



BSI Standards Publication

Petroleum measurement systems

Part 2: Pipe prover design, calibration and operation

National foreword

This British Standard is the UK implementation of EN ISO 7278-2:2022. It is identical to ISO 7278-2:2022. It supersedes BS ISO 7278-4:1999 and BS EN ISO 7278-2:1996, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PTI/12, Petroleum Measurement and Sampling.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Systèmes de mesurage des produits pétroliers - Partie 2: Conception, étalonnage et fonctionnement des tubes étalons (ISO 7278-2:2022)

Flüssige Kohlenwasserstoffe - Dynamische Messung - Prüfsysteme für volumetrische Messgeräte - Teil 2: Rohrprüfer (ISO 7278-2:2022)

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European foreword

This document (EN ISO 7278-2:2022) has been prepared by Technical Committee ISO/TC 28 "Petroleum and related products, fuels and lubricants from natural or synthetic sources" in collaboration with Technical Committee CEN/TC 19 "Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin" the secretariat of which is held by NEN.

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of an identical text or by endorsement, at the latest by May 2023, and conflicting national standards shall be withdrawn at the latest by May 2023.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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The text of ISO 7278-2:2022 has been approved by CEN as EN ISO 7278-2:2022 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 2, *Measurement of petroleum and related products*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 19 *Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 7278-2:1988), which has been technically revised. It also cancels and replaces the first edition of ISO 7278-4:1999, the content of which has been incorporated.

The main changes are as follows:

- The content and scope now covers the design of pipe provers given in ISO 7278-2:1988 and the guidance for operators given in ISO 7278-4:1999, which will be withdrawn.
- The different types of pipe prover designs and operating methods have been defined and described.
- The variety of operational methods and the means to apply them to flowmeter calibration of different relative sizes has been described.
- The design, calibration and use of small volume (compact) prover designs has been included.
- The document has been changed from a normative document to a guidance document to reflect best practices.
- The document takes into account changes in practice described in alternative standards produced by the American Petroleum Institute (API) and the Energy Institute (EI).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In the petroleum industry the term “proving” is used to refer to the calibration of devices used in the measurement of quantities of crude oils and petroleum products. Proving uses specified methods to show, or prove, that the result falls within specified acceptance criteria. Proving provides an assurance that the resultant measurement provides an acceptable uncertainty for the duty.

A pipe prover, otherwise called a displacement prover, is a volumetric reference device providing a calibration reference standard for flowmeters with an electronic pulsed output. The fluid remains contained within the piping system and proving can be carried out dynamically at various flowrates and pressures without interruption to the flow.

Pipe provers are used extensively within petroleum industry to provide in situ calibration of flowmeters used for fiscal, custody transfer and pipeline integrity applications. They are used with both crude and refined oils and products but may be used with many other fluids within and outside the petroleum industry.

A pipe prover consists of a length of pipe, a section of which has had its internal volume determined by calibration. A displacer, usually a piston or a tightly fitting sphere or ball, travels along this section of pipe displacing an accurately determined volume of liquid. This volume can be compared with an equivalent volume measured by the flowmeter under test.

The calibrated volume of the prover is established by the detection of the displacer passing along the calibrated section of pipe. Detectors sense the passage of the displacer indicating the start and end of travel through the calibrated section. The detectors trigger the counting of pulses produced by a flowmeter using electronic counters or counters within a flow computer. As the pulses represent the volume measured by the associated flowmeter, a calibration is achieved through the relationship with the calibrated volume of the pipe prover.

Pipe provers are of different designs and are manufactured with a wide range of pipe diameters and volumes. They are available for use as part of a fiscal measurement system in fixed locations and as mobile reference devices.

Any type of flow meter giving a pulsed output may be calibrated however the volume, design and type of the prover may impose limitations on the type and size of meter which would be compatible.

This document describes the design, construction, calibration and use of pipe provers primarily used for the calibration, proving and verification of flowmeters used for liquid petroleum products and may be applied to other liquid applications requiring a high standard of measurement accuracy.

Petroleum measurement systems —

Part 2:

Pipe prover design, calibration and operation

WARNING — The use of this document may involve hazardous materials, operations and equipment. This document does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this document to establish appropriate safety and health practices.

1 Scope

This document provides descriptions of the different types of pipe provers, otherwise known as displacement provers, currently in use. These include sphere (ball) provers and piston provers operating in unidirectional and bidirectional forms. It applies to provers operated in conventional, reduced volume, and small volume modes.

This document gives guidelines for:

- the design of pipe provers of each type;
- the calibration methods;
- the installation and use of pipe provers of each type;
- the interaction between pipe provers and different types of flowmeters;
- the calculations used to derive the volumes of liquid measured (see [Annex A](#));
- the expected acceptance criteria for fiscal and custody transfer applications, given as guidance for both the calibration of pipe provers and when proving flowmeters (see [Annex C](#)).

This document is applicable to the use of pipe provers for crude oils and light hydrocarbon products which are liquid at ambient conditions. The principles apply across applications for a wider range of liquids, including water. The principles also apply for low vapour pressure, chilled and cryogenic products, however use with these products can require additional guidance.

2 Normative references

There are no normative references.

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1.1

accuracy

closeness of the agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept “measurement accuracy” is not a quantity and should not be given a numerical value. The quantitative expression of accuracy should be in terms of uncertainty. “Good accuracy” or “more accurate” implies small measurement error. Any given numerical value should be taken as indicative of this.

[SOURCE: ISO/IEC Guide 99:2007; 2.13, modified — Note 1 to entry modified; Notes 2 and 3 deleted.]

3.1.2

adjustment

set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Adjustment should not be confused with calibration which is a prerequisite for adjustment.

Note 2 to entry: After adjustment, a recalibration is usually required.

[SOURCE: ISO/IEC Guide 99:2007; 3.11, modified — Note 1 deleted; Notes 1 and 2 to entry shortened.]

3.1.3

batch

proving batch

set of consecutive proving runs that is deemed to be necessary to derive both a mean value of volume, *meter factor* (3.1.22) or *K-factor* (3.1.19), suitable for subsequent use and may also be used as an indication of the repeatability of the measurements

Note 1 to entry: A batch may consist of multiple *runs* or one *run* (3.1.38) of a significant number of multiple *passes* (3.1.24).

3.1.4

block-and-bleed valve

double-block-and-bleed valve

twin seal valve

high integrity valve with double seals and provision for detecting leakage past either seal

3.1.5

calibration

set of operations that establish, under specified conditions, the relationship between quantities indicated by an instrument and the corresponding values realized by standards

Note 1 to entry: Calibration should not be confused with adjustment of a measuring system.

Note 2 to entry: *Proving* (3.1.27) is used in the oil industry and has the same meaning but can include a check of the results against specified acceptance criteria.

[SOURCE: ISO Guide 99:1993¹⁾; 6.11, modified.]

3.1.6

calibrated volume

base volume

volume of a prover between detectors, or of a volumetric measure between a top and bottom datum, as determined by calibration and expressed at standard conditions

1) Withdrawn.

3.1.7**cavitation**

phenomenon related to, and following, *flashing* (3.1.14), where vapour bubbles or voids form and subsequently collapse or implode

Note 1 to entry: Cavitation causes significant measurement error and also potentially causes damage to the pipes, valves and meter components through erosion.

3.1.8**cyclic distortion**

periodic variation in the pulse frequency generated by a meter caused by mechanical asymmetry within the meter and accessories

Note 1 to entry: See also *intra-rotational linearity* (3.1.18).

Note 2 to entry: Examples of accessories are calibrators and temperature compensators, mechanical or electronic.

3.1.9**detectors**

devices set to directly, or indirectly, sense the passage of the *displacer* (3.1.11) hence indicating each end of the calibrated volume

3.1.10**discrimination**

ability of a measuring instrument to respond to small changes in the value of the input

3.1.11**displacer**

sphere or a piston used to sweep out the calibrated volume between the *detectors* (3.1.9) of a pipe prover

3.1.12**correction factor**

numerical factor by which the uncorrected result of a measurement at the measured conditions is multiplied

Note 1 to entry: Correction factors to standard conditions are used to convert a volume at observed conditions to the volume at another (standard) condition.

3.1.13**error**

measured quantity value minus a reference quantity value

Note 1 to entry: Relative error is error divided by a reference value. This can be expressed as a percentage.

[SOURCE: ISO/IEC Guide 99:2007, 2.16, modified — Notes 1 and 2 deleted; new Note 1 to entry added; and admitted terms "measurement error" and "error of measurement" deleted.]

3.1.14**flashing**

phenomenon which occurs when the line pressure drops to, or below, the vapour pressure of the liquid, allowing gas to appear from solution or through a component phase change

Note 1 to entry: Vapour pressure of the fluid can increase with increasing temperature.

Note 2 to entry: Flashing is often due to a local pressure drop caused by an increase in liquid velocity, and generally causes significant measurement error.

Note 3 to entry: The free gas produced remains for a considerable distance downstream of the meter even if pressure recovers.

3.1.15

four-way valve

flow reversal valve

single high-integrity valve which reverses the directional flow passing through a bidirectional prover

3.1.16

gating

initiation and cessation of pulse totalization in a counter, triggered from an external event or signal from detectors

3.1.17

interchange valve

sphere handling valve

high integrity mechanism to relocate the *displacer* ([3.1.11](#)) from the downstream end of a unidirectional sphere prover to the launch position

Note 1 to entry: The valve enables continuous flow through the prover barrel while preventing flow across the mechanism during a proving pass.

3.1.18

intra-rotational linearity

quantitative measure of the degree of regularity of spacing between the pulses produced by a flowmeter at a constant flowrate

Note 1 to entry: This is generally expressed as the standard deviation of the pulse widths around the mean value.

Note 2 to entry: This may be referred to as inter-pulse deviations.

Note 3 to entry: Inter-rotational linearity is the regularity which repeats in a periodic or cyclic manner normally attributed to the rotation of a meter internal mechanism. This may be referred to as pulse rate modulation.

3.1.19

K-factor

ratio of the number of pulses obtained from a meter to the quantity passed through the meter

3.1.20

end chamber

launch chamber

receive chamber

enlarged section at the ends of the pipe prover in which the *displacer* ([3.1.11](#)) rests prior to launch or decelerates and comes to rest upon completion of a pass

3.1.21

linearity

total range of deviation of the accuracy curve from a constant value across a specified measurement range

Note 1 to entry: The maximum deviation is based on the mean of derived values at any one flow point.

Note 2 to entry: The deviation is the largest minus the smallest value of mean values at each flowrate.

Note 3 to entry: Relative linearity is the range of values divided by a specified value, e.g. the independent linearity as defined in ISO 11631.

3.1.22

meter factor

ratio of the quantity indicated by a reference standard to quantity indicated by a meter

3.1.23

nominal volume

design volume of a prover or volumetric measure

3.1.24**pass**

single movement of a *displacer* ([3.1.11](#)) between two detector actuations

3.1.25**pipe prover**

displacement prover

device where a volume of fluid is displaced from a calibrated length of pipe and used to provide a calibration reference for flowmeters

3.1.26**performance indicator**

derived value which may be used to indicate the performance of the meter

Note 1 to entry: Examples of performance indicators are *error* ([3.1.13](#)), *K-factor* ([3.1.19](#)), or *meter factor* ([3.1.22](#)).

3.1.27**proving**

calibration with comparison to specified acceptance criteria

Note 1 to entry: The term proving is used in the oil industry and is similar to verification.

Note 2 to entry: Proving is a calibration, sometimes of limited measurement range, according to methods specified in standards, regulations or procedures, providing a determination of the errors of a device and showing (proving) it performs to specified acceptance criteria.

3.1.28**pulse interpolation**

means of increasing the effective resolution of the pulses output from a meter by multiplying the pulse frequency or measuring the fraction of a pulse associated with the total collected across a time period

Note 1 to entry: The most common method employed is the double timing (chronometry) technique.

3.1.29**pulse interpolation divisor**

ratio of the enhanced pulse frequency to the frequency of the pulses generated by the meter

Note 1 to entry: A pulse interpolation divisor is usually associated with the phase-locked-loop system of pulse interpolation.

3.1.30**range**

measuring range

set of values of flowrate for which the *error* ([3.1.13](#)) of a measuring instrument (flowmeter) is intended to lie within specified limits

[SOURCE: ISO Guide 99:1993¹, 5.2]

3.1.31**range**

range of values

difference between the maximum and minimum values of a set of values

Note 1 to entry: This can be expressed as a half range ($\pm$) number. Relative range is normally expressed as a percentage of a specified value e.g. mean, minimum or other calculated value.

3.1.32

reference condition

reference conditions of measurement

operating condition prescribed for evaluating the performance of a measuring instrument

Note 1 to entry: The reference conditions generally include reference values or reference ranges for the influence quantities affecting the measuring instrument.

[SOURCE: ISO/IEC Guide 99:2007, 4.11, modified — Notes deleted; new Note 1 to entry added.]

3.1.33

reference measure

volumetric measure calibrated, used and maintained to provide traceability to other volume measures and devices, including *pipe provers* (3.1.25) and reference flowmeters

Note 1 to entry: A reference measure can be calibrated gravimetrically (primary measure) or volumetrically by means of a primary measure which itself has been calibrated gravimetrically.

Note 2 to entry: A reference measure may be a test measure or proving tank as described in ISO 8222.

3.1.34

repeatability

measurement precision

closeness of agreement between indications or measured quantity values obtained by replicate measurements under specified conditions

Note 1 to entry: Specified conditions normally implies the same reference, same conditions, same operators and procedures and that the data are obtained sequentially over a short period of time.

Note 2 to entry: Repeatability can be expressed as the range (difference between the maximum and minimum) values of *error* (3.1.13) or *K-factor* (3.1.19). Alternatively, repeatability can be expressed as a function of the standard deviation of the values.

Note 3 to entry: Dividing repeatability by the mean value gives the relative repeatability which can be expressed as a percentage. It is noted some standards suggest dividing by the minimum value.

[SOURCE: ISO/IEC Guide 99:2007, 2.15, modified — Notes to entry have been revised; term "repeatability" added as preferred term.]

3.1.35

resolution

quantitative expression of the ability of an indicating device to distinguish meaningfully between closely adjacent values of the quantity indicated

3.1.36

round-trip

movement of the *displacer* (3.1.11) between the detectors of a bi-directional prover that corresponds to a run being a pass in both the forward and reverse directions

3.1.37

round-trip volume

sum of the swept volumes in both the forward and reverse directions in a bi-directional *pipe prover* (3.1.25)

3.1.38

run

single determination of a prover volume or of a flowmeter meter *performance indicator* (3.1.16) [*error* (3.1.13), *meter factor* (3.1.22) or *K-factor* (3.1.19)] suitable for reporting

Note 1 to entry: A run may consist of a single prover pass for a unidirectional prover, two passes of a bidirectional prover or a larger number of consecutive passes for a small volume prover to give single a reportable result.

Note 2 to entry: The individual results within a multi-pass run are not normally reported unless required, but may be recorded and retained for diagnostic purposes.

Note 3 to entry: The repeatability of a multi-pass run may be used to monitor performance consistent with an acceptance criteria.

3.1.39

run-in length

pre-run length

length of prover barrel between *displacer* (3.1.11) launch point and the first detector chosen to ensure all valves have fully operated, sealed and the flowrate and flowmeter are stable

Note 1 to entry: The design run in length is chosen for the maximum rated flowrate.

3.1.40

standard condition

base condition

condition of temperature and pressure to which measurements of volume or density are referred to standardize the quantity

Note 1 to entry: These are the specified values of the conditions to which the measured quantity is converted.

Note 2 to entry: For the petroleum industry, the standard conditions are usually 15 °C²⁾, 20 °C and 101 325 Pa.

Note 3 to entry: Standard conditions can refer to the liquid or the volume of the measure. These may be different.

Note 4 to entry: Quantities of volume expressed at standard conditions may be indicated by prefixing the volume unit by "S", e.g. 4 Sm³ or 700 kg/Sm³. This abbreviation is used in place of the unit m³ (standard conditions) where there is limited space and there is no risk of confusion regarding the unit.

Note 5 to entry: Standard conditions should not be confused with the reference (operating) conditions prescribed for evaluating the measure.

3.1.41

standard volume

base volume

volume expressed as being at standard conditions

3.1.42

traceability

metrological traceability

property of a measuring result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

[SOURCE: ISO/IEC Guide 99:2007, 2.41, modified — Notes to entry deleted; term "traceability" added.]

3.1.43

transfer point

point or location in a fluid transfer where the quantity and accountability of the fluid passes from one measurement system to another

Note 1 to entry: For any system a transfer point be designated as being a valve, a solenoid valve, a swan neck or weir. It may also be the meniscus formed at the bottom of an open ended filling pipe,

2) In the US, the standard conditions are usually 60 °F (15,6 °C).

3.1.44 uncertainty

non-negative parameter characterizing the dispersion of the quantity values attributed to a measurand, based on the information used

[SOURCE: ISO/IEC Guide 99:2007, 2.26, modified — Notes 1-4 deleted; new Note 1 to entry added.]

Note 1 to entry: The uncertainty is normally expressed as a half width range along with the probability distribution with that range. It can be expressed as a value or as a percentage of the perceived true value.

3.1.45 volumetric measure

measure used to provide an accurate measurement of volume to provide a reference for other volume measuring devices e.g. *pipe provers* (3.1.25) or flowmeters

Note 1 to entry: Proving tanks are volumetric measures of larger size with a top and bottom neck.

3.1.46 water-draw

technique for calibrating a *pipe prover* (3.1.25) or *volumetric measure* (3.1.45) by withdrawing liquid from the prover or measure into a *reference measure* (3.1.33) (volumetric or gravimetric)

3.2 Symbols and units

Symbol	Quantity	Unit
$C_{\text{subscript}}$	volume correction factor to correct a volume to or from a standard condition. The subscripts define the correction parameter. There may be up to three subscripts.	
C_{pl}	volume correction factor for the pressure expansion of liquid from measured pressure to the standard pressure	
C_{ps}	volume correction factor for effect of pressure change on material (steel) of construction from measured pressure to the standard pressure	
C_{tl}	volume correction factor for thermal expansion of liquid from measured temperature to the standard temperature	
C_{ts}	volume correction factor for thermal expansion of material (steel) of construction from measured temperature to the standard temperature	
	Additional subscripts can be used to denote the device, condition or source. These may be applied as a third subscript to the correction factors or to a measurement correction and is defined where used. The following are commonly used:	
D	the difference between a reference device and the device under test rather than correction to standard conditions;	
M	a flowmeter	
R	a reference device;	
T	a device under test or calibration.	
D	internal diameter of prover	mm
E	elastic modulus of prover barrel	
F	meter factor	
f_i	pulse interpolation factor	
K	K-factor of a flow meter	Pulses/m ³
K_n	nominal K-factor of meter	Pulses/m ³
L	length between detectors	m
m	mass throughput during a delivery	kg
m_t	mass of water collected in weight tank	kg
N	number of pulses collected during a delivery or a run	

Symbol	Quantity	Unit
n	number of pulses collected during a proving pass	
p	Pressure. Unless specifically stated, this is the pressure in excess of atmospheric pressure. i.e. gauge pressure. Atmospheric pressure may be assumed as 101 325 Pa.	Pa (bar)
R	pulse interpolation divisor	
r_d	detector resolution	
t	Temperature. A subscript indicates the temperature referred to.	°C
t	value from the Student's t -distribution	
U	uncertainty - expanded	
u	uncertainty - standard	
V	observed volume, i.e. volume of fluid at actual pressure and temperature	m ³
V_M	volume indicated by a flowmeter at observed temperature and pressure	m ³
V_R	volume from reference device, at standard or observed temperature and pressure	m ³
V_S	volume at standard conditions, 15 °C and 101 325 Pa (see NOTE 2)	m ³ (at standard conditions)
w	wall thickness of prover	mm
W_a	weight of water (in air) collected in a weight tank	kg
α	linear coefficient of thermal expansion of metal	°C ⁻¹
β	compressibility factor of liquid in use	bar ⁻¹
ρ	density of liquid at measured pressure and temperature	kg/m ³
ρ_a	density of air	kg/m ³
ρ_n	nominal density of weights used to calibrate weighing machine (8 000 kg/m ³)	kg/m ³
ρ_p	density of fluid in pipe prover during calibration	kg/m ³
ρ_t	density of pure water at temperature t	kg/m ³
ρ_w	density of water	kg/m ³

NOTE 1 The preferred unit for kinematic viscosity is metre squared per second (m²/s) or millimetres squared per second (mm²/s). The practical unit used in this document is the industry recognized unit centistoke (cSt); 1 cSt = 1 mm²/s.

NOTE 2 The preferred unit for a volume expressed at a standard condition is m³ (standard condition). In practice this is conventionally abbreviated to Sm³ where there is limited space and there would be no confusion of units used.

4 Design classification of pipe provers

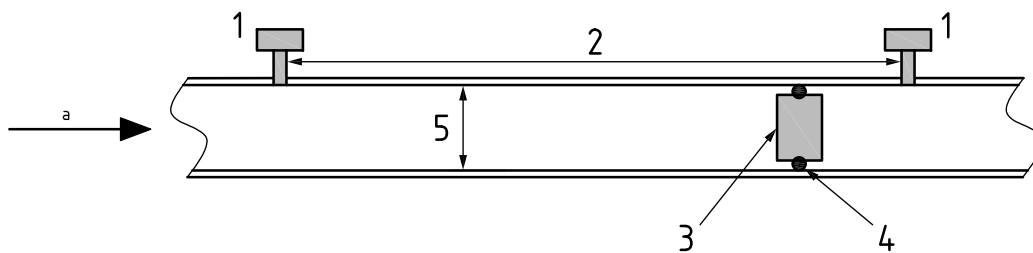
4.1 Common features

A pipe prover consists of a length of cylindrical cross section pipe through which flow is directed. The pipe can be straight or in the form of a loop consisting of straight lengths joined by long radius bends or elbows. The pipe can be assembled from standard pipe sections or specially manufactured and machined pipe sections. It can be made from carbon or stainless-steel, or an alternative material. The internal bore should be cylindrical and smooth, and usually has a hard plated, epoxy or phenolic internal coating. Provers are normally found with pipe diameters ranging from 50 mm (2 inch) to over 1 050 mm (42 inch).

A displacer is inserted into the pipe. The displacer may be a piston, free or constrained (captive) piston or a free elastomer sphere (ball). A sphere is able to pass through bends or elbows while maintaining a seal, hence allowing a shorter footprint for the prover assembly. When introduced to the flow the displacer travels along the length of the pipe displacing fluid to the flowmeter under test.

Detectors are installed to sense the passage of the displacer at the beginning and end of the measurement section of the prover. When actuated, the detector triggers the counting of pulses from the output of the flowmeter being calibrated. Detectors can be directly actuated by the displacer or remotely through a connecting rod.

The volume of the measurement section, between detectors, is established through calibration. The volume of liquid contained is displaced from the pipe by the passage of the displacer hence giving an equivalent volume passed to the flowmeter under test. The flowmeter K-factor, error or meter factor can then be determined. The operating principle is shown in [Figure 1](#).



Key

- 1 detectors
- 2 calibrated length and volume
- 3 displacer
- 4 seal
- 5 pipe inside diameter
- a Flow (from flowmeter).

Figure 1 — Principle of operation

There can be one or two detectors at the start of the calibrated section and one or two detectors at the end. These may be designated by number or letter e.g. A&B, C&D or 1&2, 3&4.

Pipe provers are divided into four design classifications based on the displacer movement and type. The classifications are:

- unidirectional provers;
- bidirectional provers;
- sphere provers;
- piston provers.

A proprietary small volume provers (SVP), sometimes referred to as a compact prover, is a unidirectional piston prover specifically designed and constructed to operate, for the most part, as a small volume prover.

Further operational classification is given by the relationship between the volume of the prover and the characteristics of a meter being proved. This relationship relates to the resolution, internal volume and the time constants associated with the meter along with the maximum and minimum flowrates being covered. The operational classifications are:

- conventional;
- reduced volume;
- small volume.

Provers have a run-in length of pipe between the displacer launch position and the first detector to allow all valves used to start a proving pass to fully close and seal and to allow the displacer to achieve

a stable velocity. Provers should never be operated at more than the maximum rated velocity and flowrate as the run-in length may prove inadequate. Operating above the maximum rating can also cause hydraulic shock, leading to damage the prover and components when launching, decelerating and capturing the displacer.

4.2 Sphere provers

4.2.1 General

Sphere or ball provers use a solid elastomer sphere for small diameters. More commonly a hollow, inflated elastomer sphere is used as the displacer. The sphere is inflated by filling with a liquid chosen to be compatible with the sphere and the duty. A sphere can travel around a bend while maintaining a seal to the pipe wall. This allows the prover measurement section of pipe to be constructed utilizing and combining lengths of straight pipe and bends forming a loop or loops. This minimizes the footprint occupied by the prover.

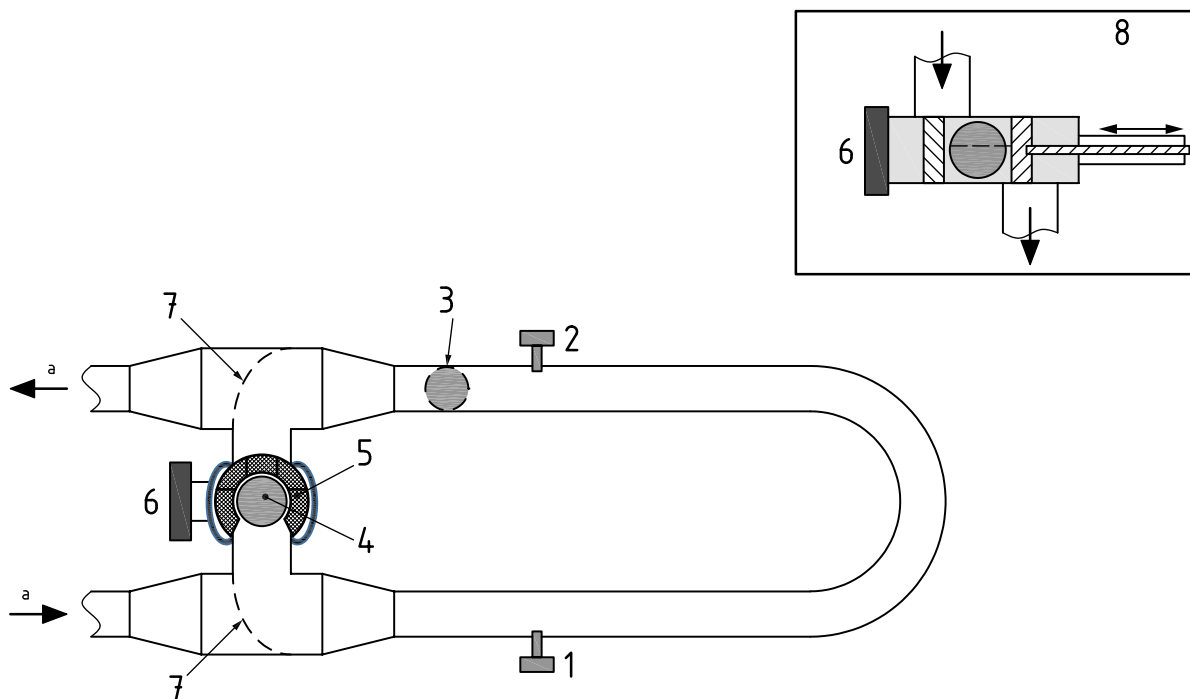
The sphere is nominally chosen to match the internal diameter of the pipe. A solid sphere has a diameter slightly larger than the pipe diameter. A hollow sphere is inflated to a controlled diameter larger than the inside diameter of the pipe. When introduced to the flow, the sphere travels with minimal resistance along the pipe while making a seal with the pipe wall.

The elastomer of the sphere is chosen to be compatible with fluids, products and temperature with which it is intended to be used.

Mechanically operated detector switches are used to signal the start and finish of a proving pass. Either one or two detectors may be placed at each end of the measurement section. Only one pair (two detectors) are required to establish one calibrated volume of a prover however the use of two detectors at each end allows four volumes to be established. This is good practice as it provides redundancy and an indication of a detector malfunction.

4.2.2 Unidirectional sphere provers

A unidirectional sphere prover uses an elastomer sphere as a displacer which travels through the pipe loop in one direction only. The most usual form of unidirectional prover is shown diagrammatically in [Figure 2](#).



Key

- 1 detector 1(A)
- 2 detector 2(C)
- 3 sphere displacer – passing through prover barrel
- 4 sphere displacer – passing through sphere handling valve
- 5 rotating sphere handling valve
- 6 closure
- 7 separator bars
- 8 alternative slide type sphere handling valve
- a Flow.

Figure 2 — Unidirectional sphere prover

The critical component of a unidirectional sphere prover is the interchange, or sphere handling, valve. This is a mechanism, valve or assembly of valves which allows the sphere to be captured at the end of a proving pass and then transferred back to the upstream launch position. The interchange valve should demonstrably prevent liquid leaking or by-passing between the prover inlet and outlet during a pass. Flow through the prover should be continuous and not significantly changed during the transfer of the sphere. The operation of the valve should be such that, during a pass, it does not change the interface inventory i.e. the volume between the prover and the meter under test.

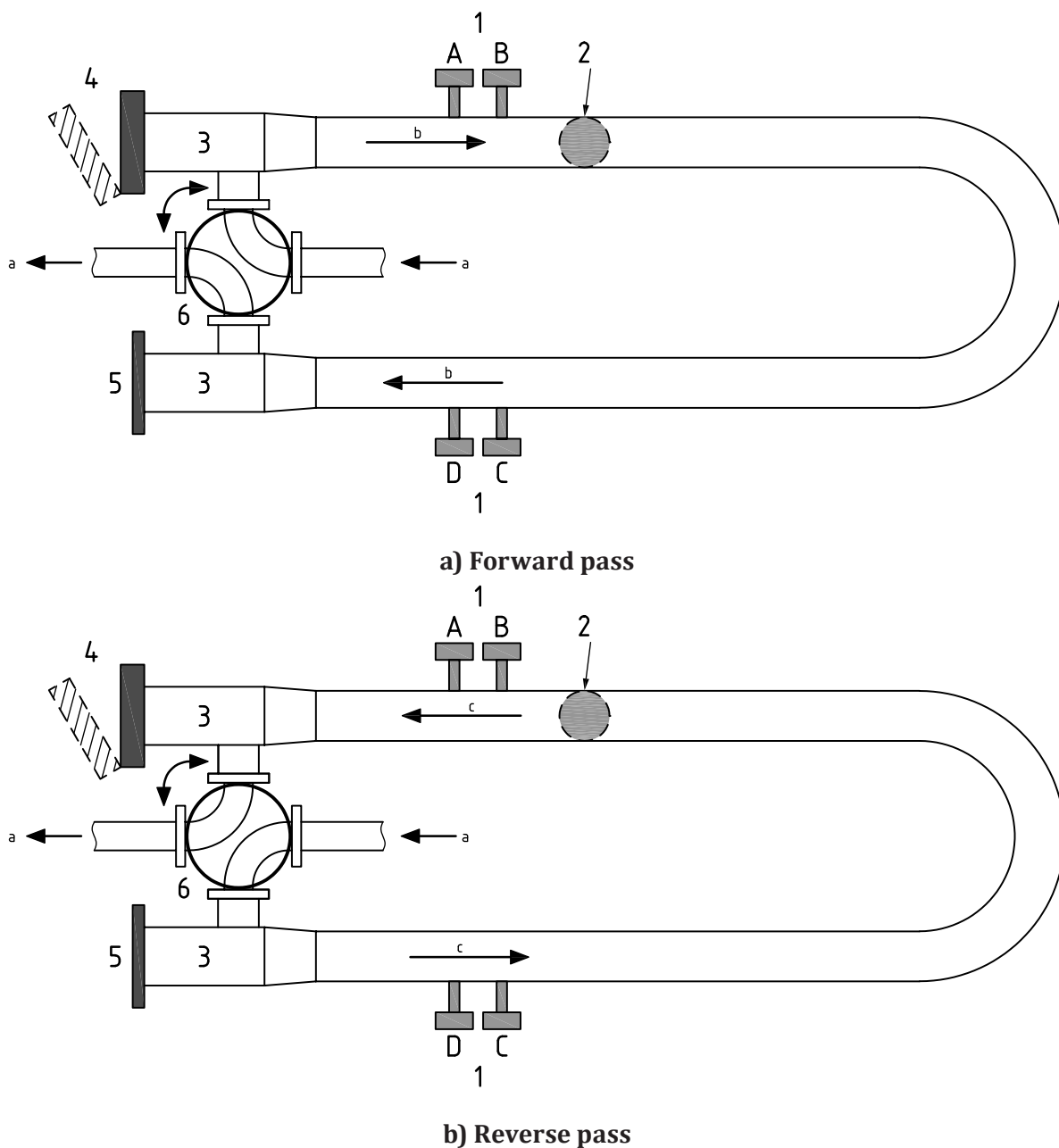
A run-in length of prover pipe is provided between the point of entry of the sphere and the first detector. This length is chosen to ensure the interchange valve is fully closed, sealed and the flow is at a constant velocity before the sphere reaches the first detector. For a unidirectional prover, a run-in length is only required at the upstream end of the prover barrel. This allows a unidirectional prover to be shorter than a bidirectional prover. A short length of pipe downstream allows the displacer to clear the detector and potentially decelerate before being captured. The stability of the flowrate and the delay times of a flowmeter should also be considered in the selection of run-in length.

A less common form of unidirectional prover interchange mechanism is used in a multiple sphere prover. The short length of pipe linking upstream and downstream ends of the prover is designed to hold two or three spheres. To initiate a proving pass, the foremost of the spheres is introduced into the flowing stream while the remaining sphere(s) are mechanically held in place. These act as a seal against

bypass flow. A sphere handling mechanism returns the sphere to the short holding section at the end of a pass where it again forms a seal. The second sphere can then be introduced to the flow for the next measurement.

4.2.3 Bidirectional sphere provers

A bidirectional sphere prover uses an elastomer sphere as a displacer, but in this case the sphere shuttles back and forth along the length of the prover. Forward and reverse passes are made alternately, with a proving run consisting of the sum of forward and reverse pass volumes, i.e. a round-trip volume. A run always starts with a forward pass. The most usual form of bidirectional prover is shown diagrammatically in [Figure 3](#).



Key

- 1 detectors A-D
- 2 sphere displacer
- 3 end chambers
- 4 home chamber with closure for sphere access
- 5 end chamber with flanged closure
- 6 four-way flow reversal valve
- a Flow direction- in and out.
- b Flow direction - forward.
- c Flow direction - reverse.

Figure 3 — Bidirectional sphere prover

A four-way valve is employed to enable the flow through the prover to be reversed while the flow through the flow meter is continuous. This valve is usually a proprietary device however some small provers use four linked valves for flow reversal. Flow through the inlet and outlet of the prover should be continuous and not significantly changed during the operation of the valve.

The sphere rests in an end chamber. When the four-way valve is operated, the sphere is launched and starts to travel on its forward pass until being received at the end of the pass. The flow is reversed and the sphere launched for a return pass. After launch the sphere does not reach its full speed until the movement of the valve is complete and sealed. One end chamber should be designated as the home chamber and indicates the launch direction of a forward pass followed by the reverse pass from the other end. The home chamber is normally fitted with a closure to allow removal of the sphere.

A run-in length is chosen between the end chamber and the first detector to allow for the valve operating time. A run-in length is provided at both ends of the barrel. End chamber design may incorporate a means of holding the sphere delaying launch until the four-way valve has turned, hence reducing the run-in length required. The stability of the flowrate and the delay times of a flowmeter should also be considered in the selection of run-in length. The operation of the valve or the retaining or launch rams should be such that, during a pass, they do not change the interface inventory, i.e. the volume between the prover and the meter under test.

As with the unidirectional prover, one or two detectors may be installed and designated to indicate the ends of the calibrated section. The volume between sphere detectors A and C, (V_{A-C}), is not be quite the same as when the sphere travels between detector C and detector A, (V_{C-A}). If two detectors are installed, two single pass volumes may be determined; one in the forward direction and one in the reverse direction. When two pairs (four) detectors are installed, eight single pass volumes are possible. Comparison of these results may be used for diagnostic information.

It is common practice for a bidirectional prover to define the calibrated volume as that for a round trip, i.e. the sum of V_{A-C} and V_{C-A} . The volumes may be calibrated as one round trip or calibrated and reported as the sum of the two directional passes. There are therefore one or four round trip volumes measured by calibration. Again, comparison of results from the different volumes may be used for diagnostic information.

In use, it is customary to totalize the sum of the pulses collected in each direction, (n_{A-C}) + (n_{C-A}), to give the round-trip pulse count (N) to compare with the round-trip volume. Single pass totals may also be recorded and in some circumstances compared with the single pass volumes and additionally reported as separate measurements.

4.3 Piston provers

4.3.1 General

Piston provers have a piston as the displacer with high integrity seals to the pipe wall. The prover pipe is a straight length with a smooth, round cross section across the full operating length to provide a sealing surface. Piston provers usually have the internal bore of the pipe honed and possibly have a hard coating or plating applied. Piston provers are usually specified for low viscosity or corrosive fluids where an elastomer sphere potentially has unacceptable leakage or wear. They are also used for low temperature applications where sphere elastomers or the liquid fill may be unsuitable.

As mechanical switches can damage piston seals, these should be carefully designed and specified. Non-mechanical, high precision sensors are preferred. These include magnetic or inductance switches mounted on or through the wall of the prover or optical switches fitted externally and activated by a constraining rod, connected to the piston, projecting through a seal in the end of the pipe section. Proprietary small volume provers are usually of piston prover design with external detectors.

Piston provers are normally found with diameters between 50 mm (2 inch) up to 500 mm (18 inch) however can be of larger and smaller diameters.

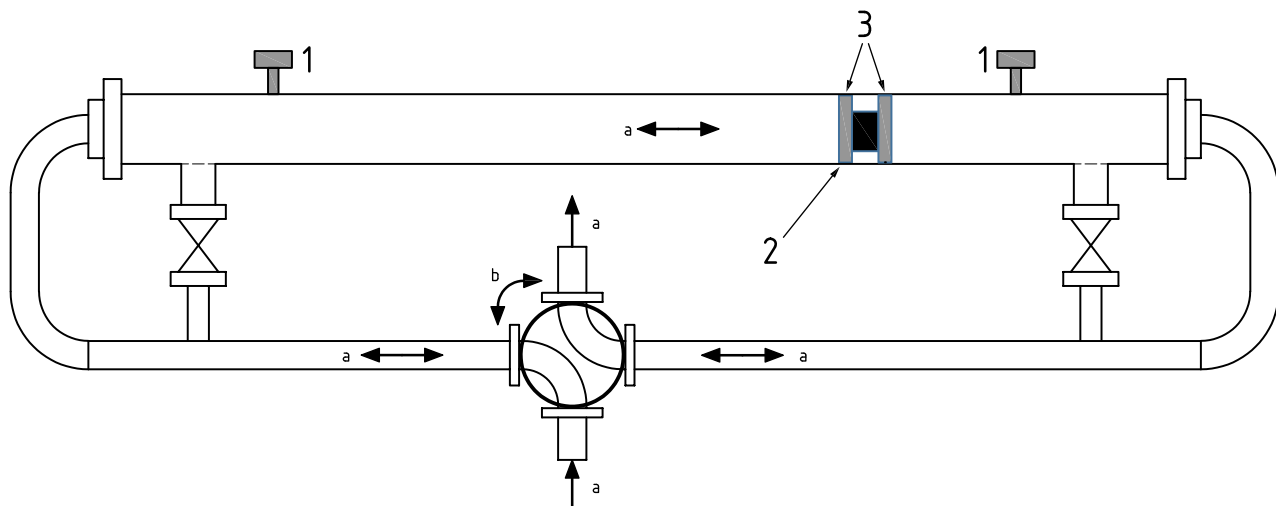
4.3.2 Unidirectional piston provers

The unidirectional piston prover has a forward measurement pass with the piston being returned to the start position by retracing its path. Some means, mechanical, hydraulic, or electromagnetic, is provided to enable the piston to be returned to its upstream launching position without interruption to the continuous flow through the flowmeter being tested. This can be achieved by a valve within the piston or an external valve arrangement allowing flow to bypass the prover during the piston retraction.

Unidirectional piston provers are normally manufactured as proprietary small volume provers and these are discussed further in 5.4.

4.3.3 Bidirectional piston provers

A bidirectional piston prover allows the piston to be shuttled back and forward through the pipe by reversing the flow. This flow reversal is accomplished by using a four-way valve, or four individual valves. In this way, proving passes can be made alternately in each direction to make up a proving run. The flow reversal valves should be configured to allow the piston to be stopped at the end of a run and reversed without undue shock loading or interruption of the flow. As a bidirectional piston prover has a straight calibrated section, provers are usually quite long and have a larger footprint than equivalent sphere provers. This type of prover is shown diagrammatically in Figure 4.



Key

- 1 detectors
- 2 piston displacer
- 3 piston seals
- a Flow.
- b Four-way flow reversal valve.

Figure 4 — Bidirectional piston prover

5 Operational classification of provers

5.1 General

The operational classification of a prover is based on the complex relationship between the calibrated volume of the prover, the resolution of the meter output signal, the internal volume of the meter and the meter time constants.

The relationship was first considered when twin-blade helical turbine meters were introduced as an alternative to multi-bladed meters. Previous to that, it was required to collect at least 10 000 pulses.

a proving pass, hence providing a pulse resolution of less than 0,01 %. The reduced pulse content from fewer blades prevented this resolution from being achieved thereby increasing the repeatability of the calibration. There was however, no evidence to show the meters were less repeatable in service.

This issue was addressed through the introduction of pulse interpolation which effectively increased the resolution of the meter output during proving.

The introduction of small volume provers showed the limiting factor for satisfactory proving was not only the resolution of the meter output, but also an ill-defined relationship between the internal meter resolution and the volume of a proving pass. For a turbine or displacement meter, the internal resolution is effectively the number of revolutions of the rotor providing variation of pulse intervals and additional effects introduced by any external gearing. Satisfactory proving was however found to be achievable for twin-bladed turbine meters, in most cases, by increasing output resolution of the meter by pulse interpolation, and also increasing the effective volume of the prover by taking an average from multiple passes.

The introduction of electronic meters, such as Coriolis and ultrasonic meters, has shown the internal resolution of the meter is very important. While the meter output resolution can be chosen and increased arbitrarily by the meter electronics, this does not alter the internal resolution. The internal resolution of such a meter is based on the internal averaging of a large number of low-resolution measurements providing a single value which is then used to calculate the output frequency. The time constant associated with this calculation and the update of the output frequency plays a significant part in defining the internal resolution. As a result, the volume chosen for a prover used for the calibration of these meters should recognize this limitation and it may not be compensated for solely by providing multiple passes.

To assist in defining the operation of a prover, three operational classifications have been used in this document:

- conventional prover;
- reduced volume prover;
- small volume prover.

The small volume prover classification usually, but not exclusively, applies to proprietary small volume piston provers.

The classifications relate to the combination of the prover and the meter being calibrated. A prover may be operated as a conventional prover with one type and size of flowmeter, or as a reduced volume or small volume prover when combined with different meter size, resolution or type.

5.2 Conventional prover

Conventional provers can be of unidirectional, bidirectional, sphere or piston designs. They can be used to calibrate any type of suitable flowmeter where a minimum of 10 000 pulses collected in a pass. This guidance suggests they are generally sized to enable proving of multi-bladed turbine flowmeters where, without enhancement, a minimum of 10 000 pulses is collected in a pass. The guidance to determine the classification of a prover, for a particular duty, based on 10 000 pulses, should be adopted with care where electronic type meters may allow output pulse frequencies to be selected.

As a guide, designers suggest a calibrated volume for a conventional prover to be no less than 18 s when operating at maximum flowrate, i.e. half a percent of hourly flowrate. This is an indicative design guide from past practice and not a definitive value. Significantly shorter times for a pass are possible when all the design limitations of the prover equipment and the flowmeters are considered. These include the maximum velocity allowed for the displacer, the four-way or interchange valve design, the run-in length and the valve operating speed.

The number of passes to be combined as a run for also plays a part when considering bidirectional provers. Since a round-trip volume is used, i.e. two passes are averaged, some reduction in volume from the above guidance may be possible. This does not however suggest the calibrated volume is halved.

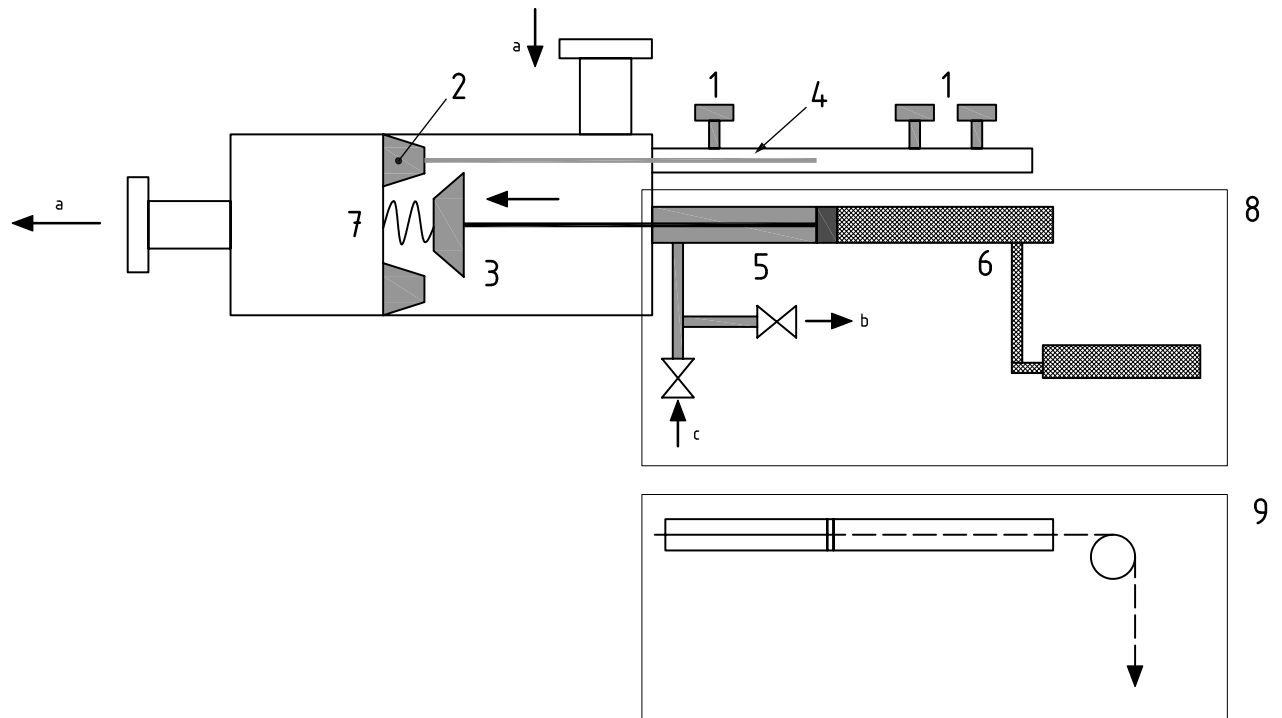
5.3 Reduced volume prover

A reduced volume prover is designed as a conventional prover but is used where the meter output (pulse) resolution requires, to be enhanced through pulse interpolation. A reduced volume prover is used to prove low resolution output meters e.g. helical blade turbine meters. A reduced volume prover may also be used to prove meters where the effective volume can be increased by averaging multiple proving passes to enhance the meter internal resolution, e.g. to prove ultrasonic or Coriolis meters.

5.4 Small volume prover

This is a prover which is specifically designed to operate as a reduced volume prover for all meters normally calibrated. There are two types of small volume prover recognized. Both types employ pulse interpolation and use statistical evaluation of the calibration results from multiple passes to produce a reportable result.

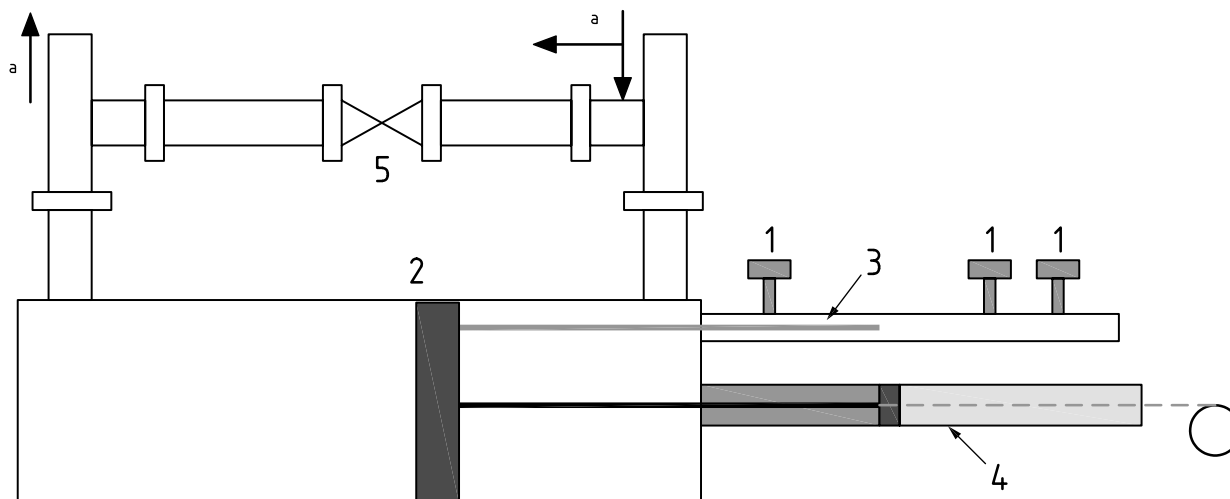
- a) A prover of more conventional design but with a volume significantly less than advised for the size, resolution or flowrate of the meters that are to be calibrated. Suitable performance enhancements are made to conventional design to improve uncertainty in volume, for example lower uncertainty and higher resolution detectors, leak reduction etc. Alternative application would be a conventional prover used where a calibration of a meter is required but a higher uncertainty than the normal is acceptable.
- b) Proprietary small volume provers (SVPs) are usually unidirectional piston types and come complete with precision external detectors, associated electronics and control systems. These have a calibrated volume about one-tenth of that of a typical conventional prover designed for the same maximum flowrate. They have a precision-bore cylinder containing a piston displacer, whose position is detected by high precision, non-mechanical, switches. SVPs of this type can be custom built but are more usually of a proprietary design. The term compact prover is sometimes used, however this is a trade name of one particular manufacturer. Two schematic designs are shown in [Figure 5](#) and [Figure 6](#).



Key

- 1 detectors
- 2 piston displacer
- 3 poppet valve
- 4 detector rod
- 5 hydraulic cylinder to return piston
- 6 pneumatic pressure to assist shutting poppet valve
- 7 spring to shut poppet valve.
- 8 option; hydraulic-pneumatic system to return piston
- 9 option; mechanical (chain or belt), electro-magnetic or other means to return piston
- a Flow.
- b Hydraulic flow to launch.
- c Hydraulic flow to return.

Figure 5 — Unidirectional small volume prover with internal valve



Key

- 1 detectors
- 2 piston displacer
- 3 detector rod
- 4 hydraulic cylinder or mechanical (chain or belt), electro-magnetic or other means to return piston
- 5 high integrity by-pass valve
- a Flow.

Figure 6 — Unidirectional small volume prover with external valve

6 Design

6.1 General considerations

A prover should be designed or specified with the following considerations.

- a) Mobility requirement for the application. Consider if the prover is to be mobile, transportable or located in a permanent location.
- b) The available space and weight restrictions for a structure, ground conditions or transportation.
- c) Means of transportation.
- d) Range of flowrates and flowmeter types to be proved.
- e) Physical properties of the liquids, including viscosity, lubrication characteristics, corrosive properties and vapour pressure. This should also include cleaning and calibration liquids.
- f) Operating conditions, including range of temperature, pressure and the allowable pressure loss.
- g) Requirements for continuous flow through the prover or through a by-pass when not in service.
- h) Environmental protection from extremes of temperature, wind, precipitation etc. The need for a shelter, burial or insulation.
- i) The hazardous area classification.
- j) Power supplies and utilities available at site including water for calibration.
- k) Provision for safe pressure relief, venting and drainage of liquids.

- l) Adequate and safe access to and around the prover.
- m) Manifolds and connections to the meter(s) under test.
- n) Extent of automation and connection to wider plant instrumentation as part of a measurement system.
- o) Space and access to allow access for lifting equipment for maintenance.
- p) Equipment to facilitate calibration. This includes access for reference devices, means to extract displacers and working at height requirements.
- q) Manifolds and connections to allow access and installation of calibration equipment.
- r) The requirement to calibrate the prover at significantly lower flowrates than the normal operating range.
- s) Storage for spares, including switches, seals, spheres, and sphere inflation and measurement equipment.

6.2 Prover barrel

6.2.1 End chambers (launch and receive chambers)

- a) The cross-sectional area of the launch or receive chamber should be such that, with a displacer located within, it has sufficient unrestricted flow area to avoid unacceptable pressure loss at maximum flowrate.
- b) End chambers should be fitted with vents at the highest point to allow venting of air and vapour in a safe manner. These are used during filling and operation to ensure all gas is removed from the prover. The vents should be demonstrably closed and leak tight during proving.
- c) End chambers should be fitted with drains.
- d) The receiving chambers of the prover should facilitate the deceleration, arrest and retention of the displacer with minimum hydraulic or mechanical shock and without damage to the displacer through impact or vibration within the chamber.
- e) The launch chamber should be designed to provide a method of reliably launching the displacer to achieve required stable velocity in as short a time as practicable, while minimising hydraulic shock and flowrate disturbance. This may involve mechanical or hydraulic arrangements.
- f) One chamber may be designated as the home chamber where the displacer can be installed and retrieved. The home chamber can be fitted with a hinged quick release closure to allow access to the displacer. The other launch chamber would normally be closed with a bolted flanged closure to allow access if required. Some provers may have access from both end chambers.
- g) Provision should be made to retain the sphere within the home chamber and to prevent it being sucked back into the prover barrel during drain down. This is especially relevant to provers with inclined or vertical end chambers. Such provision may be in the form of drain points both above and below the displacer when it is in the end chamber. The drain allows the sphere to be exposed for extraction prior to the draining the rest of the prover.
- h) To avoid the chance of a significant risk to operators, safety interlocks, vents and a means to ensure depressurisation before opening are strongly recommended for both chambers. This is particularly important for the home chamber. Releasing an end chamber closure where there remains residual pressure above or below the displacer provides a potentially fatal safety risk.

6.2.2 Run-in length

A run-in length is provided at one end of a unidirectional prover and both ends of a bidirectional prover. Sufficient length of pipe upstream of the first detector is necessary to ensure that:

- a) All valves that can affect the integrity of the proving operation are either fully open, or closed and sealed, before the first detector is actuated. The run-in length can be reduced by employing mechanical means of restraining the displacer until all valve movements are complete prior to launch.
- b) Before reaching the first detector the displacer is moving at a constant velocity. As a displacer is launched, the flowrate reduces. This is due to the friction between the displacer and the pipe wall. This is usually observed as a sudden drop in flowrate followed by a recovery to a marginally lower flowrate than before launch.
- c) The flowmeter has responded to a change in flowrate and is stable before the first detector is activated. While turbine and displacement meters respond quickly, the output pulses from electronic based meters may lag behind a change in flowrate.

6.2.3 Prover pipe or barrel

- a) The calibrated volume should be sized as recommended in [6.4](#).
- b) The calibrated section of the prover barrel should be free of connections such as vents, drains and pressure relief valves. In those instances where a vent or drain is necessary within the calibrated length, it should be of such small diameter that a leak path around the displacer is not formed as it passes.
- c) Where connections are fitted to any location on the prover barrel, care should be taken to ensure the inside bore of the barrel has no intrusions, sharp edges or changes in ovality due to welding stress.
- d) The barrel is manufactured to ensure the internal diameter is round and to avoid ovality. This is most important in the selection or manufacture of long radius bends or elbows.
- e) Flange unions located in the calibration section should be specially designed so that both flanges are of equal inside diameter and have concentric alignment of internal bores achieved during installation. When connected there should be no step or groove.
- f) A means of leak detection should be provided associated with for all critical connections, e.g. vent and drain points and seal verification. It should be possible to inspect any flanges or joints and this may require removable sections of insulation or inspection pits.

6.2.4 Internal finish

The prover barrel may be lined or unlined depending on the material, the properties of the fluids which may enter the prover, the process conditions, and the prover type. The purpose of the lining is to:

- a) enhance the seal between the displacer and pipe wall, hence minimizing the leakage of liquid past the displacer;
- b) reduce friction between the displacer and the pipe wall;
- c) provide a surface resistant to corrosion, abrasion and erosion from the fluids to be used and the displacer contact.

The fluids to be used should be considered. These should include the fluids used in operating, calibrating and cleaning the prover, as well as the atmosphere when empty. Potential changes for future service should be considered.

Unlined provers are normally made of stainless steel and the bore machined to provide a smooth finish. Piston provers may have a further machined finish by honing.

Linings are commonly applied to carbon steel pipe and are usually of epoxy, or phenolic material. Alternatively, particularly for piston provers, the lining may be a plating of chrome, or nickel. Most small volume piston provers have a hard metal (chrome) lining.

Care should be exercised in the choice of non-metallic linings since not all resist aromatic hydrocarbons, and some can become thermoplastic (soften and change thickness) at elevated temperatures.

6.3 Proprietary small volume piston provers

A proprietary small volume piston (SVP) prover has a piston running inside an accurately machined cylinder or pipe. Two designs are illustrated in [Figures 5](#) and [6](#). The movement of the piston, and hence the location of detectors, is by means of a measurement constraining rod connected to the piston and extending out through one end of the cylinder. In most designs, this rod is on the upstream side of the prover. Typically, this separate detector rod carries flags to trigger detectors located at fixed positions indicating the location of the piston and triggering the measurement. Optical detectors are usually employed, however alternative precision detectors such as proximity switches can be used. Potentially linear velocity displacement transducers (LVDTs) can be used to monitor the position of the piston. Most designs have three fixed detectors. One indicates the piston is at the upstream piston, while the second and third are measurement detectors. The third also provides the control signal to detect the end of a pass and trigger a piston return. Alternative designs may use a single detector or utilize the constraining shaft rather than a separate detector rod.

Locating the detectors external to the cylinder allows precision electronic detectors to be used. The external rod and detector assembly should be enclosed to provide mechanical protection and stability. The enclosure should also provide environmental protection. Some designs purge the enclosure with dry gas to provide control of temperature and prevent condensation or icing. The enclosure may need to be removed to allow observation of the movement and approach to detectors during calibration. A transparent enclosure, permanent or temporary, may be considered.

The distance between detectors, hence the prover volume, is affected by the ambient temperature rather than the fluid temperature within the prover. This is a function of the materials used to position the detectors. To reduce the effect, some designs separate the detectors by low expansion coefficient materials such as Invar. Locating the detectors externally requires the temperature of the external assembly to be measured. Volume correction to standard conditions is derived from the linear expansion of the materials associated with the detector mounting combined with the area correction of the prover barrel.

All current designs of proprietary small volume piston provers are unidirectional. Flow is continued at the end of a pass by opening a by-pass valve located externally or by opening a concentric poppet valve located in the piston assembly, the latter being the most common approach. A constraining actuation shaft connected to the poppet valve and piston is extended through the end of the prover where a mechanism opens the valve allowing flow to pass through the piston. This allows the piston to be drawn back to an upstream position. It also provides the means to close and seal the valve in a controlled way hence launching the piston.

Mechanisms to control the piston and draw it back to the launch position may be mechanical (chain or belt driven by a motor), hydraulic or electromagnetic. With a hydraulic mechanism, the external shaft is connected to a hydraulic cylinder. Hydraulic pressure is applied to one side of which pulls the shaft backward, opening the poppet valve and pulling the piston to the start position. Pneumatic pressure may be applied to the upstream side of this hydraulic cylinder to apply a positive force to close and maintain the poppet valve closed when launched. This force may be set to also overcome the frictional resistance of the piston. This also reduces the change in flowrate when the piston is launched. The effect of this may be observed by the extent by which the flowrate may rise or fall when the piston is launched and is dependent on the pressure applied. This force may be adjusted in such a way as to reduce pressure loss across the piston which also reduces potential leakage. The force applied should however ensure the closure and sealing of the internal valve is not compromised.

Some designs may have a guide shaft extending from the other side of the piston to balance and stabilize the movement.

The volume occupied by constraining rod and shaft changes the volume within the calibrated section such that the volume displaced upstream and downstream of the piston is different. Where a downstream shaft is fitted, this reduces this difference and some designs ensure upstream and downstream rod and shaft volumes displace the same volume.

The presence of a rod and shaft along with the operation and displacement of the poppet valve and seals, leads to different upstream and downstream volumes for the prover. For this reason, SVPs are usually installed upstream of the flowmeter being proved hence utilizing the volume downstream of the piston.

The determination of the upstream volume is difficult and requires significant skill and detailed procedures to be developed and followed. This would require a liquid (water) to be introduced into the prover outlet from a volumetric measure. This would not provide sufficient pressure to drive the piston. Alternatively, the internal valve can be held closed and a return sequence initiated. Pressure is applied to the inlet, driving the piston to an upstream position and displacing fluid from the prover inlet to a reference measure. In this scenario, detectors are triggered from the opposite edge from that used when the piston is travelling in the forward direction. It should also be ensured that the valve seals adopt the same compression and hence displacement as they would in a forward stroke.

Upstream volume may also be derived from measuring the diameter of the external shaft and rod along with the distance between the detectors. The resultant shaft and rod volumes can be subtracted from the calibrated downstream volume. The volume of the rods should be corrected for the volumetric thermal expansion of the material, both in diameter and length, based on the fluid temperature. This correction is in addition to the thermal expansion of the distance between the detectors based on the external temperature.

As the master meter method of calibration does not provide the adequate uncertainty normally required, an SVP is calibrated and proved by water draw either gravimetrically or using a dedicated volumetric measure designed to match the prover volume.

A procedure for testing the internal valve for leakage should be prepared and followed. This test is normally a static test. Observation of the proving results is particularly important to ensure any sign of leakage from the internal valve is detected during service. One method of dynamic leak detection during calibration of the SVP is to perform calibrations at different flowrates. It is noted that leakage not detected by a static test has been observed to occur when the prover is in use. This has been noted particularly when higher viscosity fluids provide increased resistance to the internal valve closing.

To provide a mobile calibration system, an SVP may have a suitable flowmeter permanently installed on the outlet from the prover as a master meter. This combination may be used to calibrate operational flowmeters or large pipe provers. The meter is usually installed downstream of the SVP and within the envelope of the SVP package. This may provide significant flow disturbance upstream of the meter. The effect of this is minimized by installing a flow straightener to reduce installation effects and any remaining systematic errors should be insignificant as the meter is calibrated and used in situ.

6.4 Sizing of provers

6.4.1 General

The size of a prover depends upon its intended application and its type as classified in [Clauses 4](#) and [5](#). The size is determined by the following factors:

- a) The output resolution of the meters to be proved (minimum number of pulses per unit volume generated by the meters to be proved).
- b) The internal resolution of the meters to be proved (number of revolutions of a mechanical meter or the internal averaging times of an electronic type meter).

- c) The maximum and minimum flowrate to pass through the prover and the meters to be proved.
- d) The linear resolution of the displacer detectors.
- e) The maximum tolerable pressure loss.
- f) The maximum and minimum velocity of the displacer.
- g) The viscosity and vapour pressure of the fluid.
- h) Operation timing of the four-way valve in a bidirectional prover or the interchange valve of a unidirectional prover to determine run-in length required.
- i) The response time of the flowmeter to ensure adequate the run-in length to allow the meter to reflect and recover from any change in flowrate or disturbance after launch.

These factors influence the prover design parameters. Further guidance is given in [Annex B](#).

6.4.2 Calibrated volume

One of the factors which influences the choice of calibrated volume is the resolution of the meter pulse counting system. The resolution of a digital counter is unity. A counter can only indicate a whole number of pulses therefore the totalised number of pulses has a random uncertainty of ± 1 pulse. It is therefore recommended to limit the uncertainty of ± 1 pulse to a value which may be considered. To give an uncertainty of $\pm 0,01$ %, at least 10 000 pulses should be collected during a proving pass. [Formula \(1\)](#) represents the degree of uncertainty as follows:

$$u_r = \frac{1}{n} \quad (1)$$

where

u_r is the uncertainty due to the resolution of the pulse count arising from this source alone, commonly called the discrimination error;

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

The minimum volume between detectors is determined by [Formula \(2\)](#) as follows:

$$V_{\min} = \frac{1}{u_r \times K_{\min}} \quad (2)$$

where

$V_{\min}$ is the minimum volume between prover detectors;

$K_{\min}$ is the minimum K-factor (number of counts per unit volume) of any meter proved.

It follows that the required prover volume in relation to the output resolution of the meters can be reduced by increasing the pulse generation rate of the meters. Electronic means of pulse interpolation can be used and are described in [Clause 8](#).

Increasing output resolution by electronic or mechanical means has a limitation. The internal resolution of the meter and the stability of the output frequency should be considered, as do the minimum number of revolutions of the meter or the internal averaging and time constant of an electronically based meter.

6.4.3 Length between detectors

The resolution of the prover detectors in terms of distance provides a second design criteria. The length of the calibrated section is dependent on the resolution, r_d , of the detectors. This is the resolution in the

linear distance of the detector as it is activated by the displacer (or external flag). The relationship between the minimum length, L , and r_d is obtained as indicated in [Figure 7](#).

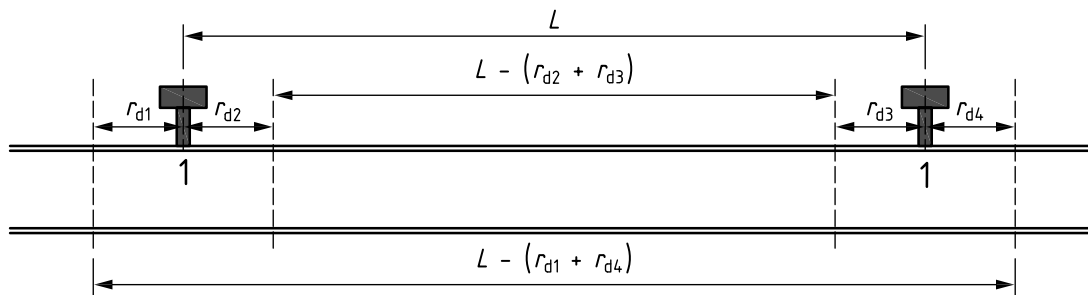


Figure 7 — Length between detectors

It is noted that r_d may normally be considered as a single value, however [Figure 7](#) shows that it can be different for each detector and for a particular direction of travel of the displacer.

From this diagram, the maximum possible difference in length due to the resolution of the detectors is $4r_d$. Hence, to meet an acceptance criterion of repeatability of 0,02 %, the minimum length between detectors for a range is obtained from [Formula \(3\)](#):

$$L_{\min} = \frac{4r_d}{0,02} \times 100 = 20\,000r_d \quad (3)$$

The value of r_d for each particular detector should be obtained from the manufacturer. It is noted that commercial detectors of the mechanical piston type can have a resolution of 1 mm to 5 mm in any one direction. The resolution can be a combination of insertion depth and shape, vertical travel and the resolution of the electrical switch. External optical switches on a small volume prover have a resolution of between 0,1 mm to 0,001 mm.

NOTE The above simplified method yields a worst case value for $L_{\min}$. When the probable length variation is expressed in statistical terms, the prover repeatability is based, not on the arithmetic sum of the detector resolution, but on the use of the root sum square method.

6.4.4 Diameter and Velocity

Having derived a design volume and a minimum length, the prover diameter, D , is calculated from [Formula \(4\)](#):

$$D = \sqrt{4V / \pi L} \quad (4)$$

The diameter calculated should be rounded up to the nearest standard pipe size.

From the estimated volume and diameter, the displacer velocity is now considered to determine the flowrate range which required. The velocities associated with minimum and maximum flowrates, should allow for a smooth travel of the displacer without judder or leakage and is discussed further in [6.6](#).

6.4.5 Pressure loss

The prover constitutes a source of pressure loss to the system and should be considered in the overall metering system design. Constraints may be imposed on the maximum tolerable pressure loss in the prover, which may further influence the sizing calculations in addition to the parameters set out in [6.1](#) to [6.3](#).

Pressure loss can be calculated from standard methods, taking into account the pipe diameter and length, connecting pipe diameters and lengths and making allowances for bends and connections.

Pressure loss through end chambers and valves may also be significant. When computing this initial pressure loss, the loss due to the displacer friction should be estimated and added to the hydraulic losses.

It is noted pressure loss may be significantly greater during a pass.

6.5 Displacers

6.5.1 General

The design of the prover displacer is such that:

- a) There is no leakage of the liquid past the displacer as it traverses the calibrated section.
- b) Friction between the displacer and the bore is low enough to ensure smooth judder-free travel across the full flowrate range and at the much lower velocities associated with calibration. Friction should be low enough to avoid wear or damage to the displacer, seals and pipe bore.
- c) The displacer and seals should be compatible with the liquids being metered and the operating temperature range. Polyurethane, polychloroprene (neoprene), nitrile or rubber-fluoropolymer materials are the most commonly used materials. Other materials may be used provided that they can be shown to be suitable for the service requirements. Many rubber-based materials may swell with exposure to light hydrocarbons resulting in the displacer becoming jammed within the prover barrel.
- d) The design and materials should not wear, damage or score the prover lining. For pistons, the risk of damage to the prover lining in event of a piston seal failure should be recognized.

6.5.2 Spheres

Prover spheres are usually manufactured from an oil resistant elastomer with polyurethane being the most common. Nitrile, polychloroprene (neoprene) and rubber-fluoropolymer materials are also employed with the material chosen to suit the fluid. Spheres are made available with different material compatibility and shore hardness (durometer) chosen to suit the fluid viscosity, lubricity and wall friction. Some materials have low friction additives in the compound to reduce wear.

Spheres are either one-piece mouldings or manufactured in two halves joined with a seam. They can be solid but are almost exclusively hollow for larger provers. A hollow sphere has the centre filled and pressurized with liquid. This allows the sphere to be inflated in a controlled manner to a diameter larger than the prover pipe bore.

Spheres are normally inflated using a hand pump and an appropriate liquid. All air should be removed from the interior of the sphere during the inflation process. The liquid chosen is normally water with a water/glycol mixture used when the operating temperature is potentially sub-zero.

The size and degree of inflation is recommended by the manufacturer of the prover and may be adjusted as necessary to suit the duty or for calibration. Both the inflated and un-inflated diameter should be recorded and stated on the prover calibration certificate. Inflated sphere diameters are typically between 2 % to 4 % oversize from the prover internal diameter chosen to suit the prover, the sphere material and the fluid. Sphere inflation higher than 5 % may be required for larger sizes of prover.

Spare spheres should be stored un-inflated in cool dark conditions where possible. They should be stored in such a way as to be fully supported and avoid developing a flat on the surface. Nets and sand beds are usually employed with protection to avoid the net or sand marking or embedding into the surface. As an elastomer can degrade with time and storage conditions, the date of manufacture and any use-by date should be documented.

The correct inflation kit should be made available and stored for use with the prover. As spheres are difficult to handle, and can be extremely heavy in larger sizes, a specialist tool to extract and handle the sphere should be available.

A means to verify the diameter of the sphere should be available. The use of a calibrated steel circumference tape measure is the preferred method. The diameter is calculated from the measurement of circumference. All measurements of diameter are taken with the tape in a vertical orientation. To achieve this, the tape is placed around the chosen equator of the sphere and the sphere rotated until the tape is vertical and then pulled tight. The supporting surface for the sphere should be chosen with care to ensure the sphere and tape are not damaged during the measurement process. It is noted that very large spheres may distort under their own weight and measurement procedures and methods should take account of this.

The sphere is measured several times across a number of diameters in order to identify any ovality in the sphere. Once diameter and ovality are established as being satisfactory the final reported diameter is the smallest of the diameters measured.

Callipers and diameter rings can be used to provide a validation that the sphere is not oval and to provide a rough guide to confirm the size of the sphere.

The sphere should be inspected for bulges, flats or surface defects not shown by diametric measurements alone.

When initially sizing or inspecting a sphere, it is good practice to over-inflate the sphere to check for leakage of fluid from the inflation (Schrader) valve, the seam or the body. The sphere can then be reduced to the correct inflation size by letting water out of the valve. The sphere is held with the valve in a vertical position thereby ensuring there is no air left in the sphere.

When ordering a new or replacement sphere, the manufacturer should be provided with both the prover inside diameter and the inflation size diameter, or the percentage of the oversize value required, so they can provide a sphere of the optimum size as well as matching to the fluid and conditions to ensure material compatibility.

6.5.3 Pistons

- a) The design should be such that the seal integrity prevails throughout the proving operation at all velocities and flow conditions. This requirement applies to the piston diameter seals and any seals in internal valves and fittings.
- b) The length and bearing surfaces of the piston should ensure smooth, judder-free travel with the face of the piston maintained at right angles to the direction of travel. The use of slide and wiper rings may facilitate this.
- c) The design should ensure integrity during controlled acceleration, deceleration and arrest.

6.6 Displacer Velocity

6.6.1 General

The manufacturer should specify the velocity range within the prover. This may vary for different fluids and the displacer materials chosen. The figures given below are for guidance only and may vary significantly from a prover in service. A check should be made to ensure that the following criteria are observed over the operating flow range.

6.6.2 Minimum velocity

- a) The minimum velocity is chosen to ensure smooth movement of the displacer and is particularly critical in highly compressible fluids or those with poor lubrication properties.
- b) The minimum velocity should not adversely affect detector response.
- c) The time for a pass at minimum flowrates should not be excessive, however it should encompass the velocities used for calibration as well as the lowest operating flowrates.