BRITISH STANDARD

BS EN ISO
7278-2:1996

Incorporating
Amendment No. 1
BS 6866-2:1990
renumbered

Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters —

Part 2: Pipe provers

The European Standard EN ISO 7278-2:1995 has the status of a British Standard

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Petroleum Standards Policy Committee (PTC/-) to Technical Committee PTC/12, upon which the following bodies were represented:

Department of Energy (Gas and Oil Measurement Branch)
Department of Trade and Industry (National Engineering Laboratory)
Department of Transport (Marine Directorate)
General Council of British Shipping
Institute of Petroleum
Royal Institution of Naval Architects
Salvage Association

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

GAMBICA (BEAMA Ltd.)
Institute of Measurement and Control
United Kingdom Offshore Operators' Association

This British Standard, having been prepared under the direction of the Petroleum Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 31 August 1990

The following BSI references relate to the work on this standard:
Committee reference PTC/12
Draft for comment 85/55226 DC

ISBN 0 580 18713 6

Amendments issued since publication

Amd. No.	Date	Comments
8899	June 1996	Indicated by a sideline in the margin

Contents

National foreword

This Part of BS EN ISO 7278 has been prepared by Technical Committee PTI/12 (formerly PTC/12) and is the English language version of EN ISO 7278-2:1996 *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters* — Part 2: *Pipe provers* published by the European Committee for Standardization (CEN). It is identical with ISO 7278-2:1988 published by the International Organization for Standardization (ISO).

Cross-references

International Standard	Corresponding British Standard
ISO 91-1:1982	BS 6441:1983 *Schedule for petroleum measurement tables* (Identical)
ISO 2715:1981	BS 6619 *Methods for volumetric measurement of liquid hydrocarbons* Part 2:1984 *Turbine meter-systems* (Identical)
ISO 4267-2:1988	BS 7286 *Method for calculation of petroleum and liquid petroleum products* Part 2:1990 *Dynamic measurement* (Identical)
ISO 7278-3:1986	BS 6866 *Proving systems for meters used in dynamic measurement of liquid hydrocarbons* Part 3:1987 *Methods for pulse interpolation* (Identical)
ISO 8222:1987	BS 6922:1988 *Specification for temperature corrections for use in the calibration of reference measuring systems for petroleum measurement* (Identical)

ISO 5024:1976 is related to BS 5579:1978 "*Specification for standard reference conditions for measurement of petroleum liquids and gases*"; the standard reference conditions referred to in **1.3** are identical to those given in BS 5579.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN ISO title page, pages 2 to 22, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 7278-2

October 1995

ICS 75.200

Descriptors: Petroleum products, hydrocarbons, liquid flow, flowmeters, tests, dynamic tests, flow measurement

English version

Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters — Part 2: Pipe provers

(ISO 7278-2:1988)

Hydrocarbures liquides — Mesurage dynamique — Systèmes d'étalonnage des compteurs volumétriques — Partie 2: Tubes étalons
(ISO 7278-2:1988)

Flüssige Kohlenwasserstoffe — Dynamische Messung — Prüfsysteme für volumetrische Meßgeräte — Teil 2: Rohrprüfer
(ISO 7278-2:1988)

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European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN ISO 7278-2:1995 E

Foreword

The text of the International Standard from ISO/TC 28, Petroleum products and lubricants, of the International Organization for Standardization (ISO) has been taken over as a European Standard by the Technical Committee CEN/TC 19, Petroleum products, lubricants and related products'.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 1996, and conflicting national standards shall be withdrawn at the latest by April 1996.

According to CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

0 Introduction

Pipe provers are used as volume standards for the calibration of liquid meters. The purpose of this part of ISO 7278 is to outline the essential elements of a pipe prover, to provide specifications for its performance, and to give guidance on its design, installation and calibration. Pipe provers discussed in this part of ISO 7278 are of the running-start/running-stop type, in which flow is uninterrupted during proving, thus permitting the meter to be proved under its normal operating conditions. This type of prover includes a calibrated section of pipe in which a displacer travels, actuating detection devices which produce electrical signals as the displacer passes each end of the calibrated portion. The displacer finally stops at the end of the run as it enters a region where the flow bypasses it.

Both stationary and mobile provers may be constructed on this principle. The calibrated section of the prover may be straight or folded (U-shaped), and the design may be such that the displacer moves around a closed loop in only one direction (unidirectional) or, alternatively, in both directions (bidirectional).

ISO 7278 consists of the following parts, under the general title *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters:*

- *— Part 1: General principles;*
- *— Part 2: Pipe provers;*
- *— Part 3: Pulse interpolation techniques.*

Annex A forms an integral part of this part of ISO 7278. Annex B is for information only.

1 Scope and field of application

1.1 This part of ISO 7278 provides guidance for the design, installation and calibration of pipe provers. Calculation techniques for use when calibrating and operating provers are detailed in ISO 4267-2.

1.2 Most of the material in this part of ISO 7278 is general in that it applies to pipe provers for use with different liquids and types of meters and for proving them in different services. This part of ISO 7278 does not apply to the newer “small volume” or “compact” provers.

1.3 The standard reference conditions for petroleum measurement are a temperature of 15 °C and a pressure of 101 325 Pa as specified in ISO 5024.

NOTE In some countries other reference temperatures are used, e.g. 20 °C and 60 °F.

2 References

ISO 2715, *Liquid hydrocarbons — Volumetric measurement by turbine meter systems.*

ISO 4267-2, *Petroleum and liquid petroleum products — Calculation of oil quantities — Part 2: Dynamic measurement*[1].

ISO 5024, *Petroleum liquids and gases — Measurement — Standard reference conditions.*

ISO 7278-3, *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters — Part 3: Pulse interpolation techniques.*

ISO 8222, *Petroleum measurement systems — Calibration — Temperature corrections for use with volumetric reference measuring systems.*

3 Definitions

For the purposes of this part of ISO 7278, the following definitions apply:

3.1
base volume

the volume of a prover calibrated section, i.e. the length between the detectors, at specified reference conditions of temperature and pressure

3.2
***K*-factor**

the ratio of the number of electrical pulses emitted by a meter during a proving run to the volume of liquid passed through the meter

3.3
meter factor

the ratio of the actual volume of a liquid passed through a meter to the volume indicated by the meter

3.4
prover calibration

the procedure for determining the base volume of a prover

3.5
proving; proof

the determination of the meter factor or *K*-factor

3.6
range

the difference between the highest and the lowest values within a batch of results

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[1] At present at the stage of draft.

4 Description of systems

4.1 General

4.1.1 There are several types of pipe prover, all of which are relatively simple and commercially available. All types operate on a common principle, namely the precisely measured displacement of a volume of liquid in a calibrated section of pipe between two signalling detectors, by means of a displacer (a slightly oversized sphere or piston) being driven along the pipe by the liquid stream being metered. While the displacer is travelling between the two detectors, the output of the meter is recorded automatically. Pipe provers may be operated automatically or manually.

4.1.2 A meter being proved on a continuous-flow basis shall, at the time of proof, be connected to a counter which can be started or stopped instantly by the signalling detectors. The counter is usually of the electronic-pulse-counting type. The counter is started and stopped by the displacing device actuating the detector at each extremity of the calibrated section.

4.1.3 There are two main types of pipe prover: unidirectional and bidirectional. The unidirectional prover allows the displacer to travel in only one direction through the proving section, and has a transfer arrangement for returning the displacer to its starting position. The bidirectional type allows the displacer to move first in one direction, then in the other. It therefore incorporates a means of reversing the flow through the pipe prover.
(See Figure 1, Figure 2 and Figure 3.)

4.1.4 Both unidirectional and bidirectional provers shall be constructed so that the full flow through the meter being proved passes through the prover.

4.2 Unidirectional provers

4.2.1 Unidirectional provers may be subdivided into two categories depending on the manner in which the displacer is handled, namely the manual-return in-line type sometimes referred to as a "measured distance" type, and the automatic-return or circulating type, often called the "endless loop" type.

a) The manual-return unidirectional prover is an elementary form of in-line prover which uses a section of pipeline as the prover section. The entire metered stream may flow continuously through the prover even when the prover is not being used for proving. Detectors are placed at selected points which define the calibrated volume of the prover section. A displacer launching device is upstream of the prover section, and receiving facilities are installed at some point downstream of the prover section. Usually, conventional launching and receiving scraper traps are used for this purpose. To make a proving run, a displacer (a sphere or specially designed piston) is launched, allowed to traverse the calibrated section, received downstream and then manually transported back to the launching site.

b) The automatic-return unidirectional (endless loop) prover has evolved from the prover described in **4.2.1** a) and is shown in Figure 1. In this endless loop, the piping is arranged so that the downstream end of the looped section crosses over and above the upstream end of the loop. The interchange is the means whereby the displacer is transferred from the downstream end to the upstream end of the loop without removing it from the prover. The displacer detectors are located at a suitable distance from the interchange inside the looped portion. Such endless prover loops may be manually operated or they may be automated so that the entire sequence for proving a meter can be actuated by a single action. The metered stream may be permitted to run through the prover when the prover is not being used for proving, and the prover need not be isolated from the carrier line unless desired. This permits the movement of several different types of liquid in succession through the prover, and affords a self-flushing action which minimizes intermixing between them, as well as providing temperature stabilization.

4.2.2 A meter proof run in a unidirectional prover consists of a single one-way run, therefore the base volume of a unidirectional prover is the volume of liquid, corrected to standard temperature and pressure conditions, displaced between the detectors during a single trip of the displacer.

4.3 Bidirectional provers

The bidirectional prover has a length of pipe in which the displacer travels back and forth, actuating a detector at each end of the calibrated section and stopping at the end of each run when it enters a region where the flow can bypass it or when the action of a valve diverts the flow. Suitable supplementary pipework and a reversing valve, or valve assembly, 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 (see Figure 2), but it may be contoured or folded (see Figure 3) so as to fit in a limited space or to make it more readily mobile. Normally, a sphere is used as the displacer in the folded or contoured type and a piston is used in the straight-pipe type. A meter proof run usually consists of a "round trip" of the displacer, and the displaced volume in this type of prover is expressed as the sum of the displaced volumes in two consecutive one-way trips in opposite directions.

5 Essential performance requirements

The design of a pipe prover shall ensure that the following performance requirements are met.

5.1 Short-term repeatability

When a unidirectional prover is calibrated using the master meter method, the results of five successive calibration runs shall lie within a range of 0,02 %. When a bidirectional prover is calibrated with a master meter, the results of five successive runs each comprising a round trip of the displacer, shall be within a range of 0,02 %.

The short-term calibration repeatability when using the volumetric or gravimetric water draw methods shall be such that the results of three successive calibration runs are within a range of 0,02 %.

When a prover is used to prove a high-performance flow meter such as one suitable for custody transfer or fiscal measurement, the results of five successive provings shall lie within a range of 0,05 %.

5.2 Valve seating

The sphere interchange in a unidirectional prover or the flow reversing valve or valves in a bidirectional prover shall be fully seated and sealed (so that the displacer is travelling at full velocity) before the displacer meets the first detector. These and any other valves whose leakage can affect the accuracy of proving shall be provided with some means of demonstrating that they are sealed during the proving run.

5.3 Freedom from shock

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

5.4 Freedom from cavitation

When the prover is operating at its maximum design flow rate and with the liquids for which it was designed, there shall be no risk of cavitation in the prover, valves or elsewhere, over the specified pressure and temperature range.

6 Equipment

6.1 Materials and fabrication

6.1.1 The materials selected for a prover shall conform with the applicable codes specifying the pressure rating and the area where the prover is to be used. Pipes, pipe fittings and bends shall be selected for internal roundness and smoothness.

6.1.2 In the fabrication of provers, care shall be exercised to ensure proper alignment and concentricity of pipe joints. All welds within the path of the displacer shall be ground internally, and the design shall provide for this requirement. All welding shall be in accordance with applicable codes.

6.1.3 Internal coating of the prover section with a material which will provide a hard, smooth, long-lasting finish will reduce corrosion and wear and will prolong the life of the displacer and prover. Experience has shown that internal coatings are particularly useful when the prover is used with liquids having poor lubricating properties, such as gasoline or LPG.

6.2 Temperature stabilization

Temperature stabilization of the proving system is normally accomplished by the continuous circulation of liquid through the prover section, with or without insulation. When large portions of the prover are buried and the liquids are at or near ground temperature, additional insulation is usually not required. When provers are installed above ground, the application of thermal insulation will contribute to better temperature stabilization. Where a high temperature gradient can appear along the prover pipe, as with heated products, thermal insulation is recommended.

6.3 Temperature measurements

Temperatures shall be measured with an overall uncertainty not exceeding ± 0,5 °C. This requires temperature sensors with a certified accuracy of ± 0,2 °C or better. The temperature sensors shall be installed in thermowells near the inlet and outlet of the prover and in positions which receive active fluid flow during both normal and calibration operations. The thermowells shall be inserted to a minimum of 100 mm in large pipes and as closely as possible to one-half the diameter in small pipes. Thermowells shall be filled with a suitable heat transfer medium. If mercury-in-glass thermometers are used, they shall be of such a design that they can be read while remaining immersed in the heat transfer medium to the recommended depth for the thermometer in use. It is important to match the thermowell with a temperature sensor of suitable immersion requirements.

6.4 Pressure measurement

Pressure measurement devices shall be capable of measuring pressure with an uncertainty of less than ± 50 kPa (± 0,5 bar) at pressures of up to 2 500 kPa (25 bar) and ± 2 % of operating pressure at higher pressures.

6.5 Displacing devices

6.5.1 One type of displacing device commonly used in pipe provers is the elastomer sphere filled with a liquid under pressure, and expanded so that its minimum diameter is slightly larger than the inside diameter of the prover pipe. The diameter shall be such that a seal is provided without excessive friction; this can usually be achieved by inflating the sphere to a diameter which is at least 2 % greater than the inside diameter of the prover pipe. In general, the larger the sphere, the greater this percentage should be. Too little expansion of the sphere can lead to leakage past the sphere and consequent measurement error. Too great an expansion of the sphere may not improve sealing ability and will generally cause the sphere to wear more rapidly and to move erratically. Care shall be exercised to ensure that no gas remains inside the sphere. The elastomer shall be as impervious as possible to the operating liquids and retain its mechanical properties (especially its elasticity) under operating conditions. The liquid employed to fill the sphere shall have a freezing point below any anticipated temperatures. Water or water-glycol mixtures are commonly employed.

6.5.2 A second type of displacing device is the cylindrical piston with suitable seals. This is often used with straight pipe provers that have been internally honed to ensure adequate sealing.

6.5.3 Other displacers are acceptable if they give a performance equal to the two types mentioned in **6.5.1** and **6.5.2**.

6.6 Valves

6.6.1 All valves used in pipe prover systems which can contribute to a bypass of liquid around the prover, the displacer or the meter, or which can cause leakage between prover and meter, shall be bubble-tight on low differential pressure tests. A means of checking valve seal leakage during the proving run shall be provided for such valves. If a sphere or spheres are used to provide this sealing mechanism in lieu of a valve, they shall be provided with some means of testing for leakage.

6.6.2 The entire operation of the flow reversing valve or valves in a bidirectional prover, or of the interchange valve in a return type unidirectional prover, shall be completed before the displacer actuates the first detector. This is to ensure that during the trip of the displacer through the calibrated section no liquid is allowed to bypass the prover. The necessary distance between the initial position of the displacer and the first detector, commonly called the pre-run, is dependent on valve operation time and the velocity of the displacer. Any method can be used to shorten this pre-run, whether by faster operation of the valve or by delaying the launching of the displacer. However, caution shall 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, all valves shall be linked by some means to ensure that shock cannot be caused by incorrect sequence of operation.

6.7 Calibration connections

Connections shall be provided on the prover to allow for water draw or master meter calibration at a later date (see Figure 1, Figure 2 and Figure 3).

6.8 Detectors

Detection devices and switches shall indicate the position of the displacer accurately, and in a bidirectional prover they shall operate equally well in both directions. Various types of detector are in use, the most common of which is the mechanically actuated electrical switch. Other types, including the electronic proximity, the induction pickup or the ultrasonic type, may be used, provided the required repeatability criteria are met. The precision with which the detector in a prover can detect the position of the displacer (which is one of the governing factors in determining the length of the prover section) shall be ascertained as accurately as possible (see Annex A). The diameter of any opening in the wall of the calibrated section of the pipe, including the holes accommodating the detectors, shall be appreciably less than the width of the sealing zone of the displacer.

6.9 Meter pulse generator

An externally fitted pulse generator shall generate electrical pulses of satisfactory characteristics for the type of proving counter employed. The device shall generate a sufficient number of pulses per unit volume to provide the required resolution. The pulse emitter shall be designed to eliminate the generation of spurious pulses due to mechanical vibrations or other influences.

6.10 Electronic pulse counter

An electronic pulse counter is usually used in meter proving because of the ease and accuracy with which it can count high-frequency pulses and because of its ability to transmit its count to remote locations. The pulse-counting devices are equipped with a start-stop electronic switching circuit actuated by the prover's detectors. Proving systems can also be equipped with a pulse interpolation system as defined in ISO 7278-3.

6.11 Equipment for automatic-return unidirectional provers

6.11.1 Equipment necessary for the proper operation of the automatic-return or endless-loop unidirectional prover is centred around the sphere interchange unit. It is within this unit that the sphere is diverted from the flowing stream at the downstream end of the prover, passes through the interchange and is then reinserted at the upstream end of the prover, all automatically.

6.11.2 Sphere interchange may be accomplished with several different combinations of valves or other devices. Each combination comprises a system of devices designed to arrest the sphere and pass it through the interchange, yet prevent any flow of liquid through the interchange which would bypass the prover section during the proving period. Typical combinations of devices are

a) a single special ball valve modified for sphere handling;

b) a dual power-operated check valve assembly;

c) a combination of a ball or gate valve with a power-operated check valve;

d) a dual through-conduit gate or ball valve;

e) a valveless two- or three-sphere assembly;

f) an interchange using a plunger-type valve to block the flow.

6.11.3 The controls and actuators used in connection with unidirectional provers will depend primarily on the degree of automation with which it is desired to operate the proving system.

6.11.4 Separator tees, as shown in Figure 1, are sized at least one pipe size larger than the nominal size of the sphere or loop. The design of the separator tee shall ensure dependable separation of the sphere from the stream for all flow rates within the flow range of the prover.

6.11.5 Launching tees are generally one pipe size larger than the displacer sphere and shall have smooth transition fittings leading into the prover. The launching tee shall have a slight inclination downwards toward the prover section, or some other means of ensuring movement of the sphere into the prover during periods of low flow, such as might occur during calibration by the water draw method.

6.12 Equipment for bidirectional provers

6.12.1 In piston-type bidirectional provers of the design shown in Figure 2, the outlets and inlets on the prover ends shall be provided with holes or slots. These shall be deburred and shall have a total area greater than 1,5 times the cross-sectional area of the pipe beyond the outlet, in sphere-type bidirectional provers with oversized end chambers (see Figure 3), the chambers shall be designed so that the displacer cannot obstruct the inlet or outlet openings and thus prevent liquid from flowing. The receiving chambers shall be sized to ensure that the displacer is arrested without shock under maximum flow conditions.

6.12.2 A single multiport valve is commonly used for reversing the direction of liquid flow, and hence that of the displacer. Other means of flow reversal may also be used. All valves shall allow continuous flow through the meter during proving. The valve size and actuator shall be selected to minimize pressure drop and hydraulic shock.

7 Design of pipe provers

7.1 Initial considerations

Before considering the design of a pipe prover, it is necessary to establish the type of prover required for the installation and the manner in which it will be connected with the meter piping. From a study of the application, intended usage and space limitations, establish the following:

a) whether the prover will be stationary or mobile;

b) if stationary, whether it will be dedicated (on-line) or used as part of a central system;

c) if a stationary, dedicated prover, whether it will be kept in service continuously or will be isolated from the metered stream when not being used to prove a meter;

d) if stationary, what portions, if any, will be below ground level;

e) the permissible range of temperature and pressure;

f) the permissible maximum and minimum flow rates;

g) the physical properties of the fluids that will be handled;

h) the degree of automation that will be incorporated in the proving operation;

i) the size and type of meter that will be proved;

j) the facilities that will be required for safely installing and removing the displacer;

k) the facilities that will be required for safely venting and draining the prover.

7.2 Diameter

In determining the diameters of the pipes to be used in the connecting lines, or manifolding, and the prover, the head loss through the pipe prover system shall be compatible with the head loss considered tolerable in the metering installation. Generally, the diameter of the pipe prover and manifolds shall not be less than the outlet diameter of any single meter to be proved.

7.3 Volume

In determining the volume of a prover between detectors, the following factors shall be considered by the designer:

a) the overall repeatability required of the proving system;

b) the repeatability of the detectors (see Annex A, clause **A.5**);

c) the ability of the electronic counter to indicate only to the nearest pulse, unless pulse interpolation is employed;

d) the discrimination of the meter signal generator, that is, the volume passing through the meter per pulse registered;

e) the maximum permissible flow rate of the system.

7.4 Displacer velocity

7.4.1 It is not the intention of this part of ISO 7278 to limit the velocity of displacers and, provided acceptable performance is guaranteed, there shall be no arbitrary limit imposed upon velocity.

7.4.2 The maximum and minimum velocities of the displacer can be determined from the diameter of the prover pipe and the maximum and minimum flow rates of the meters to be proved. Clearly, some practical limit to maximum velocity of a displacer must exist, partly to avoid mechanical damage to the prover, partly to limit surges and partly to prevent damage to the displacer and the detectors. Nevertheless, the developing state of the art is such that it is inadvisable to set a firm limit on displacer velocity as a criterion of design. The minimum velocity shall be set at a level that ensures smooth travel of the displacer and that prevents intermittent travel of the displacer in fluids with poor lubricating properties.

7.4.3 A velocity of 3 m/s is a typical design specification for unidirectional provers, whereas the displacer velocity in bidirectional provers is usually lower. However, the use of special launching techniques allows bidirectional provers to be used at higher displacer velocities.

7.5 Repeatability and accuracy

7.5.1 The ultimate requirement for a prover is that it shall prove meters accurately. However, this accuracy cannot be established directly as this is dependent on both the repeatability of the meter and the systematic uncertainty in the determination of the base volume of the prover. The repeatability of any prover/meter combination, however, can always be determined experimentally by carrying out a series of repeated measurements under carefully controlled conditions and analysing the results statistically. It is therefore usual to adopt repeatability as the only available criterion of a prover's acceptability. But it should always be remembered that, whereas poor repeatability is an immediate indication that a prover is not performing satisfactorily, good repeatability does not necessarily indicate good accuracy since there is always the possibility of unknown systematic errors having occurred, and operators must always be on their guard against such errors.

7.5.2 The repeatability of a proving system will depend upon its components and, in particular, upon the repeatability of the detector's ability to locate the position of the displacer.

7.5.3 The selection of displacer detectors will have a direct bearing on the ultimate length of the proving section. A more precise detector will allow a shorter length. The required repeatability of the detector's ability to locate the displacer may be measured experimentally by the method described in Annex A, clause **A.5**.

7.5.4 When replacing worn or damaged parts in a detector, great care shall be taken to make sure that neither the detector's actuating depth nor any of its electrical switch components is altered to the extent of changing the calibrated volume of the prover by more than the limit allowed (0,02 %). This is especially important in unidirectional provers because, unlike bidirectional provers, errors due to changes in detector actuation depth in unidirectional provers are not reduced by the compensating effect of round-trip sphere travel. To avoid such errors, one or more of the following shall be done whenever this type of maintenance is carried out:

a) the detector assembly shall be replaced with a precalibrated duplicate unit;

b) if the prover is fitted with twin detectors at each end, the repaired detector shall be reset by the procedure described in clause **A.4** of Annex A;

c) if neither of the above is done, the prover shall be recalibrated.

NOTE Provided that either a) or b) above has been followed, and subject to the agreement of the parties involved, recalibration of the prover is not required.

7.5.5 An important source of random error when a meter is proved by a meter prover is counter resolution. A digital counter has a resolution of unity, and hence the pulse count has a random uncertainty of ± 1. For example, if it were desired to limit the uncertainty from this source alone to ± 0,01 %, without the method of pulse interpolation described in ISO 7278-3, it would be necessary to collect at least 10 000 pulses during a proving run or during a single one-way travel of the displacer in a bidirectional prover.

The degree of uncertainty is represented mathematically as follows:

$$U = \frac{1}{n} \qquad \text{. . . (1)}$$

where

U is the degree of uncertainty of the recorded pulse count arising from this source alone, commonly called the resolution;

n is the number of pulses collected during a proving run.

Having established the degree of uncertainty, the minimum volume between the prover detectors is determined as follows:

$$V = \frac{1}{UK} \qquad \text{. . . (2)}$$

where

V is the minimum volume between the detectors;

K is the minimum K-factor (number of pulses per unit volume) of any meter to be proved by the prover.

7.5.6 It follows that prover volumes can be reduced by increasing the pulse generation rate of the meters to be proved. Caution shall be exercised, however, in the use of gear-driven pulse generators on displacement meters to obtain very high pulse generation rates, because with these devices mechanical problems, including backlash, drive-shaft torsion and cyclic variations, can cause irregular pulse generation. Electronic means of pulse interpolation can also be used to reduce the resolution; such techniques shall be used with discretion, however, and provisions governing their use are contained in ISO 7278-3. Pulse interpolation is most effective for meters emitting pulses at regular intervals.

7.5.7 ***Optimum dimensions of provers***

When selecting the minimum acceptable dimensions of a prover for a particular duty, the following considerations shall be taken into account:

a) Decreasing the diameter of the prover pipe necessitates an increase in the length between detectors for a given volume, and thus reduces the effect of errors due to detector resolution. However, it also increases displacer velocity which may become a limiting factor.

b) Increasing the diameter of the prover pipe has the opposite effect, i.e. the velocity of the displacer is reduced. However, the resulting decrease in length increases the effect of errors due to detector resolution, and this may become a limiting factor.

7.6 Example of the calculation of the design parameters of a pipe prover

An example of a calculation of the design and sizing of a pipe prover is provided for reference in Annex B. The calculation is illustrative only and is not an integral part of this part of ISO 7278.

8 Installation

8.1 In relation to their method of installation, pipe provers may be classified as either mobile (portable) provers, dedicated provers or central provers.

8.1.1 ***Mobile prover***

A mobile prover is normally mounted on a road vehicle or trailer so that it can be taken to various sites for on-site proving of meters in their installed positions while they are in normal operation. Occasionally, mobile provers are mounted in containers or on self-contained skids so that they may be transported by road, rail or sea. Mobile provers are always provided with some means of connecting them conveniently to the metering system where they are to be used; this usually takes the form of flexible hoses, but any other system complying with the applicable safety standards may be used.

8.1.2 ***Dedicated prover***

A dedicated prover is connected through a system of pipework and valves to a battery of meters in parallel. Its sole function is to prove those meters one at a time, at intervals as required. Although dedicated provers normally serve several meters, the term may also be used where a prover is permanently connected to one meter.

8.1.3 ***Central prover***

A central prover is permanently installed at a location where a supply of liquid and pumping facilities are available, but is not permanently connected to a battery of meters. Instead, it is used for the proving of meters that are periodically brought to the prover, usually complete with their upstream and downstream pipework and flow-conditioning system, and temporarily connected to the prover for this purpose. The central proving system shall be capable of proving a meter under all conditions that will be encountered during the operation of the meter, and especially over its full working range of flow rate and viscosity. After centrally proving a meter, care shall be taken to ensure that the meter is not mishandled in a way that could cause its calibration to have changed by the time it is reinstalled at the operating site.

8.2 General installation guidelines

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

8.2.1 The prover and its accessories shall have suitable hangers and supports in accordance with applicable codes and sound engineering principles. In the design and construction of proving systems, provision shall be made for expansion, contraction, vibration, pressure surges and any other adverse conditions that may affect the installation. Consideration shall be given to the inclusion of suitable valving to isolate the prover unit from line pressure when not operating, thus facilitating maintenance and displacer removal. The system shall be provided with an adequate number of vent and drain connections. Vent valves shall be installed on the topmost portions of the pipe to ensure that all air can be vented from dead spaces not swept by the displacer. Provision shall be made for the safe disposal of liquids or vapours drained or vented from the prover section. This may be accomplished by pumping liquids or vapours back into the system or by diverting them to some collecting point. Thermometers and pressure gauges shall be installed in suitable locations near both the meter and the prover in order to determine the temperature and pressure of each.

8.2.2 Provision shall be made for recalibrating the prover. Examples of suitable connections are shown in Figure 1, Figure 2 and Figure 3.

8.2.3 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 shall be placed in a convenient location for operation and maintenance. Manufacturers' instructions shall be strictly followed for installation and grounding of all electrical components, such as electronic counters, controls, power units and signal cables.[2)]

8.2.4 Automatic or manual pressure relief valves, complete with discharge piping and leakage detection facilities, are usually installed to allow for the thermal expansion of the liquid in the prover while it is isolated from the main system. Where there are both local and remote controls, either lockout switches or lockout circuits, or both, shall be provided between the two sets of controls to prevent accidental remote operation of a unit while it is being controlled locally. Suitable safety devices and locks shall also be installed to prevent inadvertent operation of, or unauthorized tampering with, equipment. Automated or power-actuated provers or proving systems shall have emergency manual actuators for use in the event of a power failure.

8.2.5 All types of pipe prover shall be installed downstream from straining or filtering equipment.

9 Calibration

9.1 Principles

9.1.1 Before being placed in service, a pipe prover shall be calibrated to determine its base volume, that is the volume of the prover under standard reference conditions (see ISO 5024). Periodic recalibration of a prover is also required; the interval between calibrations will depend on the frequency of use of the prover and the nature of the liquid or liquids being metered. The prover shall be thoroughly flushed and cleaned before calibration or recalibration.

9.1.2 The base volume shall be documented on a calibration certificate. The accuracy of the base volume, as determined, cannot be better than the accuracy of the certified volumetric reference(s) used in determining it. Base volumes are usually quoted to five significant digits, with intermediate calculations having one more significant digit than the final value shown on the certificate (see ISO 4267-2 for further details on calculations). The calibration certificate or report shall be dated and signed by a person authorized to do so.

9.1.3 The base volume of a unidirectional prover is the volume, corrected to standard temperature and pressure conditions, of liquid displaced between the detectors during a single trip of the displacer. The base volume of a bidirectional prover is the sum of the volumes displaced between the detectors during the two trips in opposite directions which comprise one round-trip of the displacer, corrected to standard temperature and pressure conditions. There are two methods for calibrating a pipe prover, the water draw method (see **9.2**) and the master meter method (see **9.3**).

9.1.4 If a prover is to be operated exclusively at some fairly high pressure, e.g. above 2 000 kPa (20 bar), and will thus not be subjected to widely varying operating pressures, an alternative to the procedure outlined here is to calibrate such a prover at its working pressure and then to refer its base volume to a temperature of 15 °C and the pressure at which it was calibrated.

9.1.5 At the conclusion of the prover calibration, the data sheets and calculation shall be used to prepare the certificate of calibration. The certificate shall state the base volume, the reference temperature and pressure, the prover serial number and identification, the calibration date and the signature of the authorized person responsible for the calibration.

9.1.6 Complete records of all calibrations and recalibrations shall be kept.

9.2 Water draw method

9.2.1 The calibration of pipe provers by the water draw method requires one or more accurate volumetric references against which the volume of the prover may be determined.

9.2.2 The method may be simplified, where possible, by placing the prover, volumetric reference(s) and test liquid in an enclosure, shaded from direct sunshine and wind, so as to avoid extreme or rapid variations in temperature, thus allowing the equipment and liquid to reach a fairly stable equilibrium temperature. Due to the effect of viscosity and surface tension on the drain time of a certified volumetric reference, water is the only medium that can be used for the draw method into volumetric references that have been certified to deliver a given quantity of water. Water also has the advantage of a high heat capacity, low compressibility and low coefficient of thermal expansion when compared with petroleum liquids.

[2)] Instrumentation and ancillary equipment for liquid-hydrocarbon metering systems will be covered in a future International Standard.

9.2.3 The displacer shall be moved through the prover enough times to purge entrained air and to allow both the metal of the prover and the water to reach an equilibrium temperature. The water is then delivered at a constant rate from the prover into the volumetric reference(s). At least one trial calibration run shall be made to determine the approximate volume of the prover between its detectors, so that the approximate number of fillings of the appropriate certified volumetric reference(s) can be determined. The temperature and pressure at the discharge of the prover shall then be recorded as the temperature and pressure in the prover at the start of calibration.

9.2.4 Uninsulated provers which are calibrated outdoors under extreme weather conditions shall be temporarily insulated and/or sheltered to reduce variations in temperature.

9.2.5 Certified volumetric references for the calibration of a prover shall have been calibrated by reference measures traceable to national primary standards of volume.

9.2.6 The prover may be calibrated using small-diameter water lines and temporary valves, or by using the valves and piping which are part of the installation. Solenoid valves actuated by the detector switches are normally used to start and stop the calibration run.

9.2.7 The calculations required to derive the prover base volume from the calibration data are described in detail in ISO 4267-2. The calculations take account of the volume of the water drawn into the volumetric reference(s), the temperatures and pressures of the water 1) while in the prover and 2) when drawn into the volumetric reference(s), and the material properties of the prover and of the volumetric reference(s).

In these calculations, first the observed volume of water in the volumetric reference(s) is adjusted to give the volume it would have occupied when it was at the prover temperature (see ISO 8222). Second, this volume is further adjusted for the effect of thermal expansion on both the body of the prover and the steel shell(s) of the volumetric reference(s). Third, the volume is further adjusted for its compressibility while in the prover and for the effect of pressure on the body of the prover. Finally, the volume is further adjusted to the reference temperature, for example 15 °C, to provide one of the three determinations necessary to calculate the base volume of the prover at the reference temperature and at zero gauge pressure (or other specified reference pressure). The mean of three successive determinations shall be taken as the certified base volume of the prover, provided that the three individual values are in agreement as discussed below.

9.2.8 *Calibrating bidirectional pipe provers*

This section refers to those bidirectional pipe provers which operate on the customary round-trip basis. After taking the preparatory steps described in **9.2.2** and **9.2.3**, the following procedure shall be followed.

9.2.8.1 Direct the displacer past one of the detectors into the space beyond the section being calibrated of the prover pipe.

9.2.8.2 Reverse the position of the flow-directing valve so that the displacer travels towards the section being calibrated, while the water slowly goes to waste either via a slow-rate bleed or through the hose nozzle, if the adjustment on this is sufficiently sensitive.

9.2.8.3 Stop the flow at the instant the switch indication shows “on”. This is usually done automatically by a solenoid valve controlled by the detector switch.

9.2.8.4 Restart the flow, this time directing all water into the selected volumetric reference(s). Continue at a steady flow rate until the last filling of the volumetric reference is in progress.

9.2.8.5 Reduce the water withdrawal to a slow bleed rate until the second switch indication shows “on”.

9.2.8.6 The total of the reference volumes indicates the observed displaced volume between the detectors in that direction of travel, subject to any necessary corrections for pressure and temperature effects. The pipework connecting the prover and the volumetric reference(s) shall be full at the beginning and end of the proving operation and if this pipework is flexible the pressure within it shall be the same at the beginning and end of the proving operation.

9.2.8.7 Repeat the procedure described in **9.2.8.1** to **9.2.8.6** with the displacer moving in the opposite direction. The base volumes obtained in each direction do not necessarily have to agree, since the action of the detector switches may be different for each direction of travel. However, the base volume obtained from successive runs in a given direction shall agree within the tolerance specified in **9.2.8.8**. The total of two successive single-trip base volumes in opposite directions is the round-trip base volume and shall be one of at least three consecutive determinations required to certify the base volume of the prover. All subsequent use of the bidirectional prover for proving a meter requires a round trip of the displacer for each proof run.

9.2.8.8 With the prover, displacer and detectors in good working order, at least three consecutive determinations of round-trip volume shall agree within a range of 0,02 %. The single-trip volumes for at least three consecutive trips in each direction shall also agree within a range of 0,02 %. The average of at least three consecutive round-trip corrected volumes is considered to be the round-trip base volume, which is then recorded on the certificate of calibration (see **9.1.5**).

This part of ISO 7278 does not restrict the determination of the base volume to three consecutive runs. More may be carried out if agreed to by the parties involved.

9.2.8.9 If acceptable repeatability is not achieved after, say, ten round trips, then the calibration shall be stopped and the cause of the poor repeatability investigated. Failure to repeat may be caused by air in the system, leaking valves, varying pressure, defective detectors, improper condition of the displacer or poor calibration technique.

9.2.8.10 It is recognized that repeatability is only one component of accuracy and that even an experienced operator, filling the same reference measures and with the test runs made at an equal rate, can complete a batch of erroneous calibrations because of a consistent leak. This hazard can be reduced or eliminated by making an additional run at a rate of flow differing by at least 50 % from that previously used. With a changed flow rate, a base volume that differs by more than ± 0,02 % from the average of the first three (or more) values indicates the possibility of a leak in the system which shall be rectified before calibration can be obtained. This holds true for both unidirectional and bidirectional provers.

9.2.9 *Calibrating unidirectional pipe provers*

9.2.9.1 The procedure for calibrating a unidirectional pipe prover by the water draw technique is substantially the same as the procedure described in **9.2.8.1** to **9.2.8.6** and **9.2.8.10** for a single one-way trip of the displacer in a bidirectional prover. Every calibration run shall be made by passing the displacer through the unidirectional prover in the normal direction of travel. In calibrating an automatic-return or endless-loop unidirectional prover, it is necessary to fill the entire loop and interchange with water, bringing water through its inlet connection and expelling it through its outlet connection. The interchange valving may then be used to launch the displacer at the start of each calibration run. When calibrating a manual-return or in-line unidirectional prover, it is necessary to fill the entire prover and associated piping with water, launch the displacer in the normal manner in the proper direction, and return it for relaunching in each subsequent calibration run. Care shall be exercised to ensure that all air is eliminated and that stable temperature and pressure conditions prevail.

9.2.9.2 The base volume of a unidirectional prover is the volume (after correction) of liquid displaced when the displacer passes from one detector switch to the other. The described procedure is repeated until satisfactory repeatability is achieved. The base volume of the prover at standard conditions shall be the average value of at least three consecutive determinations. The corrected volumes from at least three consecutive trips shall agree within a range of 0,02 %.

9.2.10 It is recognized that a water draw calibration may also be accomplished by using a gravimetric reference. This method is neither described in this standard nor prohibited by it.

9.3 Master meter method (master meter/master prover method)

9.3.1 *Principles and apparatus*

9.3.1.1 In this method, a meter is used as an intermediate link between the prover being calibrated and the reference against which it is being calibrated. A meter used in this manner is commonly called a master meter. The reference may take the form of either a pipe prover (a "master pipe prover"), a volumetric tank (a "master tank prover") or a receiver for weighing. The master prover is used to prove the master meter, and then the master meter is immediately used to determine the volume of the pipe prover requiring calibration.

9.3.1.2 The master meter method can be used for any installation, but in certain situations, such as in the Arctic, in the desert or on an offshore platform, it may well be the most practical method. An ample supply of a stable liquid shall be available, together with a master meter and the equipment required for proving the master meter against the master prover.

9.3.1.3 The three main pieces of equipment — the prover to be calibrated, the master prover and the master meter — may be piped together in series. The sequence in which the three devices are arranged can be modified to suit local conditions. If the master prover is a pipe prover, then the master meter pulse emitter, the proving counter and the detector switches on the prover shall initially be connected so that the master meter can be proved. When the master meter is switched to the pipe prover to be calibrated, the connections to the pulse emitter, proving counter and detector switches shall also be switched.

9.3.1.4 If the master prover is a pipe prover, its base volume shall have been determined by the water draw method as described in **9.2**. If it is a tank prover, it shall have been calibrated to a high standard of accuracy by an approved method and shall be of sufficient size to ensure that the master meter can be accurately proved by it. The master prover may be fixed or mobile.

9.3.1.5 The master meter shall be a meter of high quality and known to have an excellent short-term repeatability. It may be either a pulse-generating displacement meter or a turbine meter, but if it is the latter it shall be permanently connected to its normal conditioning section (straightening vanes or a sufficient length of straight pipe) as specified in ISO 2715.

9.3.1.6 The master meter shall have the same minimum number of connected accessories when it is being proved as when it is being used to calibrate the prover. The meter shall not be fitted with any device — such as a calibrator or temperature compensator — which might enable the operator to change, in any way, the ratio between the indicated output of the meter and the number of revolutions it has turned. Unnecessary meter-driven accessories shall be avoided in order to avoid applying unnecessary torque to the meter.

9.3.1.7 The meter shall be in good mechanical condition and have a history of consistent performance, and it shall present a curve of error as linear as possible over its flow rate range.

9.3.1.8 In order to reduce discrimination errors to an acceptable level, the master meter shall generate at least 20 000 pulses during any one run of the master prover. The term “run” in the previous sentence shall be interpreted to mean a single round trip of the displacer in the case of a bidirectional master pipe prover, and one emptying or one filling of the tank in the case of a master tank prover.

9.3.1.9 Attention shall be given to the equipment requirements discussed in clause **6**, especially in as far as they apply to pressure gauges, valves, flow-reversing valves, displacers, pulse generators and counters. In addition, vents shall be available at all high points in the calibration system to permit the removal of air before calibration begins. A strainer shall be placed upstream of the master meter/master prover unit.

9.3.1.10 When hydrocarbons are used in the master meter method, accurate thermometry becomes even more important than when water is used. Such liquids typically have low heat capacities and high coefficients of thermal expansion. Temperature sensors as described in **6.3** shall be used. When two or more are required for a master meter calibration, it is advisable either to compare their readings at the anticipated temperature by immersing them all in a water bath at the same time and to apply provisional corrections to those that are not in agreement, or to standardize them against a reference thermometer.

9.3.1.11 Absolute pressure throughout the whole length of hydraulic line shall be kept well above the liquid’s vapour pressure at the maximum temperature. If necessary, a back-pressure valve shall be installed downstream to enable adequate pressure to be maintained. Even a local or momentary drop in pressure below saturation vapour pressure may result in cavitation, that is the formation of vapour and/or gas bubbles.

9.3.2 *Preparation and procedure*

9.3.2.1 Slowly introduce the chosen liquid into the system, venting the air or gas carefully as the filling proceeds.

9.3.2.2 Start the flow through the system and vent the remaining air or gas from each piece of equipment. While venting the prover to be calibrated, and also the master prover if it is of the pipe prover type, launch the displacer as often as required to flush air or gas towards the vents. The required repeatability of calibration will not be obtained until the system is rendered completely free of air or gas.

9.3.2.3 Continue the flow until the temperature of the system stabilizes. While doing this, prove the master meter against the master prover a number of times on a trial basis, to see whether consistent results are being obtained. During the first few of these provings, it may be unnecessary to calculate meter factors if the successive pulse counts differ by so much that the repeatability is obviously inadequate. When a point is reached at which five successive meter factors lie within a range of 0,02 %, this may be taken as evidence that the master meter and the master prover are performing acceptably.

9.3.2.4 Next, a similar check shall be made to ensure that the prover to be calibrated is functioning correctly. Repeated provings of the master meter against this prover shall therefore be made until five successive results lie within a range of 0,02 %. Should it prove impossible to obtain this degree of repeatability, there is a likelihood that one or both of the prover detectors is malfunctioning and needs attention. When the required repeatability is obtained, the calibration of the prover may begin.

9.3.2.5 The procedure described below assumes the use of either a turbine meter or a displacement meter with an electrical pulse generator. This part of ISO 7278 does not preclude the use of a displacement meter having only a mechanical register for this method of prover calibration, provided that the meter has a discrimination less than 0,01 % of the volume of the master prover, and preferably less than 0,005 %, but appropriate modifications to the procedure given here are necessary if such a meter is used, especially with respect to the mode of reading of the indicator.

9.3.2.6 First, set the flow rate to the value desired. This flow rate shall be maintained at a constant nominal value, within limits of ± 2 %, throughout the entire procedure, and shall fall well within the linear range of the meter.

9.3.2.7 The calibration procedure consists of three operations in immediate succession:

1) proving of the master meter against the master prover;

2) calibration of the prover on test;

3) a second proving of the master meter against the master prover.

At least two of these three operations shall take place on one day, and it is preferable for all three to take place on the same day.

9.3.2.8 To prove the master meter, make a series of five consecutive proving runs. The results of these shall lie within a range of 0,02 % or all five runs shall be regarded as invalid. The calculation of the meter factor shall be made in accordance with the procedures specified in ISO 4267-2. The mean of the results of five valid proving runs shall be recorded as the “initial” meter factor.

9.3.2.9 Next, a series of five calibration runs of the master meter against the prover to be calibrated are made. The results of these five runs shall be regarded as valid only if they lie within a range of 0,02 %. The calculation of the prover base volume shall be carried out in accordance with the procedure specified in ISO 4267-2. In evaluating these results, the meter factor shall be regarded as a known quantity (obtained from the previous proving of the meter), and a provisional value, the base volume of the prover, shall be the quantity to be determined.

9.3.2.10 Finally, the meter shall again be proved against the master prover to check that its meter factor has not changed significantly during the operation. Again, five consecutive proving runs shall be made, and the results are valid only if they lie within a range of 0,02 %. The mean of these five results is adopted as the “final” meter factor.

9.3.2.11 The initial and final mean values of the meter factor shall not differ by more than 0,02 %, and if they do differ by more than this the entire procedure from **9.3.2.8** to **9.3.2.10** shall be repeated. If they do agree within the prescribed limit, the mean of the initial and final values of the meter factor shall be used to recalculate the base volume of the prover being calibrated.

9.3.2.12 It is essential that full records of all the provings of the master meter be kept since a detailed history of its performance is a valuable guide to its reliability.

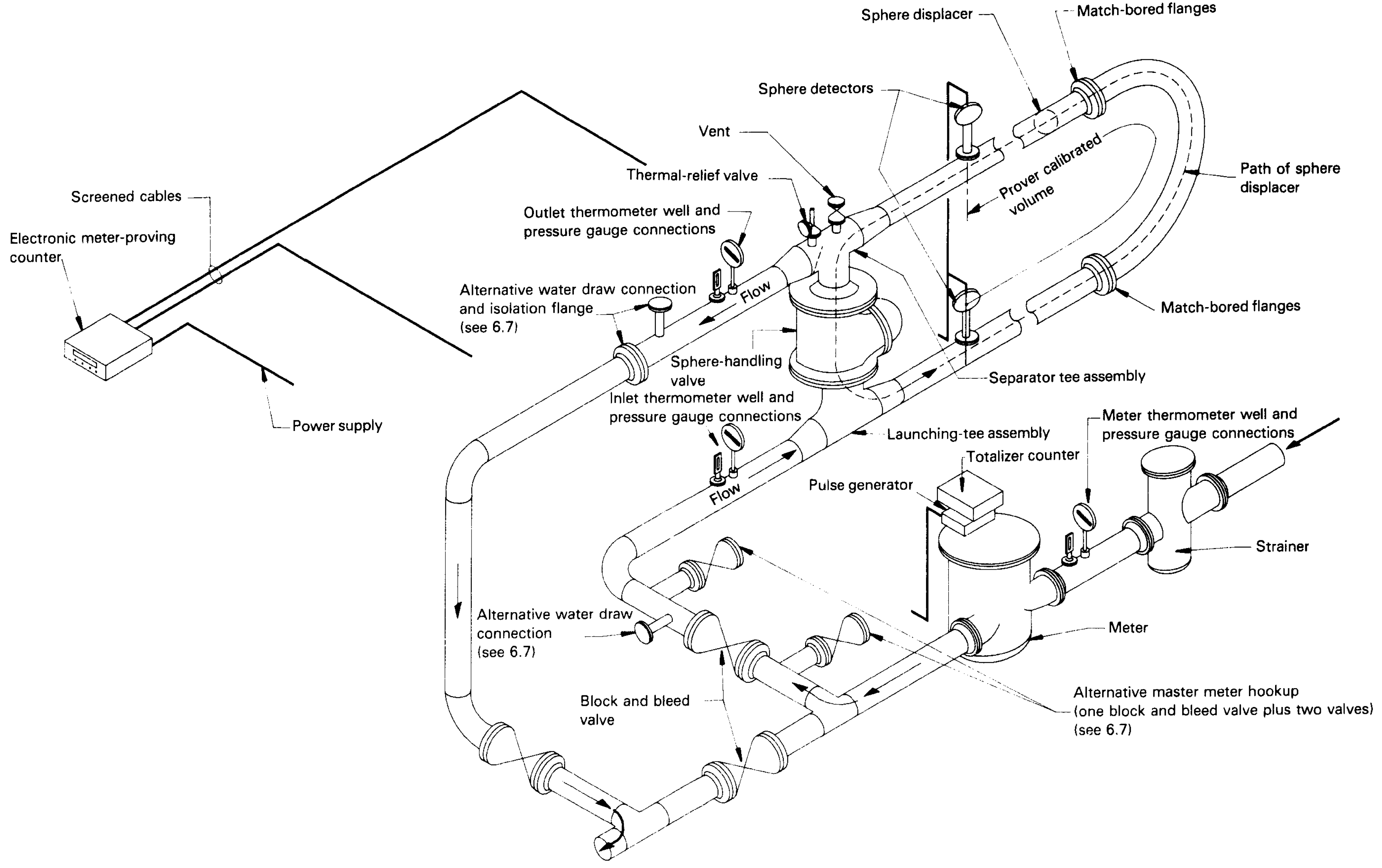

Figure 1 — Typical unidirectional return-type prover system

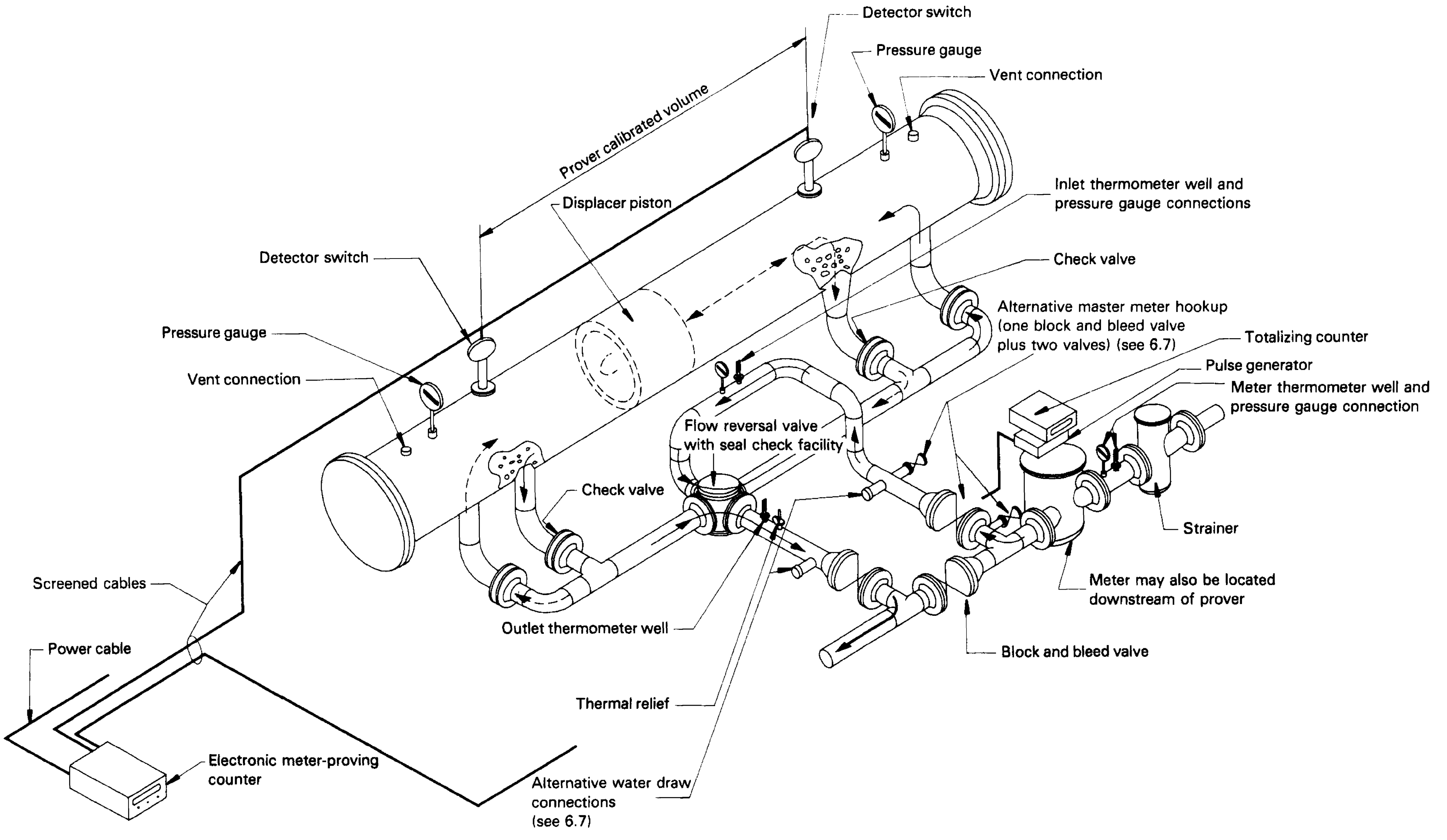

Figure 2 — Typical bidirectional straight-type piston prover system

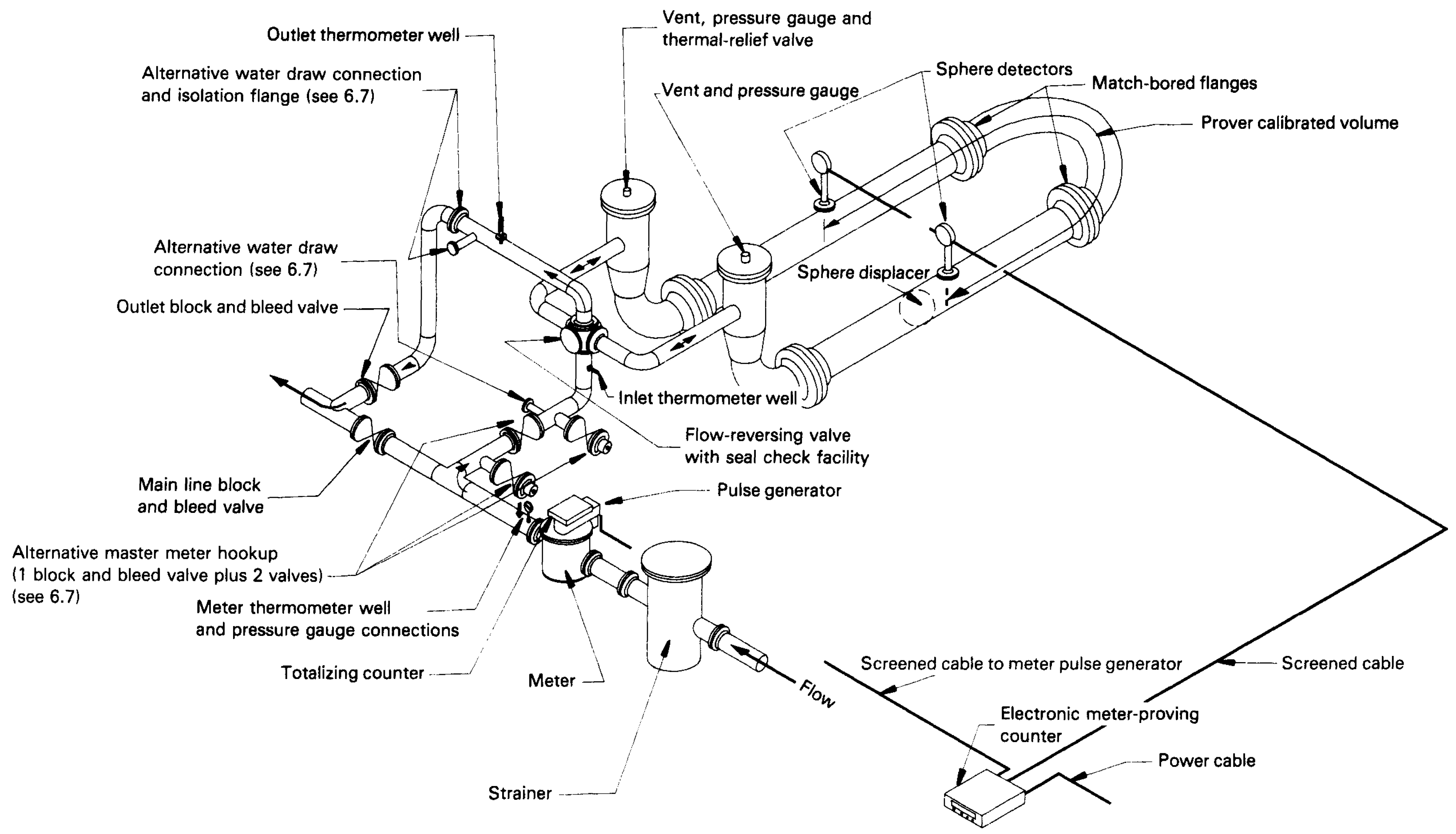

Figure 3 — Typical bidirectional U-type sphere prover system

Annex A The use of pipe provers with four detectors

(This annex forms an integral part of the standard.)

A.1 General

A.1.1 A recent development in pipe prover technology is for two sphere detectors to be installed at each end instead of the usual one. This arrangement has several potential advantages. First, the accuracy of proving can be increased (or, alternatively, the number of repeat runs required for a proving can be reduced without loss of accuracy). Second, the correct functioning of all four detectors can be continuously monitored, and an alarm signal given to the operator immediately if one detector starts to malfunction. Third, if a detector has to be replaced it is possible to check positively that the calibrated volume of the prover has not been altered as a result of the change of detector.

A.1.2 Procedures for obtaining these benefits are given below.

A.2 Increasing the accuracy of proving

A.2.1 When two detectors are fitted at each end of a prover, they may be installed on adjacent cross-sections, or they may be installed nominally on the same cross-section. Even in the latter case, however, they will not signal at precisely the same moment because of manufacturing tolerances, and the arrangement shown in Figure 4 can therefore be taken to represent all cases. Detectors A and B are sited very close together, and, assuming that the displacer sphere travels from left to right in Figure 4, a very small number of pulses, n_1, will be emitted by the meter on test while the sphere travels from detector A to detector B. The sphere will then travel the full length of the prover and a large number of pulses, N, will be emitted while the sphere travels between detector B and detector C. Finally, a very small number of pulses, n_2, will be emitted while the sphere travels from detector C to detector D.

A.2.2 For maximum benefit, the two pairs of detectors shall be treated as if they constituted two separate provers utilizing one length of pipe. That is to say, when the prover is first calibrated, one base volume shall be determined for the length between detector A and detector D, and the second base volume shall be determined for the length between detector B and detector C. Subsequently, when the prover is used, one counter (C_1) shall be connected between detectors A and D, and the second counter (C_2) shall be connected between detectors B and C. In this way, two independent sets of data are obtained from one proving run, and thus, if the mean of the readings of the two counters is taken along with the mean of the two base volumes, the accuracy derived from one proving run will be roughly comparable with the accuracy obtained from making two proving runs with a normal prover and averaging the results. The operator thus has the choice of either carrying out the same number of proving runs as would have been carried out with a normal prover and obtaining an enhanced accuracy, or reducing the number of runs and obtaining the same accuracy as before.

A.2.3 It should be noted that it is of no consequence whether detector A is paired with detector D and detector B with detector C, as in Figure 4, or whether A is paired with C and B with D. In either case, the result of averaging the readings of C_1 and C_2 is to obtain a value of $N + (n_1 + n_2)/2$.

A.3 Automatic monitoring of detector reliability

A.3.1 If two counters are connected as described above, the data processor shall be programmed to evaluate the ratio of the readings of the two counters C_1 and C_2 for each proving run, or for each round trip in the case of a bidirectional prover. Provided that the detectors are all performing correctly, this ratio should remain constant within very close limits — probably within ± 0,01 % or 0,02 %. As soon as the ratio strays outside the normal limits, this is an indication that one detector is malfunctioning, and the data processor can be programmed to initiate an alarm signal as soon as this occurs.

A.3.2 A more sensitive test for detector malfunctioning can be made by temporarily reconnecting the counters, as shown in Figure 5, to count the very small numbers of pulses, n_1 and n_2. In the case of a bidirectional prover, both the single-journey and the round-trip values of n_1 and n_2 shall be noted. If any of these numbers changes by more than one pulse from its usual value, this is an indication that one detector in the pair concerned is at fault. An inspection of these two detectors shall then be made to enable the faulty detector to be identified and replaced. It is desirable for this form of test to be carried out as a matter of routine at, say, fortnightly or monthly intervals, as well as whenever the ratio of the readings of C_1 and C_2 changes by more than the permitted amount.

A.3.3 By following these procedures, it is possible to avoid entirely a situation in which the accuracy of a prover gradually deteriorates over a lengthy period without the operator being aware that one detector is no longer performing as well as it should.

A.4 Replacing a detector without loss of accuracy

A.4.1 The calibrated volume of a prover is affected significantly by the geometry of the detector plunger and its effective "triggering depth". Cases have been known in which the replacement of one detector on a normal pipe prover has changed the calibrated volume of the prover by an unacceptable amount. Unfortunately, with a conventional prover, there is no way of checking positively that this has not occurred without incurring the expense of recalibrating the prover after a detector has been changed.

A.4.2 With a prover having twin detectors, however, a check that the calibrated volume of the prover has not been altered by the replacement of one detector can be made very easily. If, in a unidirectional prover, detector A or B, for example, has been replaced, all that is needed is to compare the measured value of n_1 obtained immediately after the detector has been replaced with the values which were regularly being obtained before the detector which had to be replaced started malfunctioning. Provided that the new value of n_1 is not significantly different from its original value, it is evident that no adverse affect on accuracy was caused by the replacement of the faulty detector. Should the new value of n_1 be outside the specified limits, it will be necessary either to adjust the triggering point of the new detector until the original value of n_1 has been restored or, should that procedure not be acceptable to the certifying authority, to recalibrate the prover.

A.4.3 With a bidirectional prover, the essential requirement is that the round-trip base volume — that is, the sum of the "forward" and "reverse" base volumes — shall not change because of a detector replacement. To ensure this, it is not essential that the individual values of n_1 (forward) and n_1 (reverse) are each unchanged after detector A or detector B has been replaced. It is essential only that the *sum* of n_1 (forward) and n_1 (reverse) is unchanged. In principle, it should be easier to meet this requirement in a bidirectional prover than to meet the corresponding requirement of unchanged n_1 in a unidirectional prover, because if n_1 (forward) increases there is a tendency for n_1 (reverse) to decrease by a similar amount in a bidirectional prover.

A.4.4 These procedures assume that the prover concerned is a dedicated prover so that the values of n_1 and n_2 can be expected to remain constant at all times. In the case of a mobile prover or a central prover, in which meters of varying pulse generation rates are being proved, it will be necessary to base the procedure not on the absolute value n_1 or n_2, but on the values of the ratios n_1/N and n_2/N.

A.5 Measurement of detector repeatability

A.5.1 When a prover is fitted with two detectors at each end, it can be used to make measurements of detector repeatability. There are two ways in which this can be done.

A.5.2 If it is desired to measure the mean repeatability of four identical detectors, the two counters shall be connected as shown in Figure 4. It is then necessary to make a large number of repeated runs of the prover in quick succession under practically identical conditions, and to evaluate the standard deviation, σ, of the ratio of the readings of the two counters, C_1 and C_2.

A.5.3 The short-term single-value repeatability of a single detector can then be shown statistically to be equal to $t\sigma/2$, where t is the appropriate value of Student's t-function, and σ is expressed as a percentage of the mean of the readings of C_1 and C_2.

A.5.4 Alternatively, it is possible to base a repeatability test upon the installation of just one pair of identical detectors installed at, or very near to, the same cross-section in a prover, as with the detectors A and B in Figure 5, and a counter connected as C_1 in the same figure. Here also, it is necessary to make a large number of repeated runs of the prover, and in this case to evaluate the standard deviation σ of the repeated readings of the counter C_1. The short-term single-value repeatability of a single detector is then given by the expression $t\sigma/1{,}414$, where t is as defined in **A.5.3**.

A.5.5 In presenting the results of a repeatability test of this nature, it shall be stated whether the test is based upon two detectors or four, and the number of runs on which the test is based shall also be stated. The value of Student's t-function is commonly based on the 95 % confidence level, but if any other level of confidence is used this shall be stated.

A.5.6 Now that provers with twin detectors are being constructed in increasing numbers, it is recommended that every opportunity be taken to determine the repeatability of detectors by the above method, and thus to build up gradually a bank of data on detector repeatability. In particular, it is recommended that detector repeatability be measured during the same set of tests as are used for measuring the repeatability of the prover as a whole, when the prover is being commissioned. In this way, the prover manufacturer will obtain data on detector repeatability that will be of value to him when he comes to design future provers. Ideally, data are required for each make of detector with each diameter of prover with which it is to be used, but it will obviously be some time before such complete data has been amassed. In the meantime, it may be necessary to interpolate or extrapolate data from what is available to obtain estimated values for other sizes of prover.

A.5.7 It should be noted that it is not possible to evaluate the repeatability of detectors with a prover having only one detector at each end with a counter connected across them in the customary fashion, because in this case the random uncertainty in the meter being proved will be so significant as to invalidate the results of any attempt to determine the repeatability of the detectors.

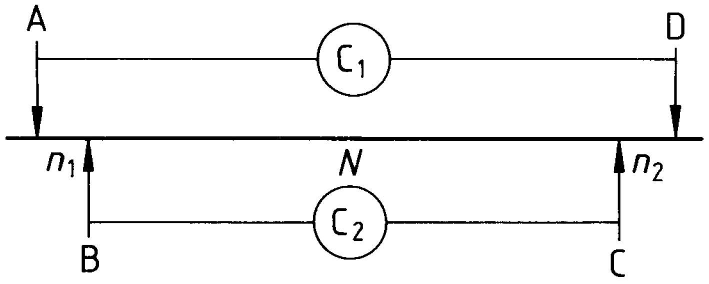

Figure 4 — Simultaneous use of two counters with a four-detector prover

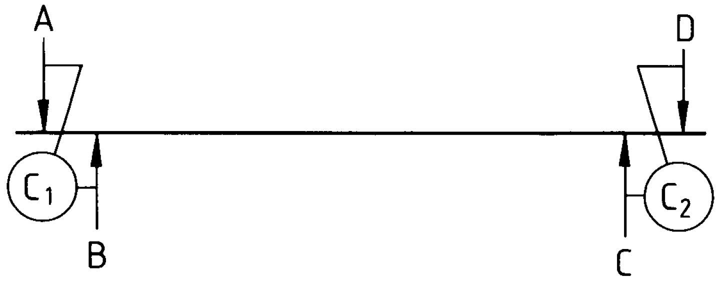

Figure 5 — Temporary connection of counters to measure n_1 and n_2

Annex B Example of the calculation of the design parameters of a pipe prover

(This annex does not form an integral part of the standard.)

A typical approach to the design of pipe provers is illustrated in the following examples for a 150-mm-diameter meter operating at 200 m^3/h and generating a nominal 12 000 pulses/m^3.

B.1 Basis of calculation

It is required by sub-clause **5.1** of this part of ISO 7278 that

a) repeatability obtained during calibration is within a range of 0,02 %.

For the purpose of this example, it will be assumed in addition that

b) the maximum acceptable discrimination error U, as defined in **7.5.5**, is ± 0,000 1 (i.e. ± 0,01 %);

c) the meter to be proved generates 12 000 pulses/m^3;

d) short-term repeatability of response, for each of the detectors, to the sphere is ± 1 mm;

e) the maximum displacer velocity is provisionally set at 3 m/s.

B.2 Calculation of minimum volume

From assumption b) above and equation (1) in **7.5.5**, it follows that

$$n = \frac{1}{0{,}000\ 1} = 10\ 000 \text{ pulses}$$

From assumptions b) and c) above and equation (2) in **7.5.5**, it follows that

$$V = \frac{1}{UK} = \frac{1}{0{,}000\ 1 \times 12\ 000} = 0{,}83 \text{ m}^3$$

B.3 Calculation of minimum length

The length between detector switches depends on the accuracy with which the detector switch can repeatedly determine the position of the displacer and on the required repeatability of the prover system during calibration. From requirement a), the repeatability of the prover system during calibration shall be within a range of 0,02 %. From assumption d), the repeatability of response, for each of the detector switches, to the sphere shall be ± 1 mm.

If L is the nominal indicated length of the prover, one proof run could displace a maximum volume represented by $L + 2$ mm and another proof run could displace a minimum volume represented by $L - 2$ mm. Subtracting the minimum from the maximum, the difference in indicated length cannot exceed 4 mm. The calculation for minimum length then would be 4 mm divided by 0,000 2 (i.e. 0,02 %), which gives a minimum length of 20 000 mm.

NOTE The above simplified method is sufficiently accurate for practical purposes. Strictly speaking, the repeatabilities of the detector switches should be added not arithmetically but by the root-sum-square method, and the repeatability of the master device used to calibrate the prover should be added to the result by the root-sum-square method.

B.4 Calculation of minimum diameter

From assumption e), the maximum displacer velocity is 3 m/s and the specified maximum flow rate is 200 m^3/h. Combining these gives a minimum cross-sectional area of 0,018 5 m^2, or a diameter of 154 mm, which corresponds approximately to a pipe 150 mm in diameter.

B.5 Determination of optimum dimensions

From the three previous clauses:

the minimum length is 20 m;

the minimum volume is 0,83 m^3;

the minimum diameter is 150 mm.

The object now is to select the optimum length and diameter for the prover, working within the above constraints. This can be done by considering each of a number of possible pipe diameters, as shown in the following table. It should be noted that it is generally not possible to achieve both minimum length and minimum volume simultaneously.

Diameter	Length	Volume	Displacer velocity
150 mm	47 m	0,83 m^3	3,14 m/s
200 mm	27 m	0,83 m^3	1,77 m/s
250 mm	20 m	0,98 m^3	1,13 m/s
300 mm	20 m	1,41 m^3	0,79 m/s

It is clear that a diameter of 150 mm leads to an uneconomical length, and a diameter of 300 mm leads to an uneconomically large volume. The two most economical designs are based on the use of 200 mm pipe, which leads to a minimum volume with a small excess of length, and on the use of 250 mm pipe, which leads to a minimum length with a small excess of volume.

Publications referred to

See national foreword.

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