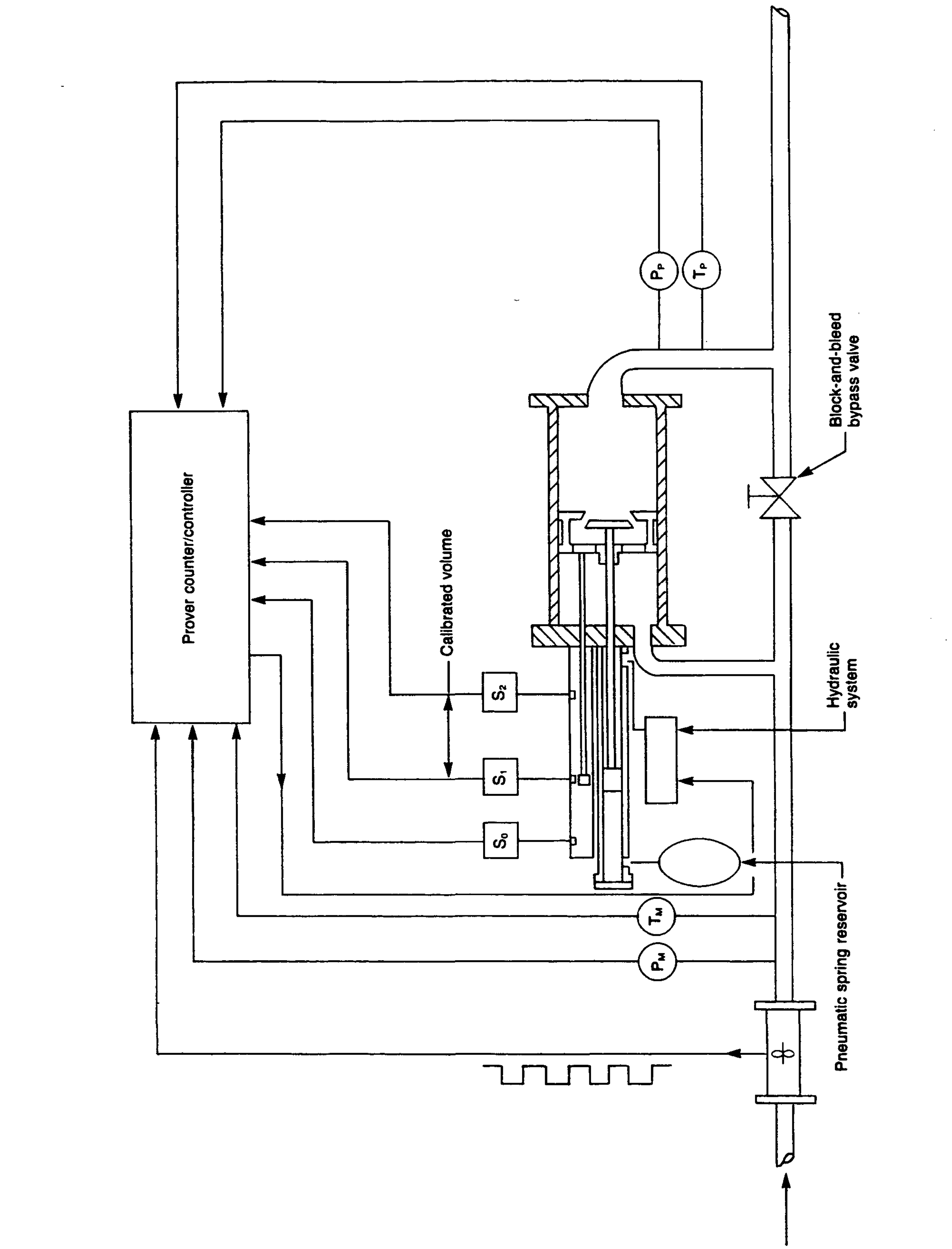

Figure 2—System Overview of Internal Valve

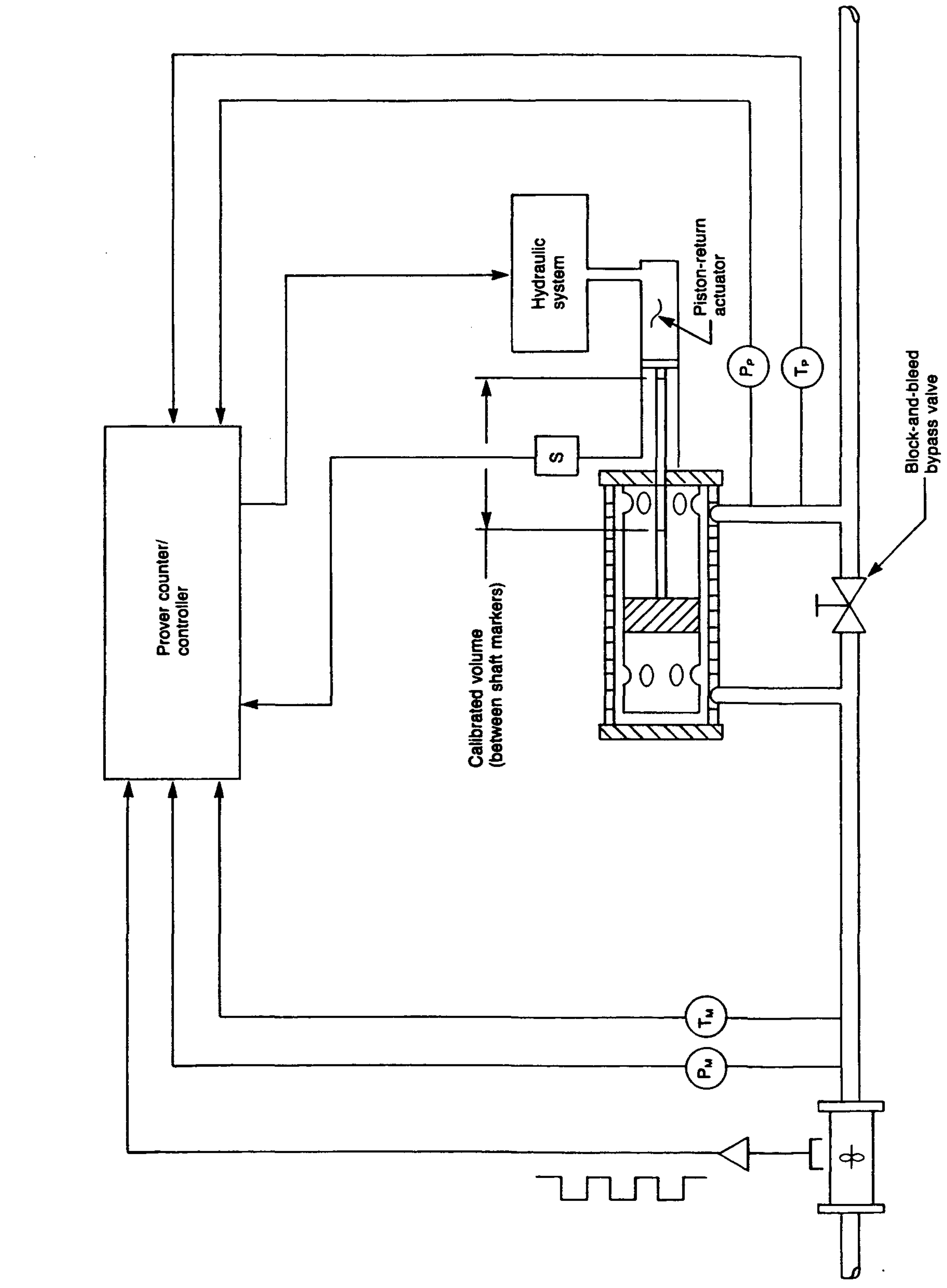

Figure 3—System Overview of Internal Bypass Porting With External Valve

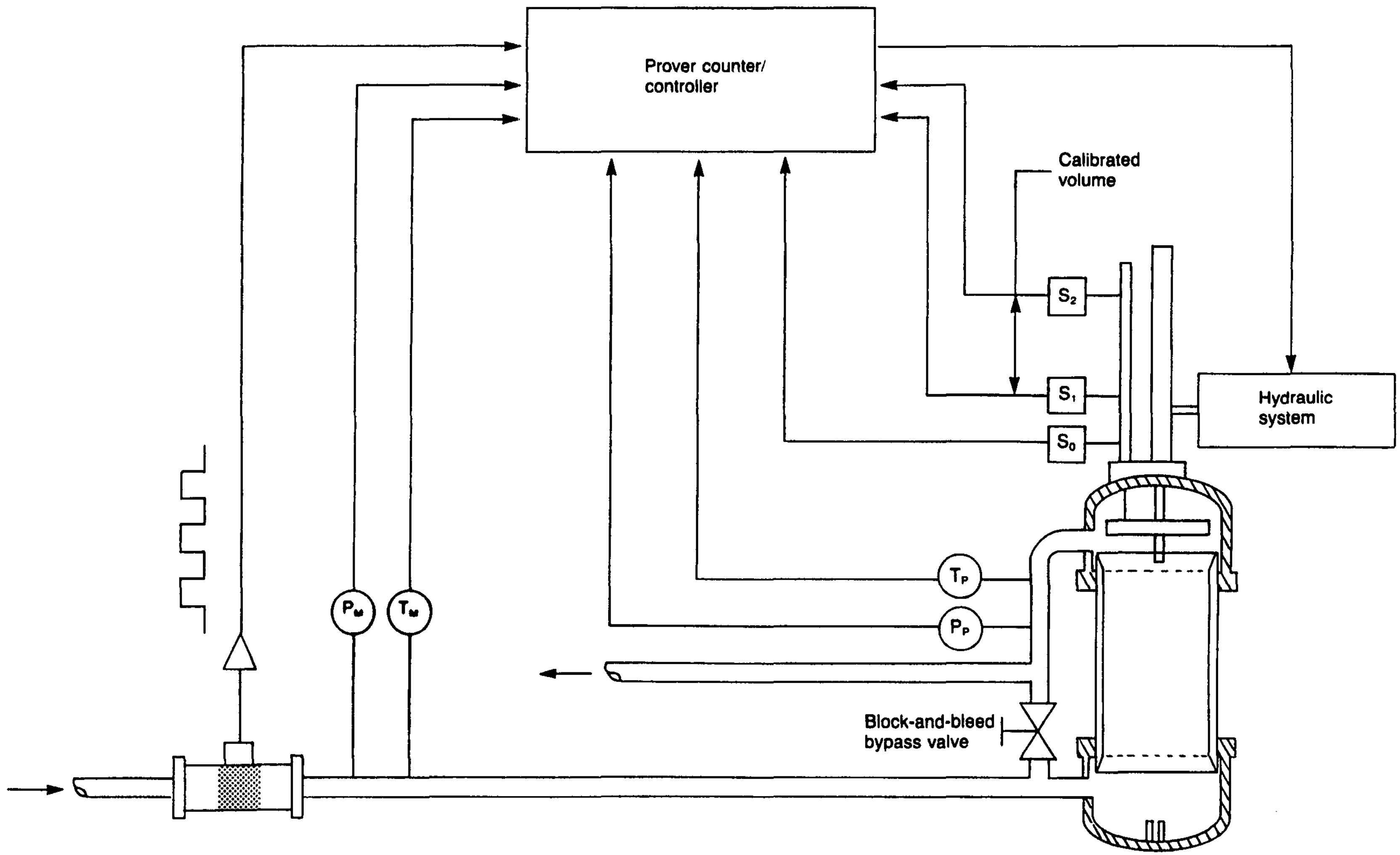

Figure 4—System Overview of Pass-Through Displacer With External Valve

consequently to measurement error. Excessive expansion of the sphere may not improve sealing ability and will generally cause the sphere to wear more rapidly and move erratically. Care must be exercised to ensure that no air remains inside the sphere. The elastomer should be impervious to the operating liquids.

A means for inspecting or monitoring displacer-seal integrity must be included in the design and operation of all small volume provers. Displacer-seal integrity may be either statically or dynamically verified under conditions of low-pressure differential that are consistent with normal operations.

Other types of displacers will be acceptable if they provide accuracy and repeatability that is equal to or better than the three types described above.

4.3.3.6 VALVES

All valves used in small volume 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 block-and-bleed type.

Full positioning of the flow-reversing valve or valves in a bidirectional prover or the interchange valve in a unidirectional prover must be established before the displacer is allowed to actuate the first detector. This design ensures that no liquid is allowed to bypass the prover during the displacer's travel through the calibrated volume. The distance before the first detector, commonly called prerun, depends on valve operation time and the velocity of the displacer. 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.

4.3.3.7 CONNECTIONS

Vent and drain lines shall be provided on the prover or the connecting piping and must have a means of checking for leaks. Provisions should be made to allow field waterdraw calibration of the small volume prover.

4.3.3.8 DETECTORS

Detectors must indicate the position of the displacer within ±0.01 percent. 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. Care must be taken to correct detector positions that are subject to temperature changes throughout the proving operation.

4.3.3.9 METER PULSE GENERATOR

A meter pulse generator shall be provided for transmitting flow data. The generator must provide electrical pulses that have satisfactory characteristics for the type of electronic instrumentation employed.

4.3.3.10 PULSE-INTERPOLATION SYSTEM

The prover timer/counter for small volume provers is an electronic device that utilizes pulse interpolation and double chronometry (see Chapter 4.6).

4.3.3.11 CONTROLLER

The controller is used to process all signals both to and from the prover. It receives the start/stop signals from the detector or detectors that gate the timers, receives the pulses generated by the test meter, performs the calculations, and displays all data. The proving controller may be equipped to provide remote operation, alarms, printing, logic sequences, and other desired functions.

4.3.4 Design of Small Volume Provers

4.3.4.1 INITIAL CONSIDERATIONS

Before a small volume 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 to the meter piping. The following items should be established from a study of the application, intended use, and space limitations of the prover:

a. Whether the prover will be stationary or mobile.
   1. Whether a stationary prover will be dedicated (on line) or used as part of a central system.
   2. Whether a stationary and dedicated prover will be kept in service continuously or isolated from the metered stream when it is not being used to prove a meter.
b. The temperature and pressure ranges that will be encountered.
c. The expected maximum and minimum flow rates and the flow-rate stability.
d. The maximum pressure drop allowable across the prover.
e. The physical properties of the fluids to be handled.
f. The degree of automation to be incorporated into the proving operation.
g. The availability of electric power and other utilities.
h. The size and types of meters to be proved.
i. The applicable codes.

4.3.4.2 PRESSURE DROP ACROSS THE PROVER

In determining the size of the piping and the openings to be used in the manifolding and the prover, the pressure loss through the prover system should be compatible with the pressure loss considered tolerable in the metering installation. Flow rate should not vary significantly during movement of the displacer.

4.3.4.3 DISPLACER VELOCITY

The velocity of the displacer can be determined by the diameter of the prover cylinder and the maximum and minimum flow rates of the meters to be proved. A practical limit to the maximum velocity of a displacer must be established to prevent damage to the displacer and the detectors.

Typical maximum displacer velocities are close to but not limited to 5 feet per second (1.5 meters per second). The developing state of the art advises against setting a firm limit on displacer velocity as a criterion for design. Demonstrated results are better to use as a criterion. The results are manifested in repeatability, accuracy, and reproducibility of meter factors using the prover in question.

Establishing guidelines for minimum velocities is difficult because of the many factors that must be considered, such as the following:

a. The smoothness of the cylinder's internal surface.
b. The type of displacer used.
c. The displacer's launching capability.
d. The lubricity of the liquid being measured.

Piston-type displacers can generally operate at lower velocities than can sphere types.

The intention of this standard is not to limit the velocity of the displacer. Provided that acceptable performance is guaranteed, there is no arbitrary limit imposed on velocity.

4.3.4.4 VOLUME

In determining the volume of a prover between detectors, the designer must consider the following items:

a. The overall repeatability required of the proving system.
b. The repeatability of the detectors.
c. The ability of the electronic counter to indicate whole pulses, unless pulse interpolation is employed.
d. The resolution of the meter pulse generator (the number of pulses per unit volume).
e. The maximum and minimum flow rates of the system.
f. The uniformity of the meter signal, or pulse, relative to time (interpulse spacing).
g. The meter's displaced volume per revolution.

4.3.4.5 CRITICAL PARTS

When a detector's worn or damaged parts are replaced, care must be taken to ensure that neither the detector's actuating depth nor its electrical switch components are altered to the extent that the prover volume is changed. This is especially important in the case of unidirectional provers because changes in detector actuation are not compensated for by round trip sphere travel, as they are in bidirectional provers. When unidirectional provers are used, recalibration is needed as soon as practical.

4.3.4.6 COUNTERS

The small volume prover requires using a meter pulse-interpolation-type system (see Chapter 4.6) to provide a resolution of at least one part in 10,000 of the indicated meter volume for each pass of the displacer between the detectors.

4.3.4.7 METER PROVING GUIDELINES

Different types of meters produce pulse trains that have different characteristics.

At a steady flow, the rotation of a turbine meter and its pulse train is uniform. Under comparable flow, the rotation of some displacement-meter elements is also uniform; however, mechanical gears, couplings, adjustors, counters, temperature-correction devices, and other accessories reduce the uniformity of the displacement-meter pulses.

Demonstrations have shown that the closer the pulse generator is to the meter rotor, the more uniform the pulse train will be. The further the pulse is moved from the meter rotor, the more erratic the pulse train becomes (see Appendix A).

For example, a displacement meter that has a close-coupled pulser will require only a minimal number of prover passes performed by a relatively-low-volume prover to establish a meter factor. (See Figure A-2 for pulse train characteristics.) A displacement meter with a full assortment of accessories will usually require more passes or the use of a larger prover to establish a meter factor. (See Figure A-3 for pulse train characteristics.)

4.3.5 Sample Calculations for the Design of Small Volume Provers

A typical approach to the design and application of small volume provers is provided in 4.3.5.1 and 4.3.5.2.

Note: Test-run observation indicates that the calculation method used in 4.3.5.1 and 4.3.5.2 should provide a minimum volume for proving a meter with a uniform pulse train (for example, a turbine meter or a displacement meter that has a uniform pulse output). A proving method that consists of five prover passes, or round trips, with a repeatability range of 0.05 percent is achievable. Proving methods for use on nonuniform pulse output meters are discussed in Appendix B. The examples used in this section are not intended to imply that the meter and prover data will be appropriate for all equipment or that other methods of prover design analysis are inappropriate.

4.3.5.1 PROBLEM

The maximum flow rate of the meter to be proved is 1715 barrels per hour (1200 gallons per minute, 272.66 cubic meters per hour). The minimum flow rate is 343 barrels per hour (240 gallons per minute, 54.49 cubic meters per hour).

The meter is a 6-inch displacement meter with a pulse rate of 8400 pulses per barrel (52,834.4 pulses per cubic meter). The maximum interpulse spacing is equal to ±10 percent of the average. The meter pulse output is approximately uniform with the rotation of the meter element.

The pulse interpolation is performed by the double-chronometry method using one clock with a frequency of 100,000 hertz.

The prover displacer-position detectors have a repeatability range of 0.001 inch (0.0254 millimeter) and a position stability range of 0.001 inch (0.0254 millimeter).

The meter output resolution at the start and end of one prover pass is ±0.01 percent (±0.0001 percent of the average). The prover displacer-position error at the start and end of a prover pass has an uncertainty of ±0.01 percent. The maximum displacer velocity is 3.5 feet per second (1.067 meters per second). The minimum displacer velocity is 1.2 inches per second (3.048 centimeters per second).

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

4.3.5.2 SOLUTION

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

$$U_t = \pm 2 / N_c \tag{1}$$

Where:

U_t = potential 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:

$$N_c = T_2 F_c \tag{2}$$

Where:

T_2 = clock operating time during a prover pass, in seconds.
F_c = clock frequency, in hertz.

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

$$T_2 = N_m / F_m \tag{3}$$

Where:

N_m = number of meter pulses during a prover pass, in pulses.
F_m = meter pulse frequency, in hertz.

Equations 1, 2, and 3 can be combined to express the error of the timers in terms of meter output and timer frequency:

$$U_t = \pm 2F_m / N_m F_c \tag{4}$$

The meter pulse frequency is calculated as follows:

$$F_m = Q_m P_r / 3600$$

Where:

Q_m = meter flow rate, in barrels per hour (cubic meters per hour).
P_r = meter pulse rate, in pulses per barrel (pulses per cubic meter).
3600 = number of seconds per hour.

In this example the maximum pulse frequency is calculated as follows:

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

In SI units,

$$F_{m(max)} = (272.66)(56,834.4)/3600 = 4002 \text{ hertz}$$

The potential error of the double-chronometry time can be calculated from Equation 4 as follows:

$$U_t = (\pm 2)(4002)/(N_m)(100,000) = \pm 0.080/N_m$$

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

$$U_m = (2)(\pm P_s)/N_m \tag{5}$$

Where:

U_m = potential error due to nonuniform meter interpulse spacing during a prover pass, expressed as a plus / minus fraction.

2 = number of displacer detections during a prover pass.

P_s = meter interpulse spacing expressed as a plus / minus fraction of a pulse.

In this example the error due to nonuniform meter interpulse spacing is as follows:

$$U_m = 2(\pm 0.10) / N_m$$
$$= \pm 0.20 / N_m$$

The combined meter output error at the start and end of a prover pass can be estimated by combining Equations 4 and 5 as follows:

$$U_t + U_m = \pm 2F_m / N_m F_c + (2)(\pm P_s) / N_m \quad (6)$$

Note: Equation 6 sums the errors U_t and U_m instead of taking the root mean square, the usual method of calculation. This approach results in a slightly larger prover than might otherwise be calculated.

In this example the combined meter pulse uncertainty during a prover pass is as follows:

$$U_t + U_m = (\pm 0.080 + \pm 0.20) / N_m$$
$$= \pm 0.280 / N_m$$

The maximum meter output error at the start and end of a prover pass is limited to the following:

$$U_t + U_m = \pm 0.0001 (\pm 0.01 \text{ percent})$$

In this example the minimum number of meter pulses that limits meter error to ±0.0001 is as follows:

$$\pm 0.280 / N_m = \pm 0.0001$$

Therefore,

$$N_m = 2800 \text{ meter pulses}$$

The minimum prover volume is calculated as follows:

$$V_{P(min)} = N_m / P_r$$
$$= 2800 / 8400$$
$$= 0.33333 \text{ barrel } (0.05299 \text{ cubic meter})$$
$$= 14.000 \text{ gallons } (52.996 \text{ liters})$$
$$= 3234.0 \text{ cubic inches } (52{,}996 \text{ cubic centimeters})$$

The minimum diameter of a prover's calibrated chamber at the maximum flow rate is calculated as follows:

$$D_p = [Q_m / (0.7854 V_d)]^{0.5}$$

In SI units,

$$D_p = [Q_m / (0.7854 V_d)]^{0.5}$$

Where:

D_p = internal diameter of the prover's calibrated chamber, in inches (centimeters).

Q_m = meter flow rate, in cubic inches per second (cubic centimeters per second).

V_d = displacer velocity, in inches per second (centimeters per second).

In this example the minimum prover diameter for the velocity limit is calculated as follows:

$$D_{P(min)} = \{4620 / [(0.7854)(42)]\}^{0.5}$$
$$= 11.83 \text{ inches}$$

In SI units,

$$D_{P(min)} = \{75{,}708.2 / [(0.7854)(106.68)]\}^{0.5}$$
$$= 30.06 \text{ centimeters}$$

The velocity of the displacer at the minimum flow rate, with the inside diameter given above, is calculated as follows:

$$V_{d(min)} = Q_m / [0.7854(D_p^2)]$$
$$= 924 / [(0.7854)(11.83^2)]$$
$$= 8.4 \text{ inches per second}$$
$$= 0.7 \text{ foot per second}$$

In SI units,

$$V_{d(min)} = Q_m / [(30.05)(D_p^2)]$$
$$= 15{,}141.6 / [(0.7854)(30.05^2)]$$
$$= 21.35 \text{ centimeters per second}$$
$$= 0.213 \text{ meter per second}$$

Since the minimum calculated displacer velocity of 0.7 foot per second (0.213 meter per second) is more than the design limit of 0.1 foot per second (0.03 meter per second), the diameter of 11.83 inches (30.05 centimeters) is satisfactory.

The prover's calibrated section is calculated as follows:

$$L_p = V_p / [0.7854(D_p^2)]$$

In this example the minimum prover length, based on the minimum volume and diameter of the prover section, is as follows:

$$L_{P(min)} = 3234 / [(0.7854)(11.83^2)]$$
$$= 29.42 \text{ inches}$$

In SI units,

$$L_{P(min)} = 52{,}996 / [(0.7854)(30.05^2)]$$
$$= 74.72 \text{ centimeters}$$

The error in the displacer's position during a prover pass can be estimated as follows:

$$U_d = [2(r_d + s_d)] / L_p$$

Where:

U_d = range of error in the displacer's position during a prover pass, expressed as a fraction.

2 = number of displacer positions during a prover pass.

r_d = range of repeatability of the displacer detector or detectors, in inches (centimeters).

s_d = range of stability in the mounting position of the displacer detector or detectors, in inches (centimeters).

In this example the minimum length of the prover's calibrated section for a maximum error range of 0.0002 (0.02 percent) in displacer positions during a prover pass would be as follows:

$$L_{P(min)} = 2(r_d + s_d) / U_d$$
$$= [2(0.001 + 0.001)] / 0.0002$$
$$= 20 \text{ inches}$$

In SI units,

$$L_{P(min)} = 2(r_d + s_d) / U_d$$
$$= [2(0.00254 + 0.00254)] / 0.0002$$
$$= 50.8 \text{ centimeters}$$

Since the minimum prover length corresponding to the minimum diameter [29.42 inches (74.72 centimeters)] is longer than the minimum prover length based on displacer detector error [20 inches (50.8 centimeters)], the former prover length is satisfactory.

4.3.5.3 SUMMARY OF PROVER DESIGN CALCULATIONS

The minimum volume equals 14.000 gallons (52.996 liters). The minimum diameter equals 11.83 inches (30.05 centimeters). The minimum length equals 29.42 inches (74.72 centimeters).

4.3.5.4 OTHER CONSIDERATIONS

When operating at its maximum design flow rate, the small volume prover shall allow the displacer to come to rest safely without shock at the end of its travel.

When the prover is operating at its maximum flow rate with liquids for which it was designed, there shall be no sign of cavitation in the prover, the valves, or any other apparatus within the specified temperature and pressure ranges.

4.3.6 Installation

All installation components of the small volume prover, including connecting piping, valves, manifolds, and so forth, shall be in accordance with the applicable piping codes. Once the prover is onstream, it becomes a part of the pressure system.

If the proving section and related components are installed aboveground, they shall have suitable hangers and supports prescribed by the applicable codes and in accordance with sound engineering principles. Adequate provisions should be made for expansion and contraction, vibration, reaction to pressure surges, and other conditions.

Suitable valves shall be installed to isolate the prover unit from line pressure during maintenance, removal of the displacer, replacement of seals, cleaning, and recalibration. Likewise, connections on the prover or in the lines should be considered for subsequent recalibrations.

All units shall be equipped with vent and drain connections, and provision should be made for the disposal of liquids or vapors that are drained or vented from the small volume prover section. This may be accomplished by pumping liquids or vapors back into the system or by diverting them to a collecting point.

Temperature and pressure devices shall be installed in suitable locations near the meter and the prover so that they can be used to determine the temperature and pressure of each.

Blinded valves or valve connections should probably be provided on either side of a bubbletight block valve in the carrier stream to serve as a permanent connection for proving portable meters.

Installations in hazardous locations must be recognized as such, and all wiring and controls in these locations shall conform to the requirements of NFPA 70 and any other applicable electrical standards. Provisions shall be made for proper grounding and electrical installation of portable small volume provers.

Components shall come from the class and group that are most appropriate for the location and operation. All electrical controls and components should be placed in a location that is convenient for operation and maintenance. Manufacturers' instructions should be strictly followed during the installation and grounding of such items as electronic counters, pulse-interpolation equipment, and signal cables (see Chapter 5.4).

Pressure relief valves and leak-detection facilities shall be installed with discharge piping to control thermal expansion of the liquid in the small volume prover while it is isolated from the main stream.

Power controls and remote controls should be suitably protected with lockout switches between remote and adjacent panel locations to prevent accidental remote operation while a unit is being controlled locally. Suitable safety devices and locks should be installed to prevent inadvertent operation of or unauthorized tampering with equipment.

Automated or power-operated meter proving systems may be equipped with emergency manual operators for use during a power failure.

Small volume provers may require straining or filtering equipment.

4.3.7 Calibration

4.3.7.1 GENERAL CONSIDERATIONS

A small volume prover must be calibrated before it is placed in service to determine its base volume (the calibrated volume corrected to standard conditions). Periodic recalibration of the prover is also required. Chapter 12.2 gives details for determining all the correction factors and calculating the base volume. Some of the differences in calculating the base volume of a small volume prover are discussed in the following paragraphs.

The accuracy of the base volume (documented on a calibration certificate), as determined, cannot be better than the accuracy of the field standard used in determining it (see Chapter 12.2).

It should be clearly understood that the base volume of a unidirectional prover is the calibrated volume corrected to standard conditions and displaced between detectors for a single pass. The base volume of a bidirectional prover is the sum of the volumes displaced between detectors for a round trip of the displacer and corrected to standard conditions.

Some unidirectional small volume provers have one or more shafts attached to the displacer. The shaft may be continuous or may be on only one side of the displacer. If the shaft is continuous and uniform, the effective upstream volume may be equal to the effective downstream volume; however, if the shaft is on only one side of the displacer, the effective upstream volume will differ from the effective downstream volume. For further clarification, if the shaft is on the upstream side of the displacer, the effective volume when a meter is proved upstream of the prover will be less than the effective volume when a meter is proved downstream of the prover. Conversely, if the shaft is on the downstream side of the displacer, the effective volume when a meter is proved upstream of the prover will be greater than the effective volume when a meter is proved downstream of the prover. The difference in volumes is equivalent to the volume displaced by the shaft. Both volumes shall therefore be stated on the calibration certificate. If only one volume is determined, the certificate shall clearly state and identify the side of the prover that is calibrated to ensure that it is the side used to prove a meter.

The methods of calibrating a small volume prover include the waterdraw method, the gravimetric method, and the master-meter method. The waterdraw method, described in 4.3.7.2, is by far the most common.

4.3.7.2 WATERDRAW METHOD

The calibration of small volume provers by the waterdraw method may be simplified where possible by placing the prover, field standards, and test liquid in a stable temperature environment shaded from direct sunshine to allow the equipment and liquid to reach an equilibrium temperature.

Water is the ideal calibrating medium because of its high heat capacity, low compressibility, and low coefficient of thermal expansion compared to petroleum liquids. The use of any other medium in these measures changes the surface tension; consequently, the measure is no longer calibrated. To prevent contamination of the water, the prover and fill lines must be void of foreign materials.

The displacers should be moved through the small volume prover enough times to flush the prover and eliminate air that may have been caught in parts of the small volume prover system and to allow both the metal and liquid of the prover system to reach a common and steady temperature. Uninsulated small volume provers that are calibrated outdoors under hot or cold conditions should be temporarily insulated and sheltered to reduce variations in temperature. In addition to stabilizing the prover, it is necessary to verify that the valves, seals, and displacer are secure and that there is no leakage from or around the prover.

The temperature and pressure of the water at the prover, between the displacer and the standard measures, shall then be observed and recorded as the temperature and pressure in the prover at the start of calibration.

Test measures for the calibration of small volume provers shall comply with the requirements given in Chapter 4.7. High-sensitivity field standards with a resolution of 0.02 percent or better are recommended for use in calibrating small volume provers. Only a single field standard or as few field standards as possible should be used during a waterdraw calibration of a small volume prover.

The prover may be calibrated using small-diameter water lines and temporary valves. Automated fast-responding valves actuated by the detector switches, commonly called solenoid valves, shall be used. (See Figure 5.) Provisions shall be made to ensure that no water bypasses the field standard. The data recording sheets should be checked and signed by all parties that witness the calibration.

4.3.7.3 CALIBRATING BIDIRECTIONAL PROVERS

After completion of the preparatory steps for flushing air out of the prover and stabilizing the temperature, at least one trial calibration run should be made to determine the approximate volume of the small volume prover between its detectors so that the appropriate number and sizes of field standards can be estimated. A

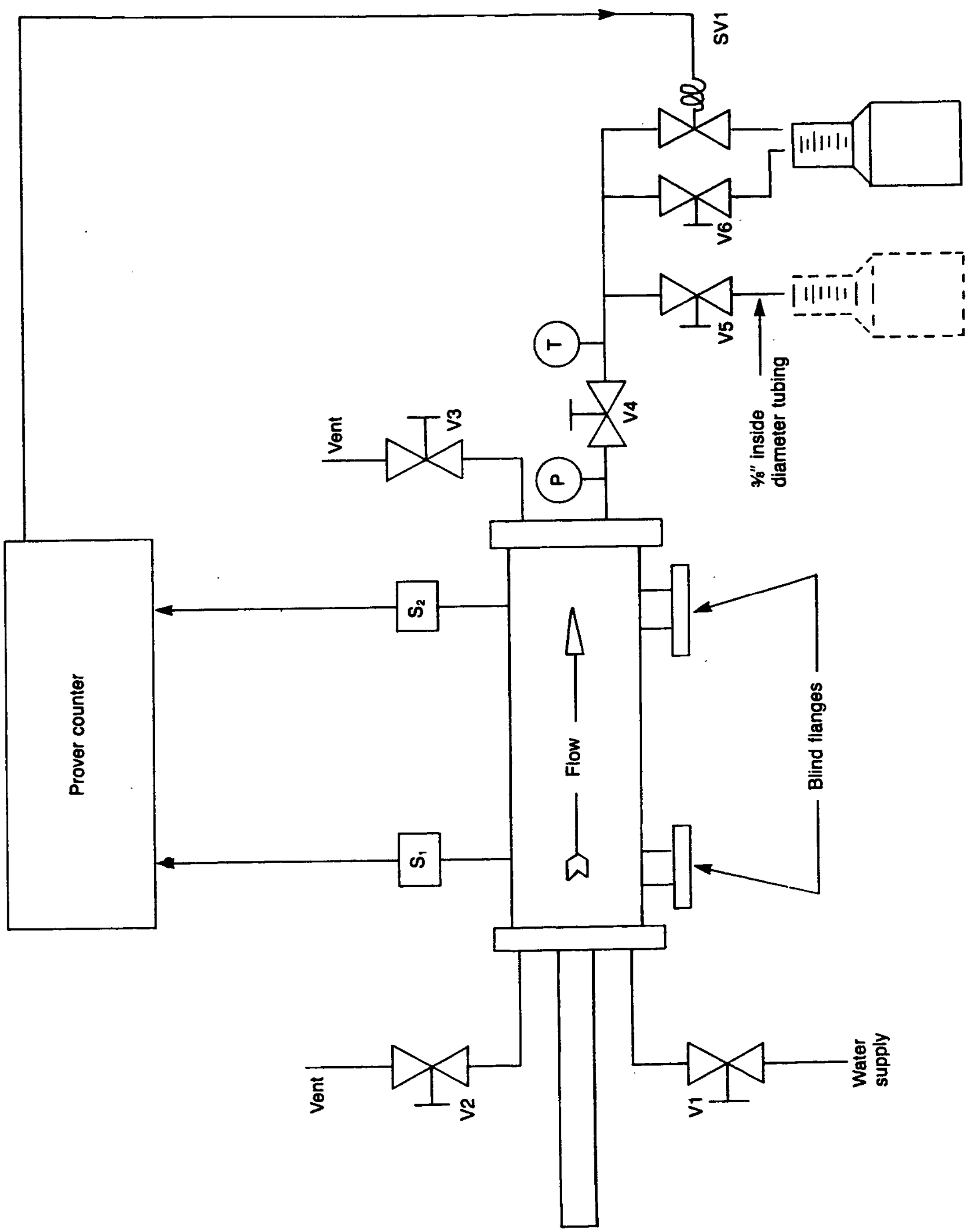

Figure 5—Generalized System Overview of Waterdraw Method

minimum number of field standards should be used (see Chapter 4.7).

Bidirectional calibration runs should now be started. The displacer should be driven past one of the switches into the space just outside the calibrated volume at either end of the small volume prover. The valves should be reversed so that the displacer travels toward the section to be calibrated while wasting the effluent water. Before reaching the detector, the water should be wasted slowly through a fast-acting automated valve. The waste should be stopped by using the fast-acting automated valve at the instant the switch indication shows "ON." The temperature and pressure of the water in the prover should be recorded. Next, all additional effluent water should be directed into the selected field standards. The withdrawals should be continued until the last field standard is being filled. The withdrawal should be reduced to a controllable slow-bleed rate through the fast-acting automated valve until the "ON" switch indication is observed at the second detector point; the withdrawal should be stopped at the instant the switch shows "ON." The total of the field-standard volumes indicates the observed displaced volume between detectors in that direction of travel under conditions of pressure and temperature that exist at the start of calibration. The fill condition of the drain hose and other withdrawal equipment shall be the same at the end of the withdrawal as it was at the start.

A similar displacer trip should now be made in the opposite direction, repeating the procedure. These two trips do not necessarily have to agree in observed displaced volume because the action of the detectors may be different for each direction of travel.

The calibrating procedure should be repeated until satisfactory repeatability is achieved. The average of at least two consecutive round trip corrected volumes within 0.02 percent (±0.01 percent of the average) is required. The corrected volume for the consecutive trips in any given direction shall also agree within 0.02 percent (±0.01 percent of the average).

The base volume is the average of two or more consecutive round trips of the displacer within the tolerances after correcting to the standard temperature and pressure.

Failure to repeat may be caused by leaking valves, air in the system, varying pressure, improper condition of the displacer or detectors, or poor calibration technique.

4.3.7.4 CALIBRATING UNIDIRECTIONAL PROVERS

The base volume of a unidirectional prover is the volume that is displaced as the displacer moves from one detector switch point to a second detector switch point. The described one-way trip procedure should be repeated until satisfactory repeatability is achieved. The average value for a minimum of two such one-way corrected volumes is considered the base volume for the prover at standard conditions.

This publication does not restrict the determination of the base volume to two consecutive runs. More runs may be used if agreed to by the parties involved.

The procedure for calibrating a unidirectional prover by the waterdraw method is substantially the same as the procedure described for a single one-way trip of the displacer in a bidirectional prover. The results of two or more consecutive runs (as agreed upon by the interested parties) shall agree within 0.02 percent (±0.01 percent of the average) or better to determine the base volume. For waterdraw calibration of the upstream section with the displacer moving in the opposite direction, the procedures are exactly the same except that care must be taken to use the same edge of the detector trigger that is used in calibrating the downstream section, and the displacer and valve seals must be confirmed in this direction. In effect, the difference between upstream and downstream volumes is equivalent to the area of the shaft or shafts times the length between detector trigger points.

4.3.7.5 REPEATABILITY

Repeatability is only one component of calibration accuracy. By filling the same field standards with the test runs made at an equal rate, an operator can complete a series of erroneous calibrations as the result of a consistent leak. This hazard can be reduced or eliminated by making an additional run at a rate change of at least 25 percent. With a changed flow rate, a different volume (after correction) that is outside 0.02 percent (±0.01 percent of the average) of the initial runs (after correction) indicates the possibility of a leak in the proving circuit, which must be corrected before calibration can be achieved. All corrected volumes at both flow rates shall fall within 0.02 percent (±0.01 percent of the average). This is true of both unidirectional and bidirectional provers.

4.3.7.6 CERTIFICATE OF CALIBRATION

After a small volume prover is calibrated, the data sheets shall be used to prepare a certification of calibration. The certificate shall state the calibration method used, the base volume or volumes, the reference conditions, the serial numbers, and the date.

For unidirectional small volume provers that have a shaft attached to the piston, the certificate shall clearly state and identify the side of the prover that is calibrated to ensure that it is the side used to prove a meter.

4.3.8 Operation

Proving with small volume provers requires the same good practices commonly associated with pipe provers.

All valves in the flow path between the meter and the small volume prover must be positioned so that fluid cannot be diverted from or added to the stream. All valves associated with the proving system must include a method for detecting leaks and must be free from leaks.

The proving system shall include at least one temperature indicator in the flow line adjacent to the meter and at least one indicator adjacent to the prover (see 4.3.5.3).

Pressure indicators shall be installed at appropriate locations to measure pressure at the meter and the prover (see 4.3.5.4).

Venting should be performed on the small volume prover and at other appropriate locations to ensure that air or gas is not trapped in the flow system before proving.

Steady flow should be established in the system to ensure stable temperature and pressure before proving.

The need for maintaining back pressure on the meter/prover system depends on various factors such as fluid velocity, fluid vapor pressure, and operating pressure and temperature. (See Chapters 5.2 and 5.3 for recommendations.)

Meter pulse output should be checked to ensure pulse integrity. Mechanical or electrical meter register tests should be conducted before proving.

The displacer seals of small volume provers should be checked for sealing integrity in accordance with the manufacturer's recommended procedure.

Pulse-interpolation or other types of counters used in conjunction with small volume provers shall be verified for correct operation before proof runs are conducted. (See Chapter 4.6 for descriptions of calibration tests and functional checks.)

Automated small volume provers that incorporate microprocessor computer sequence control, pulse interpolation, data acquisition, and data reduction shall be tested for functional operation before meter proofs are conducted. Such systems should contain self-test features to verify the operation of computer software and hardware. Manufacturers' procedures and recommendations should be followed in accordance with the appropriate sections of the *Manual of Petroleum Measurement Standards.*

In unidirectional small volume provers, a proving run consists of one trip of the displacer through the calibrated section.

Note: Care must be exercised during the use of displacers that incorporate a rod or rods, since the volumes upstream and downstream of the displacer will be different.

In bidirectional small volume provers, a proving run consists of a round trip of the displacer (that is, the sum of two consecutive trips in opposite directions through the calibrated section).

4.3.9 Nonuniform Pulses

Caution is recommended when gear-driven pulse generators are used on displacement meters to ensure that backlash, drive-shaft torsion, and cyclic effects do not cause irregular pulse generation. If these problems occur, an evaluation of the gearing and pulse-generation systems should be made to ensure that proper equipment is selected to provide optimum performance. Problems should be referred to the manufacturer of the meter and the small volume prover.

APPENDIX A—EVALUATION OF DISPLACEMENT METER PULSE VARIATIONS

A.1 General

During the development of Chapter 4.3, a question was raised about the magnitude of the pulse variations in conventional displacement meter systems. No experience or data were known, and two manufacturers volunteered to test several meters to define the range of pulse variations that could reasonably be expected.

Some of the terms used to describe pulse variations include interpulse linearity and pulse interspace variations. In fact, the concern is with pulse frequency variations within one cycle or rotation of a meter-measuring element or the gear train that provides the output motion for the proving pickup or counter. Gear systems, universal joints, and clutch-type adjustment devices are known to impart accelerations within a single revolution of a meter. The same variations may occur in gear-driven turbine-meter outputs and turbine-meter rotors where the magnetic plugs are not uniformly spaced on the perimeter of the rotor. These are probably minor variations compared with those that would be expected from displacement meters. No tests were performed on turbine meters.

Forty-four tests consisting of 10–25 provings with a small volume prover and 11 tests consisting of five pass provings with a 54-barrel unidirectional displacement prover were completed and recorded. The results are summarized in A.2 through A.4.

A.2 Equipment

A.2.1 METERS AND PROVERS

The displacement meters were connected in series in flowing-liquid test loops with nominal 15-gallon small volume provers for the tests. A conventional 54-barrel displacement prover was in the loop in one series of tests.

The meters were new production units available at the manufacturer's test facility. Each had limited pretest operation.

The pulses were generated in the conventional manner from commercial displacement meters. Two 3-inch meters, two 4-inch meters, and one 6-inch meter were used. In addition, a 3-inch and a 6-inch meter were equipped with special close-coupled pickup arrangements to monitor the performance of the measuring element only, without the influence of gears and shafts.

A.2.2 RECORDER

A precision high-frequency recording system was used for the tests at both locations. The 8-pen recorder with a chart speed of 50 millimeters per second was used to display the pulse trains generated by the meters.

A.3 Analysis of Results

The chart records of the test were analyzed manually to quantify the pulse variations. The following method was used:

a. Pulses generated by several rotations of the meter system were recorded.
b. The number of pulses representing 0.25 gallon of liquid passing through the meter was counted and marked. This resulted in 25- and 50-pulse segments for the meter outputs that were tested.
c. The length of chart represented by the pulses from 0.25 gallon was measured and recorded.
d. The series of chart lengths was plotted in bar-graph style.
e. The maximum chart length (that is, the lowest frequency segment) and the minimum chart length (that is, the highest frequency segment) within a meter rotation were identified.
g. The pulse variation was calculated as follows:

$$\text{Percent pulse range} = \pm \frac{(\text{maximum chart length} - \text{minimum chart length}) \times 100}{2 \times \text{mean chart length}}$$

A.4 Results

A.4.1 GENERAL

Figures A-1, A-2, and A-3 illustrate the typical bar-graph analysis and results. The plots represent typical results obtained for the three meter sizes and the accessory equipment noted on the respective figures. The graphs are typical and cannot be considered specific for any given manufacturer's equipment. The charts do, however, illustrate the quality of the pulse output for various accessory arrangements and indicate the trend in pulse quality that may be expected from more or less equipment on a meter stack.

A.4.2 EXPLANATION OF BAR CHART

A displacement meter equipped with a pulse generator produces a series of electrical pulses separated by spaces. For simplification, a pulse should be considered to have a length of ¼ inch, which is then followed by a space of ¼ inch. This is termed a 50-percent-on/50-percent-off pulse train. This is predicated on the meter operating at a constant flow rate.

Even though the meter may be running at a constant flow rate, irregularities in the meter's drive mechanism may cause the pulse train to be alternately compressed and expanded.

Each of the bar charts has a horizontal and vertical axis. The horizontal axis represents the total number of pulses accumulated over a given period of time, and the numbers shown represent pulses counted on a linear chart. The vertical axis represents the number of inches between the pulses counted on the horizontal axis. Thus, on Figure A-1 the first six pulses/spaces account for 15.9 inches, whereas the second six pulses and accompanying spaces account for 16.0 inches, and so forth. The shortest and the longest lengths in the bar-chart group are 15.85 and 16.1 inches, respectively. Thus, 16.1 minus 15.85 divided by the mean length of 16 inches is equal to 1.5 percent interspace variation.

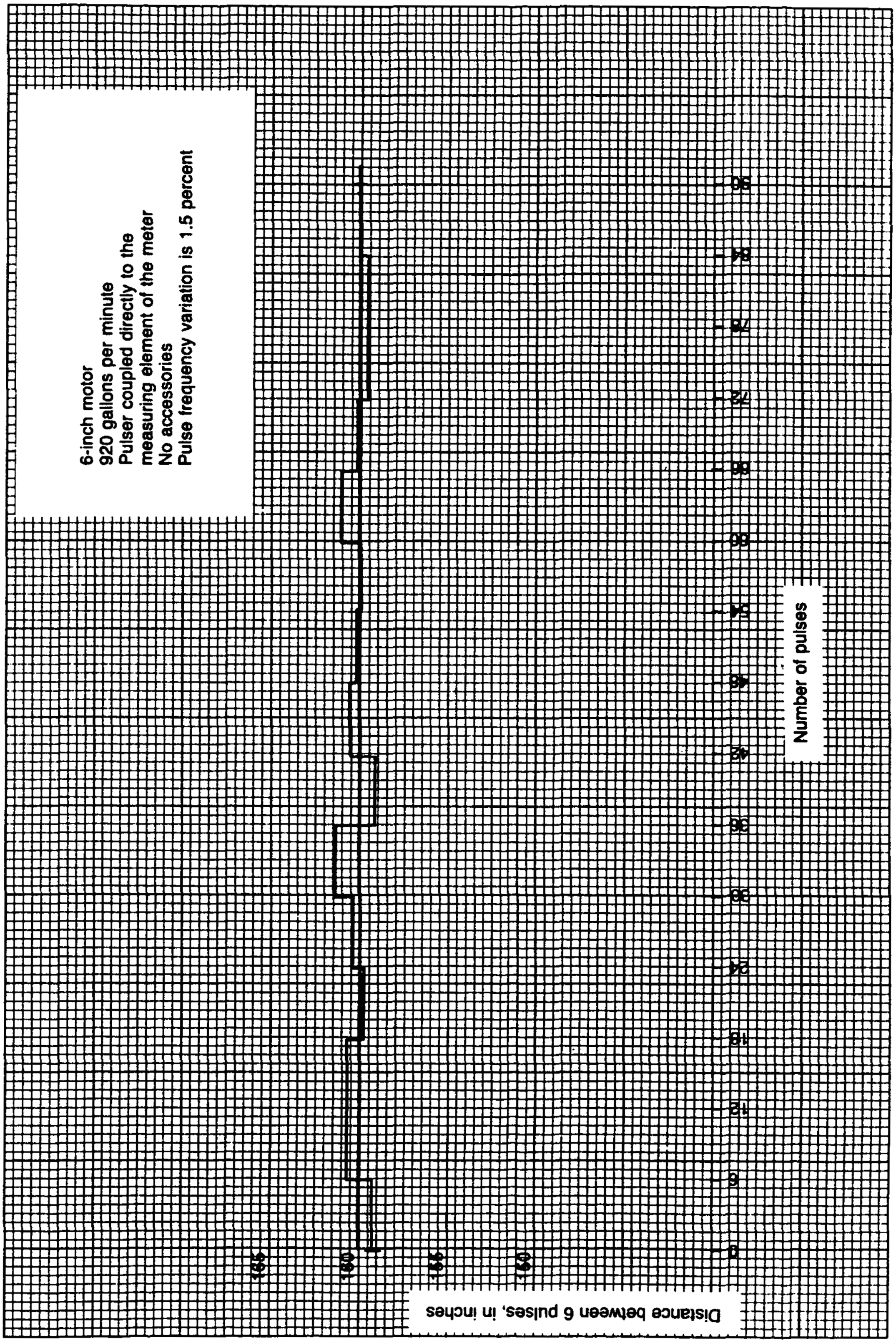

Figure A-1—Pulse Variation Graph/Direct

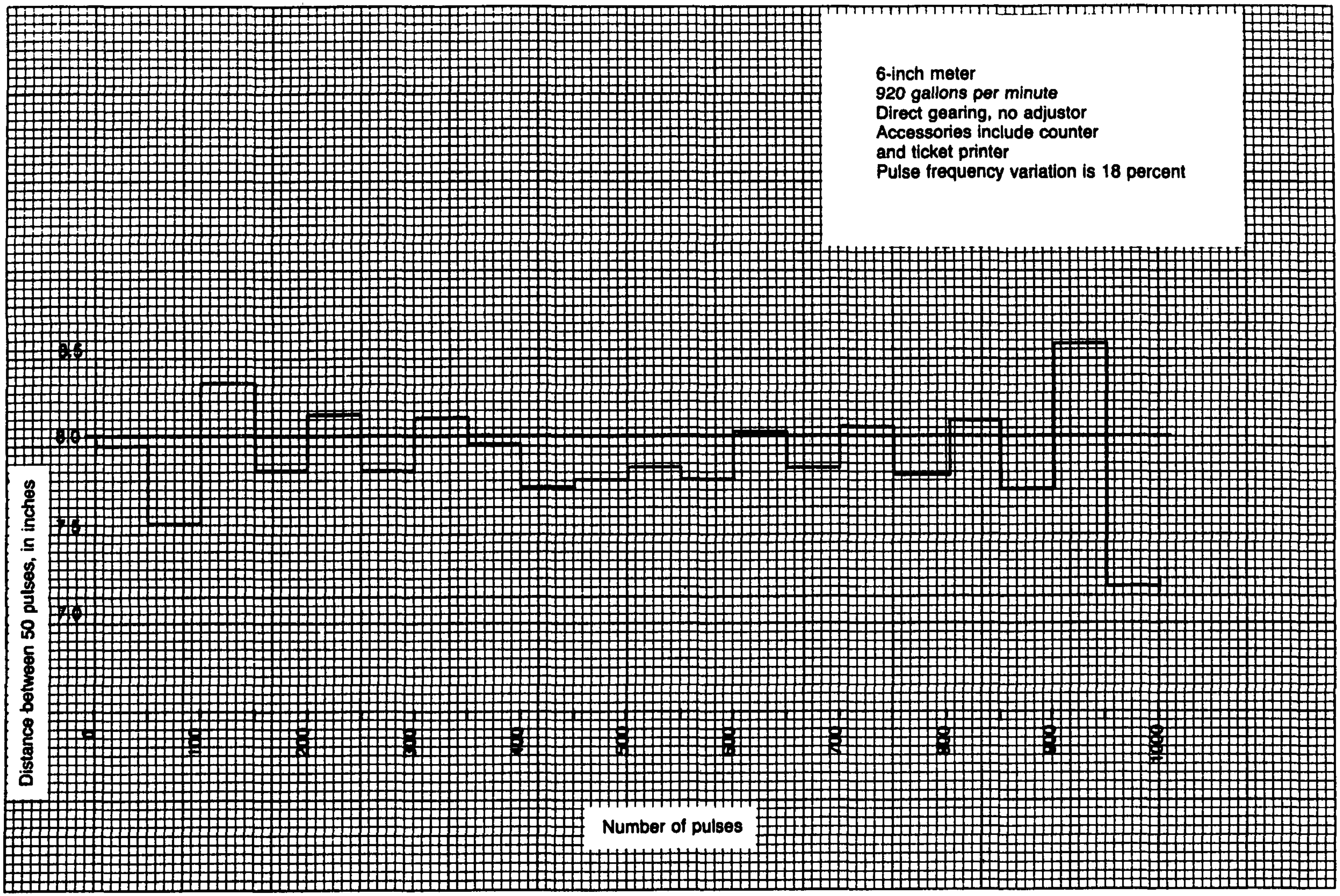

Figure A-2—Pulse Variation Graph/Geared

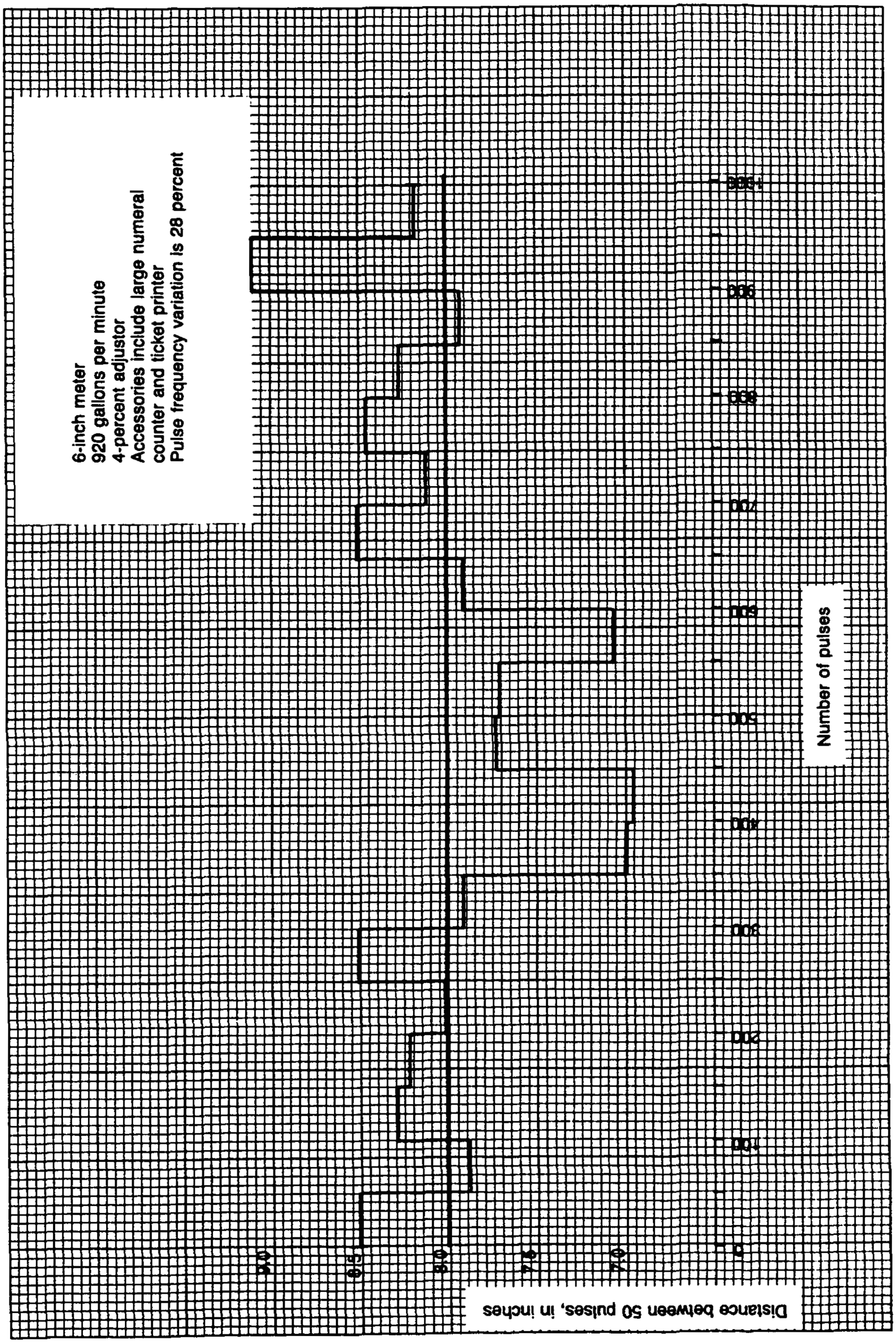

Figure A-3—Pulse Variation Graph/4-Percent Adjustment

APPENDIX B—METER FACTOR DETERMINATION WITH SMALL VOLUME PROVERS

B.1 General

The contributors to the initial Chapter 4.3 perceived a need to provide guidance for the development of acceptable meter factors with small volume provers. The methods described in the following paragraphs have been demonstrated to yield meter factors either comparable to those obtained from conventional displacement provers or considered to be accurate within usual tolerances by virtue of the repeatability of individual passes or prover round trips or groups of passes or prover round trips from properly operated systems. Calculation details shall be in accordance with the usual practices and as documented in Chapter 12.2.

The meter factors obtained from two separate provers for a specific meter and operating condition will rarely agree exactly because of the differences in the equipment, base-volume calibration tolerances, meter repeatability, and other factors. Agreement within 0.04 percent (±0.02 percent of the average) is generally considered acceptable for normal industry practice if no other agreement has been defined.

The following methods, based on observations and experience, were compiled by the working group before 1986. The methods are for guidance only; they are not a final recommendation, nor are they all-inclusive. Other methods, some of which were arrived at by various statistical techniques, exist but have not been sufficiently demonstrated to be listed here. The methods will ultimately be replaced by mature techniques to be documented in a future section of Chapter 4 that will address operational aspects of proving and will supersede this appendix.

B.2 Method 1

Turbine meters and displacement meters whose pulse generation is directly from, or very close to, the measuring elements can be proved with the same methods used for conventional displacement provers. This normally consists of five consecutive passes or round trips that repeat within 0.05 percent (±0.025 percent of the average). The average of the results from these passes or prover round trips then becomes the meter factor to be used in subsequent operations.

B.3 Method 2

Meters that have a nonuniform pulse output (that is, turbine and displacement meters with gear trains, shaft couplings, and shaft-driven accessories) may be proved by increasing the number of passes or prover round trips or by increasing the repeatability tolerance. For example,

> 10 passes or prover round trips that repeat within 0.10 percent (±0.05 percent of the average).
>
> The average of the prover-pass results becomes the meter factor to be used in subsequent operations.

Additional passes or prover round trips may be added as required to accommodate meters that repeat beyond 0.10 percent (±0.05 percent of the average) because of the nonuniform pulse characteristics. For example, 15 prover passes or prover round trips that repeat within 0.15 percent (±0.075 percent of the average) would be the next level of consideration.

The rationale for this procedure is that as the number of passes or prover round trips is increased, the repeatability performance of the meter usually increases and at the same time the quality of the average improves.

B.4 Method 3

A meter that has more severe nonuniform pulse output or a prover that is minimal in size may necessitate using the following method. The concept is to accumulate individual prover passes or prover round trips to form groups and then to average each group. The ranges of these groups should fall within tolerances that are consistent with the first and second methods. The average of the group averages then becomes the meter factor to be used in subsequent operations.

Increasing the number of passes or prover round trips in each group will improve the quality of the intergroup repeatability. Twenty passes or prover round trips per group is considered a practical limit; more will not improve the quality. If an acceptable repeatability is not obtained in 20 or fewer passes or prover round trips, the meter manufacturer should be consulted.

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