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5 June 2019

Pipe provers for testing measuring systems for liquids

Tubes étalons pour l'essai des ensembles de mesurage de liquides

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

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FOREWORD

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organization whose primary aim is to harmonize the regulations and metrological controls applied by the national metrological services, or related organizations, of its Member States.

The main categories of OIML publications are:

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- International Documents (OIML D), which are informative in nature and which are intended to harmonize and improve work in the field of legal metrology;

- International Guides (OIML G), which are also informative in nature and which are intended to give guidelines for the application of certain requirements to legal metrology; and

- International Basic Publications (OIML B), which define the operating rules of the various OIML structures and systems.

OIML Draft Recommendations, Documents and Guides are developed by Project Groups linked to Technical Committees or Subcommittees which comprise representatives from the Member States. Certain international and regional institutions also participate on a consultation basis. Cooperative agreements have been established between the OIML and certain institutions, such as ISO and the IEC, with the objective of avoiding contradictory requirements. Consequently, manufacturers and users of measuring instruments, test laboratories, etc. may simultaneously apply OIML publications and those of other institutions.

International Recommendations, Documents, Guides and Basic Publications are published in English (E) and translated into French (F) and are subject to periodic revision.

Additionally, the OIML publishes or participates in the publication of Vocabularies (OIML V) and periodically commissions legal metrology experts to write Expert Reports (OIML E). Expert Reports are intended to provide information and advice, and are written solely from the viewpoint of their author, without the involvement of a Technical Committee or Subcommittee, nor that of the CIML. Thus, they do not necessarily represent the views of the OIML.

This publication - reference OIMLD yy, edition 20xx (E) - was developed by the OIML technical committee TC 8 on measurement of quantities of fluids. It was approved for final publication by the International Committee of Legal Metrology in 20xx and will be submitted to the International Conference of Legal Metrology in 20xx for formal sanction. It supersedes the OIML R 119 dated 1996.

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Introduction

Prover is a measuring system used as a standard for volume or flow rate of liquid and it has advantages over other conventional measurement methods. For example, it enables a precise volumetric measurement with the calibrated base volume, a semi-automatic measurement in a production/calibration line, and continuous measurement without interrupting the flow (for some types of the provers).

Due to such advantages, this measuring system is widely used as a working standard to calibrate/test/verify flow meters or a capacity measures for liquids including water and oil. The users of the instrument include a wide filed such as, national/local metrology institute in legal metrology, accredited calibration laboratories, manufacturers of measuring instruments, water suppliers, food industries, and oil/chemical industries. Due to its structure, prover is normally used as a stationary working standard in a public/private testing laboratory or a factory.

This document is closely related to other international recommendations and standard such as, OIML R 49 [1], OIML R 63 [4], OIML R 117-1/2/3 [5-7], ISO 91-1 [8], ISO 4267-2 [9], ISO 7278-1/2/3/4 [10-13] and ISO 8222 [14].

1 Scope

This International Document deals with pipe provers including piston provers which are used as a working standard to verify or calibrate measuring equipment for volume or flow rate of liquids (hereinafter called "measuring systems"). These processes for verification/calibration are conducted in compliance with the relevant metrological requirements in the relevant OIML International Recommendations or other international standards. This International Document proposes model technical requirements for provers in designing, installing, calibrating and utilizing this measuring system for the users in legal metrology and industries involved in flow measurements.

2 Terms and definitions

The general terms used in this Document are in accordance with the International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM:2012) [15], and the International Vocabulary of Terms in Legal Metrology (VIML:2013) [16]. Other terms specific to this Document are defined below.

2.1 Base volume

Constant reference volume corresponds to a displacement of a single full stroke of the displacer in the calibrated section.

Note: A base volume is usually equivalent to the volume of the calibrated section.

2.2 Calibrated section

A specified section in a prover enclosed with a pipe (or cylinder) and displacer(s) which has a constant cross-sectional area.

Note: The volume inside a calibrated section, which is precisely determined in advance, may be used to define the base volume of the pipe prover.

2.3 Detector

A sensor to detect the position of the displacer.

Note: A contact or contactless (optical or magnetic) switch is used for a pipe prover, and a linear encoder used for a piston prover.

2.4 Displacer

An object (usually a sphere or a piston) delimiting the calibrated section which travels along with the liquid flowing through the prover.

3 Pipe provers employed in this document

3.1 General

A pipe prover is a pipe or cylinder whose volume is used to calibrate, verify or prove a flow measuring system for liquid. A process of calibration is accomplished by passing through the pipe a displacer (usually a sphere or piston) which actuates a pair of position detectors delimiting the calibrated section with a certain delay time. The known volume of this section (base volume) is used as a standard to determine the instrumental error of the measuring system which is connected to the prover. The measured volume is corrected for the errors due to the differences in temperature and pressure of the liquid from the reference condition. The travelling time between the detectors is used to determine a flow rate.

3.2 Types of pipe provers

The following types of devices are generally used as pipe provers. Other types of pipe provers can be used as far as their metrological characteristics comply with the requirements of this Document.

3.2.1 Uni-directional type

A uni-directional prover uses a displacer that travels in one direction to actuate detectors in the calibrated section of the pipe (Figure 1). The measured volume corresponds to one passage of the displacer.

3.2.2 Bi-directional type

A bi-directional prover uses a displacer that travels in one direction and then in the opposite direction through the same calibrated section (Figures 2a and 2b). The measured volume corresponds to the sum of both passages of the displacer. A pair or two independent pairs of detectors are used to record the movement of the displacer.

3.2.3 Small volume type

A small volume type or compact prover uses a displacer which travels through a very short section of the pipe or cylinder (Figures 3a and 3b). The volume displaced in the calibrated section is usually much smaller than that of a conventional prover. For this reason, high-precision detectors and a method for pulse-interpolation are necessary to achieve good repeatability and high accuracy.

3.2.4 Full-stroke type

This type of pipe prover uses the standing start and stop method (Figure 4). Its base volume is the volume displaced by a single full stroke of the reversible displacer. Full-stroke type may be used mainly for the verification of LPG displacers.

3.3 Accuracy

The calibration of a base volume of a prover shall be carried out such that the expanded uncertainty of the calibration be significantly smaller than the acceptable criteria which is referred as the maximum permissible error (MPE) in pattern approval tests and verification tests. The treatment of the expanded uncertainty and the acceptable criteria should follow the requirements of OIML G 19 [17], an applicable OIML Recommendation, and/or an international standard. The expanded uncertainty shall be determined using an appropriate coverage factor (k) which is usually equivalent to two (k=2).

3.4 Construction of pipe provers

3.4.1 General

Construction of pipe provers should meet the provisions of the ISO 4267-2 [9]. Typical layouts of pipe provers are shown in Figures 1 to 3b. Special care should be taken in the control system of a prover for the collection of necessary data. From the viewpoint of proper metrological control, some requirements are mentioned below.

3.4.2 Materials and fabrication

The materials of construction and the pressure rating should be compatible with the measuring systems to be tested and the fluid used for testing. The prover should be adequately insulated for the required duty and ambient conditions. If separation of the prover is necessary for transportation, the proper reassembly of the individual parts shall be guaranteed either by an appropriate and reproducible construction or by a recalibration of the base volume. Internal coating of the prover section with the correct material should be used to reduce corrosion and wear.

3.4.3 Displacer

In general, provers use one or more spheres, or a piston as a displacer. Spheres are made of a resilient material which should be compatible with the test fluid, and they shall meet certain minimum and maximum sizes. Piston displacers shall be made of rigid material with resilient seals in contact with the pipe prover wall. The diameter of the sphere shall be such that a seal is provided without excessive friction.

3.4.4 Valves

The valves used in a pipe-prover system shall not leak as their leakage would influence the measurement result. Necessary means for checking leakage in the system shall be provided.

3.4.5 Temperature measuring devices

Temperature-measuring devices with a suitable range shall be installed at the inlet and outlet of the prover. The devices shall be immersed in the fluid to enable accurate determination of the fluid temperature. The use of thermo-wells (tubular fittings used to protect temperature sensors) is normally recommended. The accuracy and range of the devices should be such that the provisions of 3.3 and 5.3 are met.

3.4.6 Pressure measuring devices

Pressure-measuring devices with a suitable range shall be used at appropriate locations to measure pressure in the prover. The accuracy and range of the devices must be such that the provisions of 3.3 and 5.4 are met.

3.4.7 Detectors

Except for the full-stroke type of prover, detection devices and switches for any given direction of the displacer shall respond to the displacer's position such that the prover meets the performance requirements specified in 3.3.

3.4.8 Vent valve and related piping

Vent valves shall be installed on the topmost part of the pipe to ensure that all the gas is vented from the dead spaces not swept by the displacer. This requirement ensures that the piping, the pipe prover and the meter to be tested are completely filled with the test liquid. Provisions shall be made for the disposal of the liquid and vapors drained or vented from the prover. Connections shall be provided if necessary for the water draw method or the master meter method.

4 Calibration of pipe provers

4.1 General

The calibration methods summarized below as a guideline. Detailed description of the calibration method is also given in the ISO 7278-2 [11]. National regulations may specify that pipe provers shall be calibrated when they are installed for testing other measuring systems for liquids, and that they may be re-calibrated periodically at an interval fixed by these regulations. Pipe provers shall also be re-calibrated when they may have been repaired or modified mechanically (e.g. change of detectors, recoating, dismantling and re-installation).

4.2 Reference conditions

The base volume of a pipe prover shall be determined on the basis of the reference conditions specified in national/regional regulations.

4.3 Methods for calibrating pipe provers

There are three methods for calibrating a pipe prover: the water draw method, the master meter method and the dimensional method.

4.3.1 Water draw method

The calibration of a pipe prover by the water draw method requires standard capacity measures or a weighing instrument with a tank, against which the base volume of the prover may be determined. To allow a continuous and uniform flowrate to be produced, the base volume of the prover may be run into a holding tank using typical arrangements such as those shown in Figures 5 and 6. This volume is measured subsequently by weighing or by transferring into the standard capacity measures. The prover shall be thoroughly flushed and cleaned before calibration.

4.3.2 Master-meter method

In this method, the reading of a master meter is compared with the values of volume obtained by a master prover and by a pipe prover being calibrated, respectively. If necessary, a proving tank may be replaced with the master prover. Where, the master meter functions merely as an intermediate link between the two provers. Therefore, it is necessary to assure before and after the calibration that the performance of the master meter is stabilized by using the master prover as a reference. A typical arrangement of the master-meter method is shown in Figure 7. This method is not applicable, however, to a full-stroke type of pipe prover with a small volume.

4.3.3 Dimensional method

This method is based on precise dimensional measurements of the calibrated section of the pipe prover. The measurements are typically conducted through evaluating effective and averaged values for inner length and inner diameter of the calibrated section which is in a cylindrical shape. This method is particularly effective to reduce measurement uncertainty for pipe prover or a piston prover using a straight tube.

5 General requirements for the testing of measuring systems using a pipe prover

5.1 Test liquids

A measuring system shall be tested using one of the liquids marked on the data plate (or instruction manual) of the measuring system, or with a liquid whose flow characteristics are within the ranges of those of the marked liquids. Any regulations concerning the security of handling of the measuring system shall be observed.

5.2 Base volume of the pipe prover

It should be ensured that the base volume of the pipe prover shall be matched to the resolution of the measuring system and shall be adequate to meet the requirements of 3.3. Where the measuring system is equipped with a pulse generator which does not generate enough pulses for the base volume, a pulse-interpolation method may be used in compliance with ISO 7278-3 [12].

5.3 Temperature measurement

In order to determine the necessary temperature corrections for the test liquid, the measuring system and the pipe prover being used, appropriate temperature-measuring devices shall be used. These devices shall be mounted at suitable places on the measuring system and the testing equipment. It is recommended to use the temperature-measuring devices with an expanded uncertainty of 0.2 °C or less. For accurate measurement of large volumes of petroleum products, it may be necessary to measure the temperature with a smaller expanded uncertainty of 0.05 °C or less to take into account of the thermal expansions of the product and the measuring system. Temperature measuring devices should be provided with the calibration certificates.

5.4 Pressure measurement

When a correction for the pressure of the liquid and/or prover is required, a pressure gauge shall be mounted at a suitable place on the measuring system or on the testing equipment in order to measure the pressure of the liquid with a necessary accuracy. Normally, pressure gauges with an expanded uncertainty of 0.05 MPa (0.5 bar) or less is suitable. For accurate measurement of large volumes of petroleum products, it may be necessary to measure the pressure with a smaller expanded uncertainty of 0.025 MPa or less to take into account of the compressibility of the product and the measuring system. Pressure gauges should be provided with the calibration certificates.

5.5 Inspection of electronic devices

The electronic devices including detectors, pulse generator and pulse counter shall be inspected to confirm that they function correctly.

5.6 Preliminary runs

A sufficient number of preliminary runs shall be carried out before the test run in order to eliminate the gas which may be contained in the test equipment including the pipe prover, and to make sure that the liquid temperature is stable and uniform. The measuring system shall be tested for leakage before the test.

5.7 Test flowrates

The total number and the range of flowrates applied for testing are specified in the OIML Recommendation(s) applied to the measuring system under legal control.

5.8 Number of test runs

The number of test runs to be carried out at a particular flowrate is specified in the OIML Recommendation(s) applied to the measuring system. In general, the number is more than two in order to evaluate the repeatability of the measuring system adequately as well as to verify whether each test result meets the maximum permissible error (MPE).

5.9 Calculation of errors

The errors of the measuring system may be calculated either from the meter factor determined according to Clause 7 of ISO 4267-2 [9], or using directly the following equations in which the second order terms are neglected.

$$E = E'' + E_\alpha + E_\beta + E_\gamma + E_\delta \quad (1)$$

$$E'' = [(V_{\mathrm{lm}} - V_{\mathrm{B}}) / V_{\mathrm{B}}] \times 100 \quad (2)$$

$$E_\alpha = \alpha \times (t_{\mathrm{lp}} - t_{\mathrm{lm}}) \times 100 \quad (3)$$

$$E_\beta = \beta \times (t_{\mathrm{s}} - t_{\mathrm{lp}}) \times 100 \quad (4)$$

$$E_\gamma = \gamma \times (p_{\mathrm{lm}} - p_{\mathrm{lp}}) \times 100 \quad (5)$$

$$E_\delta = -\,\delta \times p_{\mathrm{lp}} \times 100 \quad (6)$$

where

E is the instrumental error of the measuring system, in %
E'' is the uncorrected error, in %
E_α is the temperature correction for the test liquid, in %
E_β is the temperature correction for the pipe prover, in %
E_γ is the pressure correction for the test liquid, in %

E_δ is the pressure correction for the pipe prover, in %
V_{lm} is the volume indicated by the meter, in L
V_B is the base volume of the pipe prover, in L
t_{lp} is the liquid temperature in the pipe prover, in °C
t_{lm} is the liquid temperature in the meter, in °C
t_s is the reference temperature of the pipe prover, in °C
p_{lp} is the gauge pressure of the liquid in the pipe prover, in kPa
p_{lm} is the gauge pressure of the liquid in the meter, in kPa
α is the cubic expansion coefficient of the test liquid due to temperature, in $°C^{-1}$
β is the cubic expansion coefficient of the pipe prover due to temperature, in $°C^{-1}$
γ is the compression coefficient of the test liquid, in kPa^{-1}
δ is the pressure expansion coefficient of pipe prover, in kPa^{-1}

Notes: The four coefficients may be determined as shown below.

α: Refer to OIML R 63 or ISO 91-1[8] for petroleum products; refer to ISO 8222 for water
β: 33×10^{-6} $°C^{-1}$ for mild steel, 51×10^{-6} $°C^{-1}$ for stainless steel
γ: Refer to the coefficient C_{pl} (5.4) of ISO 4267-2
δ: Refer to the coefficient C_{ps} (5.3) of ISO 4267-2

6 Test procedures for the verification of measuring systems

6.1 General

Clauses 6.2, 6.3 and 6.4 describe examples of typical verification procedures using a pipe prover for the following measuring systems:

Clause 6.2: a measuring system on road tanker and a measuring system on pipe line

Clause 6.3: a measuring system for LPG under pressure

Clause 6.4: a measuring system for LPG dispenser

It should be noted that there exist many other acceptable test methods which may be described in OIML Recommendations or in ISO Standards. Examples below are merely given to illustrate typical applications. Any test method should, however, comply with the metrological specifications of this Document in order to ensure the integrity of testing.

6.2 Test procedure for measuring system for liquid fuel

Typical installations in which a pipe prover and a measuring system for liquid fuel are connected are shown in Figures 8 and 9, depending on the applications of the measuring systems. The basic test procedure is as follows:

(1) Carry out a sufficient number of preliminary runs.
(2) Locate the displacer at the starting position, reset the pulse counter and interval timer.
(3) Start the displacer in movement. Check whether both the pulse counter and the interval timer start when the start detector is activated.
(4) While the pulse is counted, read and record the temperature and pressure of the pipe prover and the measuring system.
(5) Check that both the pulse counter and the interval timer stop when the end detector is activated.

(6) Read and record the indicated results of the pulse counter and the interval timer.

6.3 Test procedure for measuring system for LPG under pressure

A typical installation in which a measuring system for LPG under pressure is tested using a pipe prover is shown in Figures 10 and 11. It should be ensured that the LPG remains in liquid phase inside the pipe prover by means of an appropriate device, if necessary. The basic test procedure shall be the same as those described in Clause 6.2.

6.4 Test procedure for LPG dispensers

Typical installation in which a full-stroke type of pipe prover is used for verifying the measuring systems for LPG dispenser is shown in Figure 11. The basic test procedure is as follows:

(1) Locate the pipe prover horizontally close to the dispenser and make the pipework as short as possible.
(2) Connect the outlet nozzle of the dispenser to the inlet of the pipe prover.
(3) Position the flow diverter valve to cause circulation of flow. Purge gas adequately and conduct preliminary runs. Check that no air bubbles are present by means of the sight glass.
(4) Locate the displacer at the starting position and reset the indication of the dispenser.
(5) Start the displacer movement.
(6) Read and record the temperature, pressure and flowrate of the liquid during flow.
(7) Read and record the total count on the dispenser when the displacer reaches the end point of its stroke.

7 Bibliography

[1] OIML R 49-1: 2013 "Water meters for cold potable water and hot water, Part 1: Metrological and technical requirements"

[2] OIML R 49-2: 2013 "Water meters for cold potable water and hot water, Part 2: Test methods"

[3] OIML R 49-3: 2013 "Water meters for cold potable water and hot water, Part 3: Test report format"

[4] OIML R 63: 1994 "Petroleum measurement tables"

[5] OIML R 117-1: 2007 "Dynamic measuring systems for liquids other than water, Part 1: Metrological and technical requirements"

[6] OIML R 117-2: 2014 "Dynamic measuring systems for liquids other than water, Part 2: Metrological controls and performance tests"

[7] OIML R 117-3: 2014 "Dynamic measuring systems for liquids other than water, Part 3: Test report format"

[8] ISO International Standard 91: First edition 2017: Petroleum and related products - Temperature and pressure volume correction factors (petroleum measurement tables) and standard reference conditions, International Organization for Standardization

[9] ISO 4267-2: 1988 "Petroleum and liquid petroleum products - Calculation of oil quantities Part 2: Dynamic measurement"

[10] ISO 7278-1: 1987 "Liquid hydrocarbons - Dynamic measurement - Proving systems for volumetric meters - Part 1: General principles"

[11] ISO 7278-2: 1988 "Liquid hydrocarbons - Dynamic measurement - Proving systems for volumetric meters - Part 2: Pipe provers"

[12] ISO 7278-3: 1998 “Liquid hydrocarbons - Dynamic measurement - Proving systems for volumetric meters - Part 3: Pulse interpolation techniques”

[13] ISO 7278-4: 1999 “Liquid hydrocarbons - Dynamic measurement - Proving systems for volumetric meters – Part 4: Guide for operators of pipe provers”

[14] ISO 8222: 2002 “Petroleum measurement systems - Calibration - Temperature corrections for use when calibrating volumetric proving tanks”

[15] JCGM 200:2012 "International Vocabulary of Metrology - Basic and General Concepts and Associated Terms (VIM 3rd edition)"

[16] OIML V 1: 2013 "International vocabulary of terms in legal metrology (VIML)"

[17] OIML G 19: 2017 "The role of measurement uncertainty in conformity assessment decisions in legal metrology"

[Comment by TC 8: The format of number of the references was changed.]

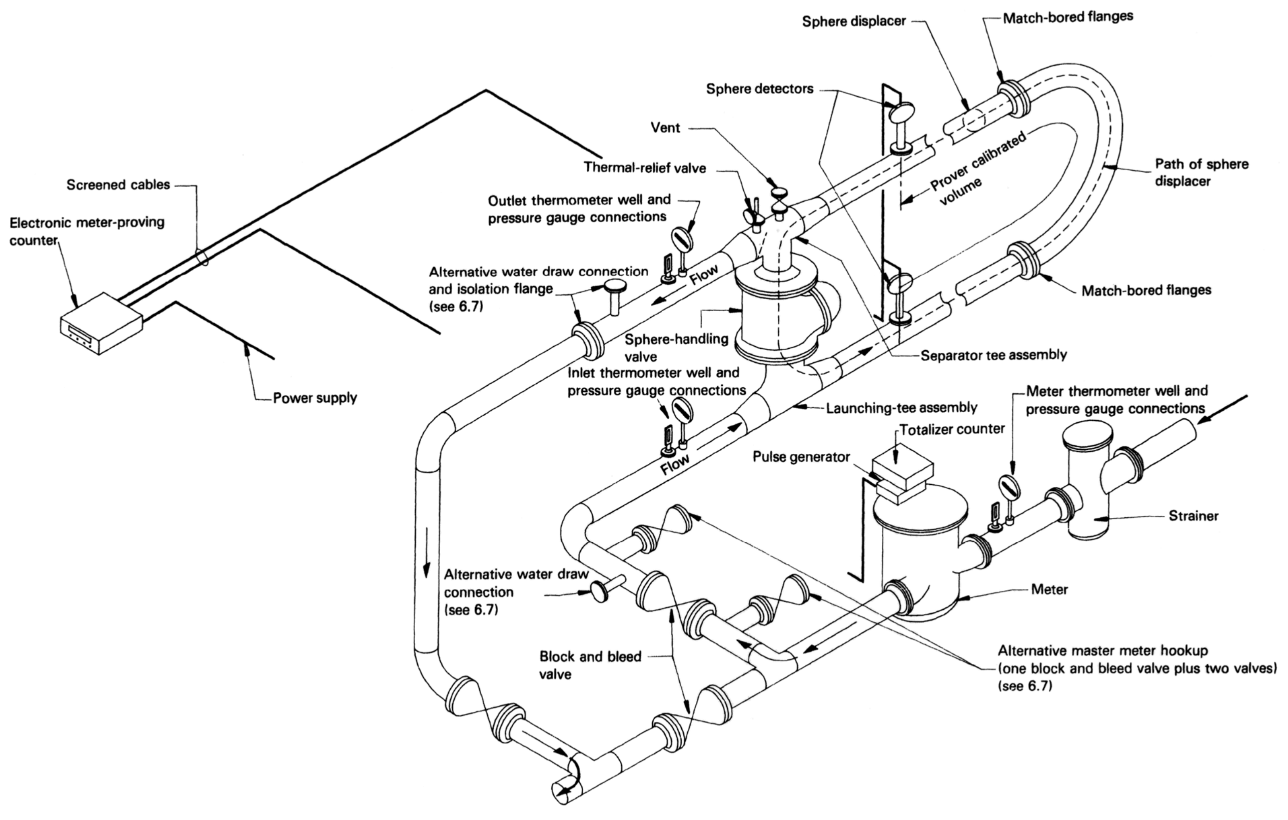

Figure 1 Typical uni-directional pipe prover
(Extracted from ISO 7278-2*)

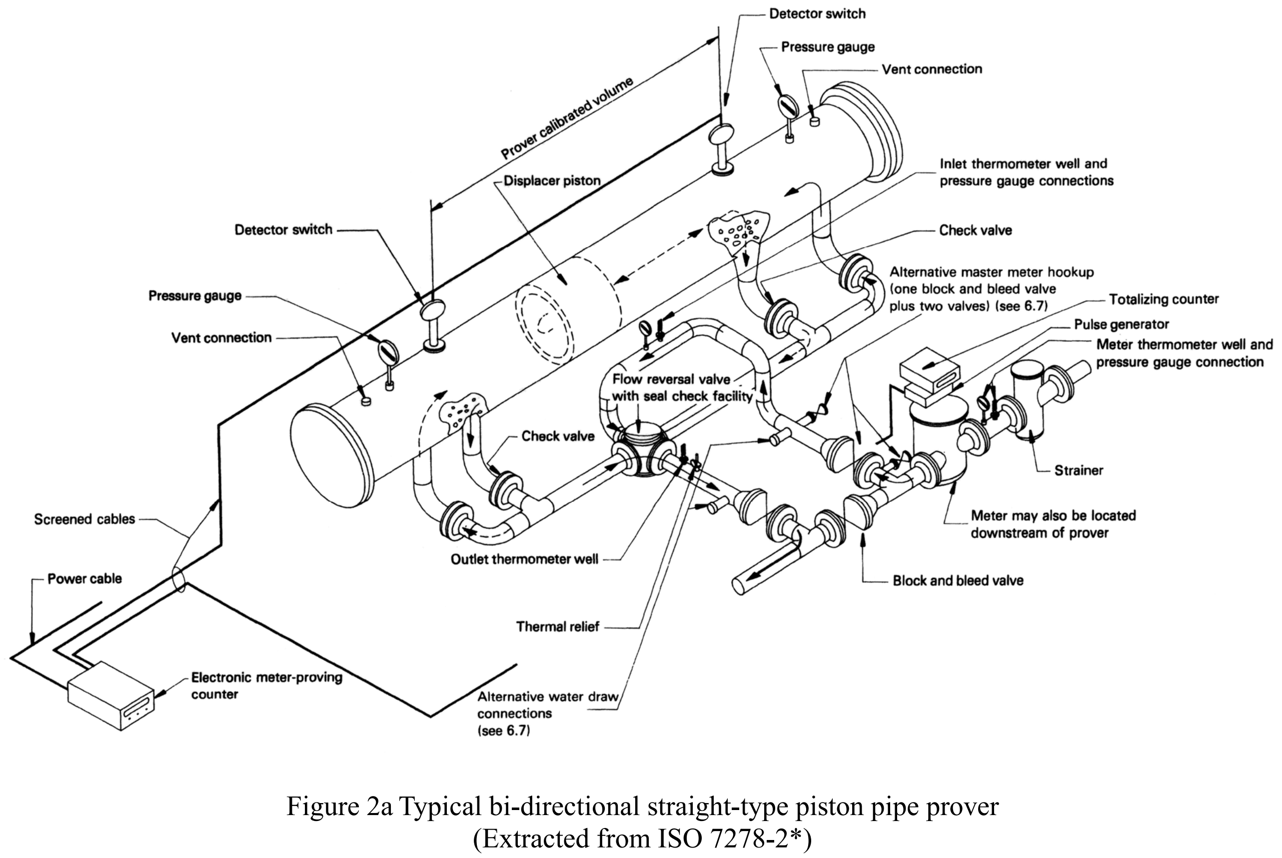

Figure 2a Typical bi-directional straight-type piston pipe prover
(Extracted from ISO 7278-2*)

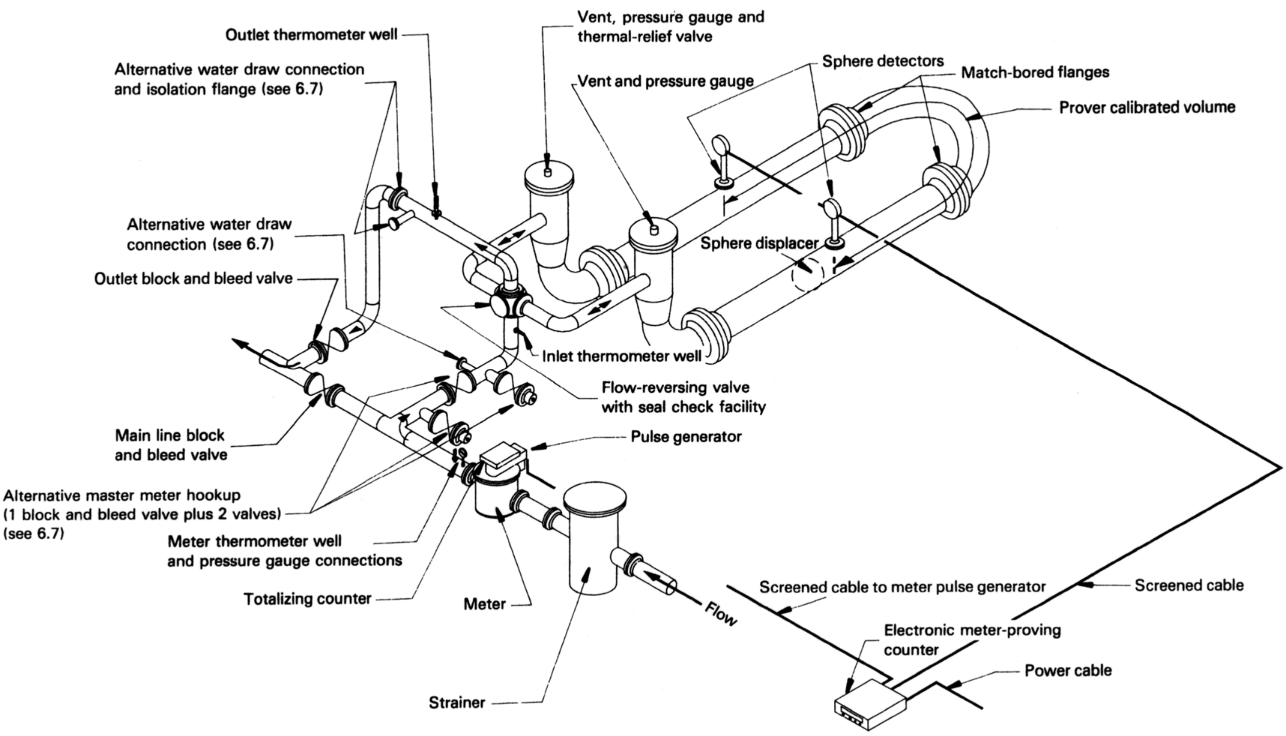

Figure 2b Typical bi-directional U-type pipe prover
(Extracted from ISO 7278-2*)

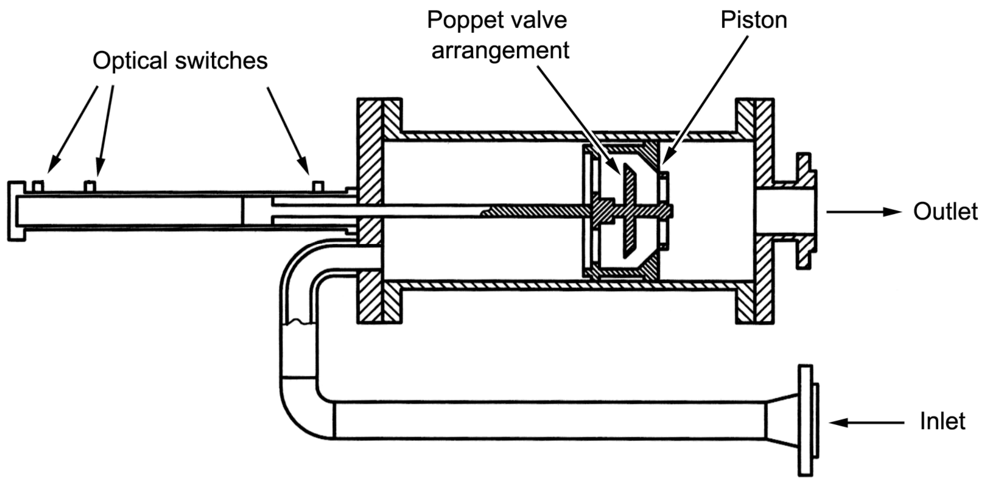

Figure 3a Typical small volume pipe prover with internal valve
(Extracted from ISO 7278-4*)

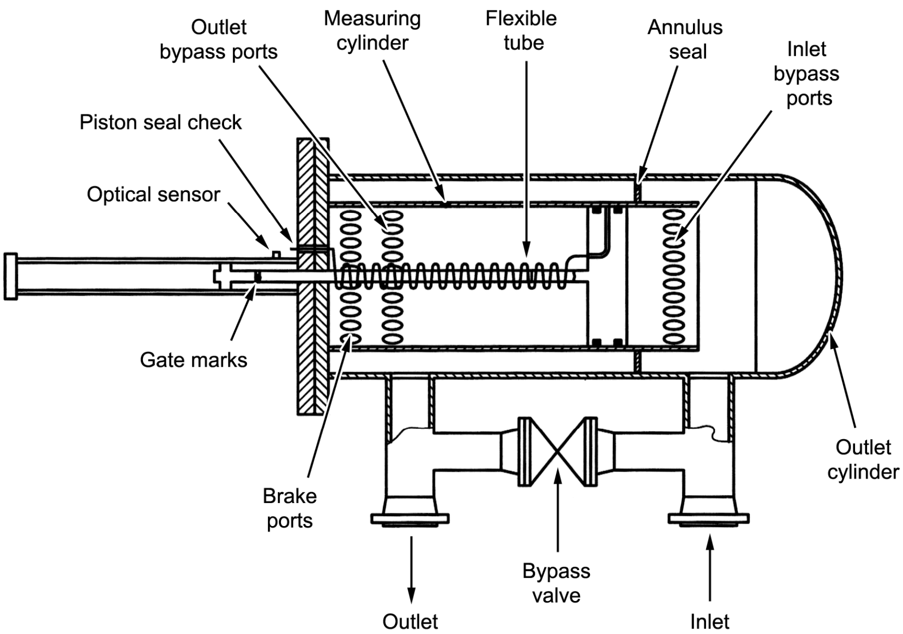

Figure 3b Typical small volume pipe prover with external valve
(Extracted from ISO 7278-4*)

(*) Figures 1 to 3b are extracted from ISO 7278-2:1988 and ISO 7278-4:1999, reproduced with the authorization of the International Organization for Standardization (ISO) which holds the copyright.
[Comment by TC 8: Figures 1 to 3b are basically the same with those in the present R 119.]

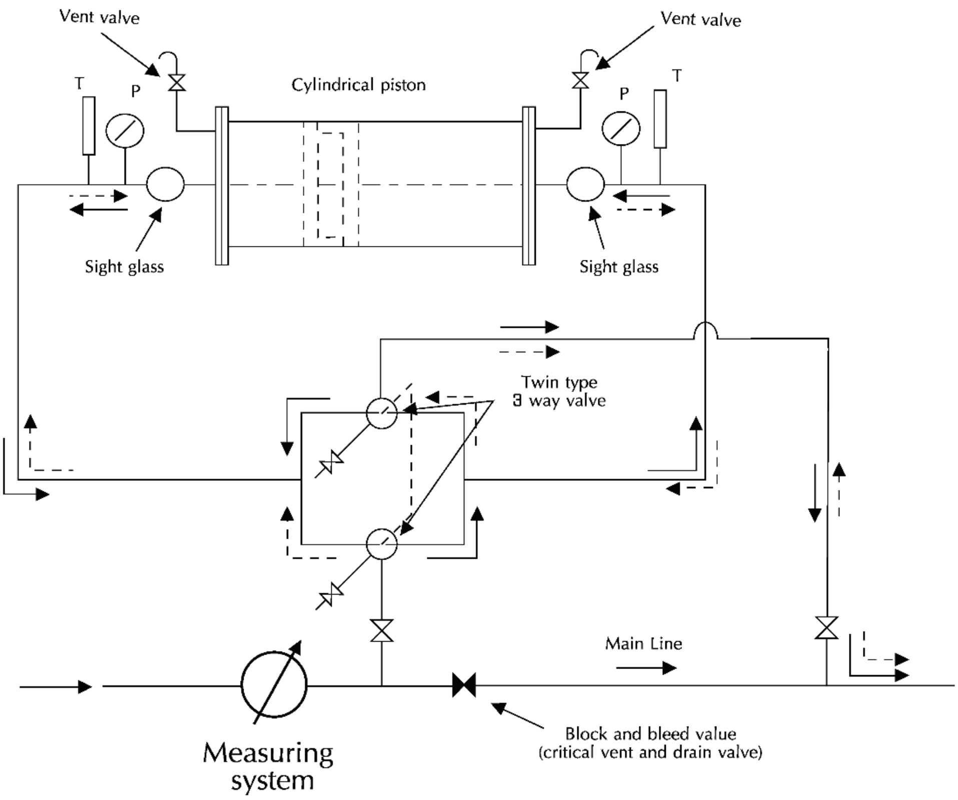

Figure 4 Typical full-stroke type pipe prover
[Comment by TC 8: This figure corresponds to Figure 4 of the present R 119 with the following change. 'Measuring system' was indicated clearly.]

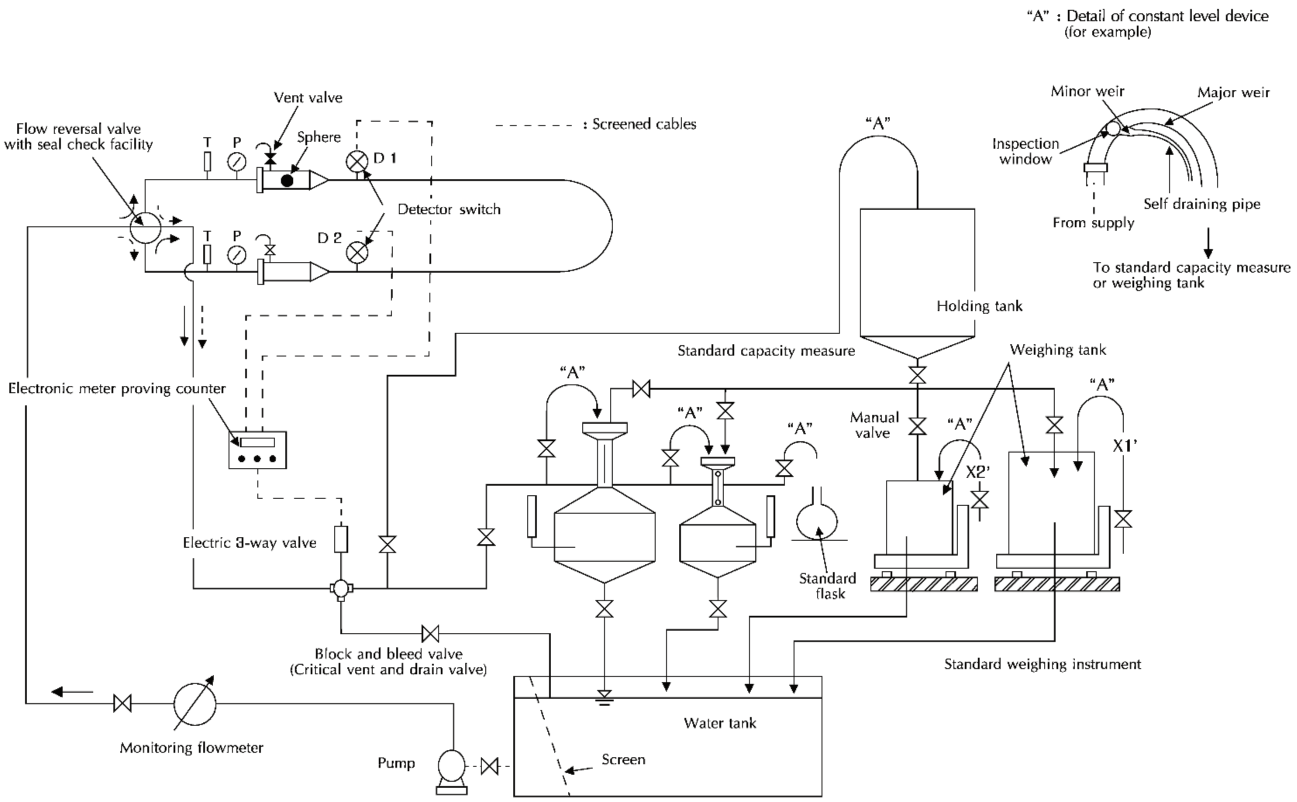

Figure 5 Calibration of pipe prover (water draw method)

[Comment by TC 8: This figure corresponds to Figure 5 of the present R 119 with the following changes. A vertical pipe in the holding tank was deleted. Piping around two standard tanks and a flask was modified. The level device was redrawn for better understanding.]

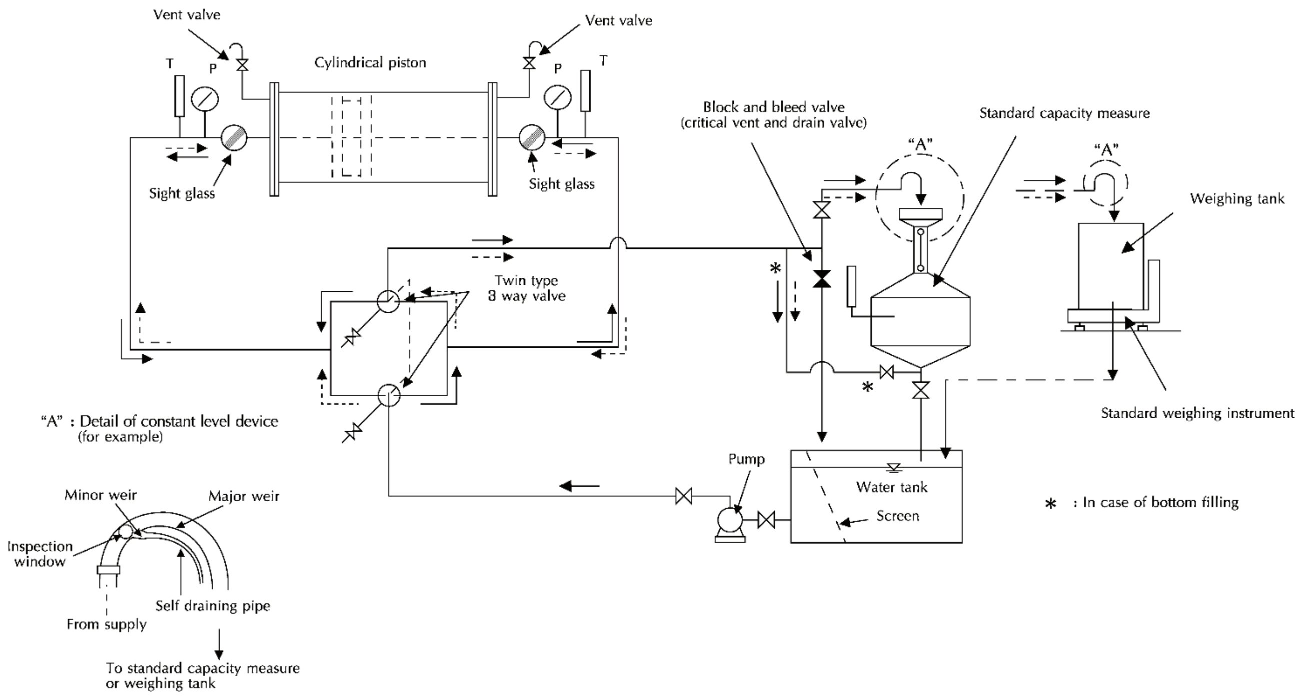

Figure 6 Calibration of full-stroke type pipe prover (water draw method)

[Comment by TC 8: Same as Figure 6 of the present R 119.]

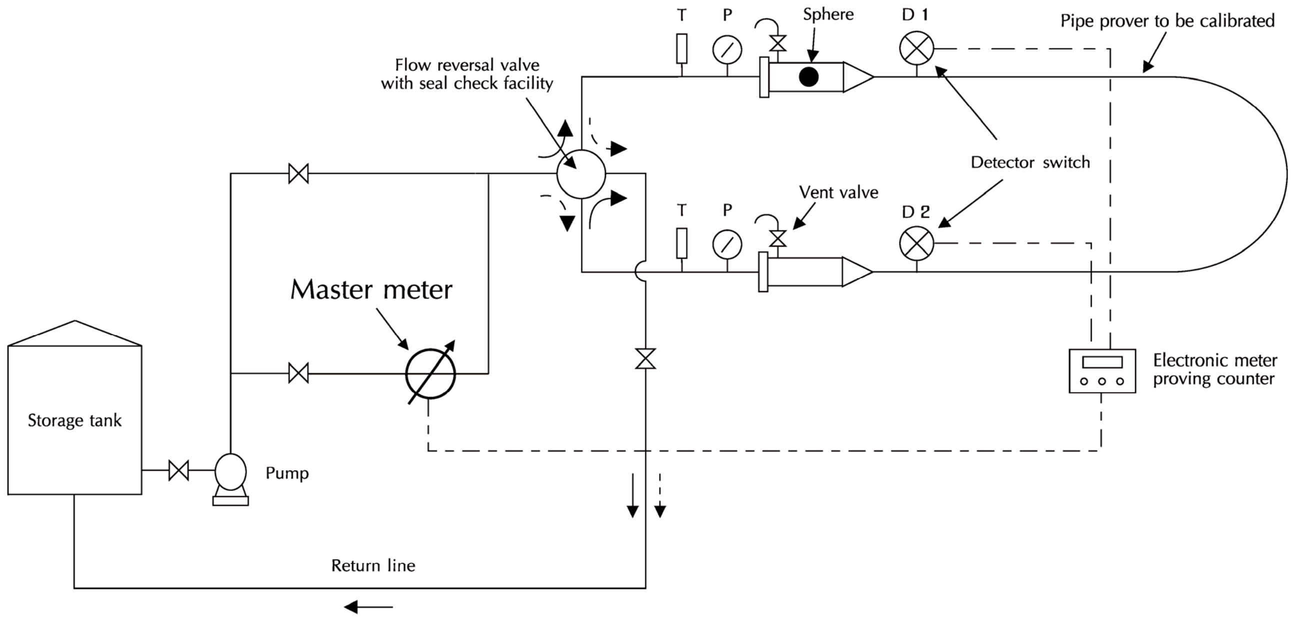

Figure 7 Calibration of a pipe prover (master meter method)

[Comment by TC 8: This figure corresponds to Figure 7 of the present R 119 with the following changes. One of the two provers in the original figure was deleted because a master meter is not used with two provers at the same time.]

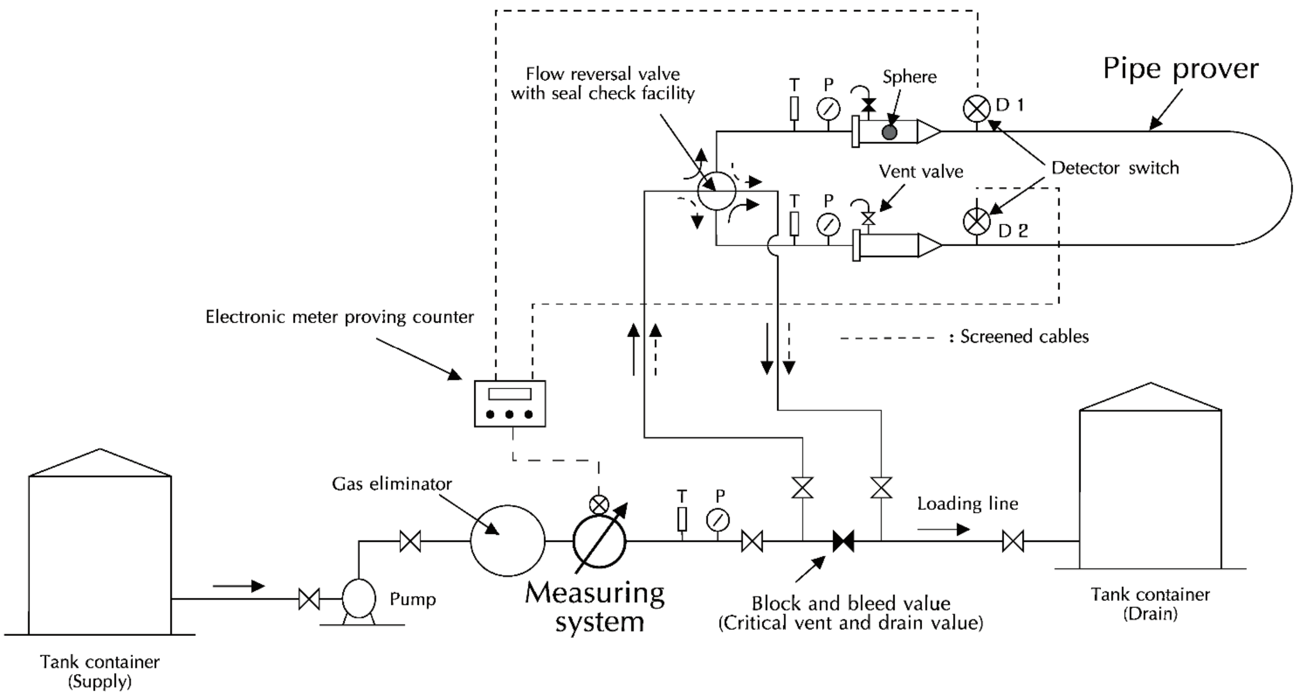

Figure 8 Verification of measuring systems for tank containers connected with pipelines

[Comment by TC 8: This figure is a combination of Figures 9, 10 and 11 of the present R 119 with the following changes. Various measuring systems in the three original figures, which were connected to supply or drain liquid, were summarized into the two tank containers for supply and drain. Measuring system' was indicated clearly.]

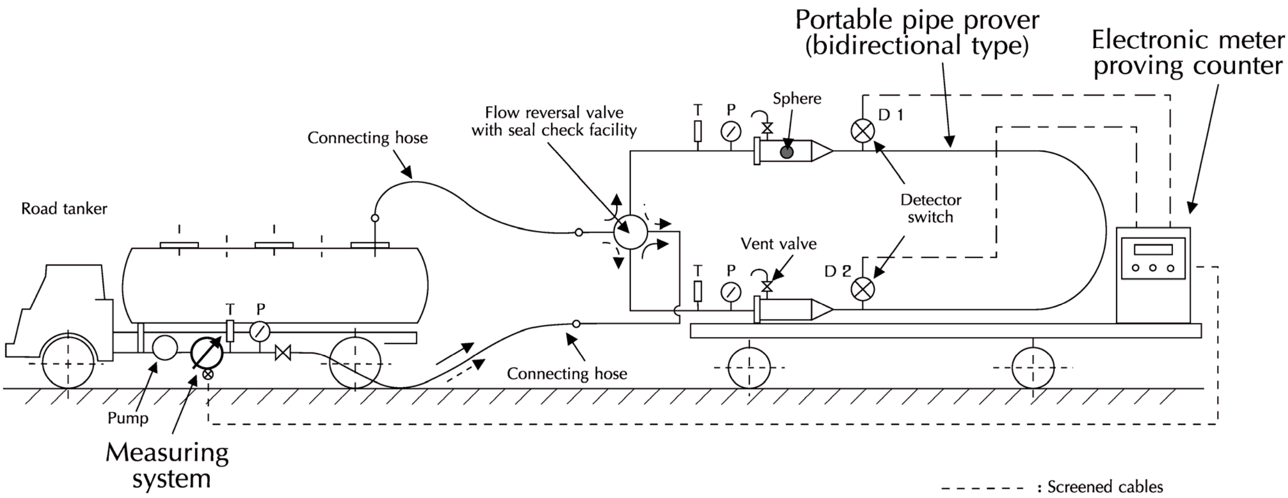

Figure 9 Verification of measuring systems on road tankers

[Comment by TC 8: This figure corresponds to Figure 8 of the present R 119 with the following change. Measuring system' was indicated clearly.]

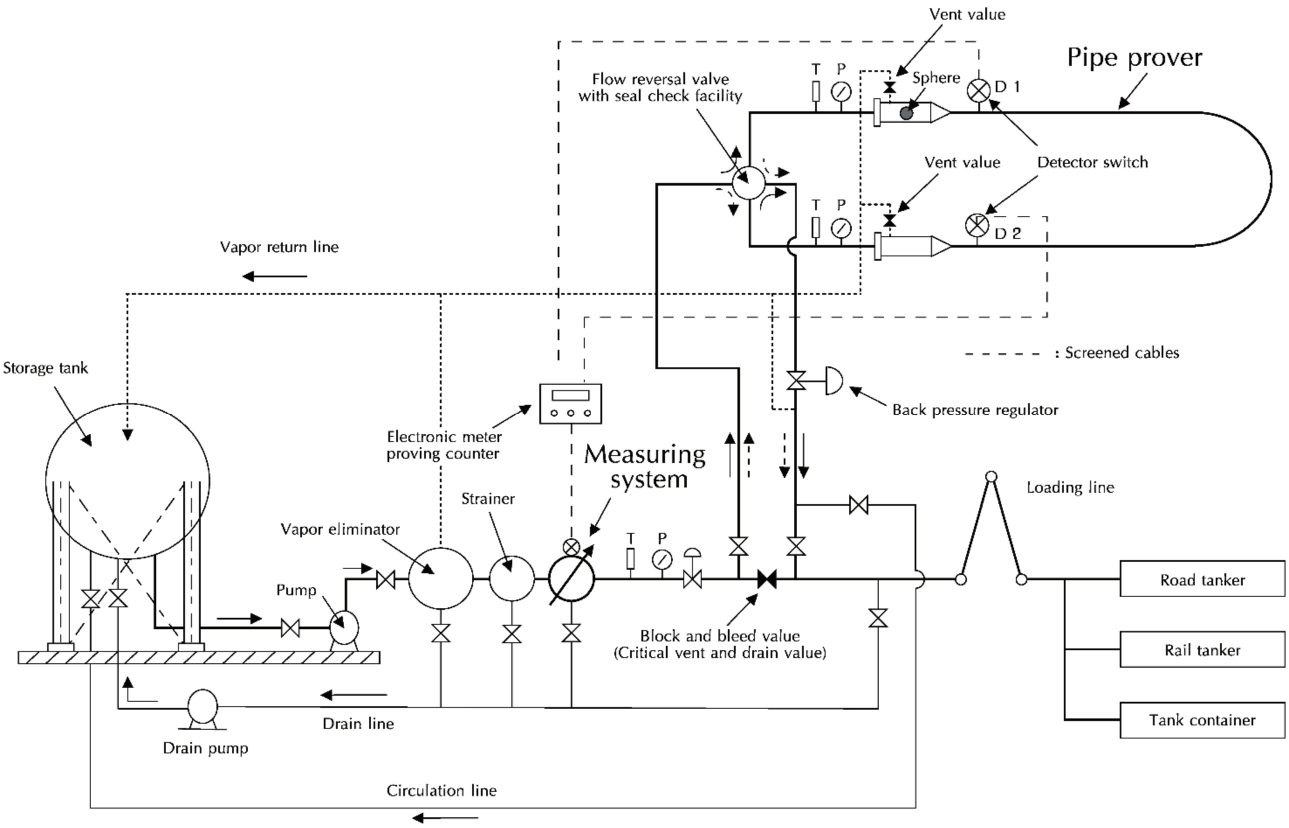

Figure 10 Verification of measuring systems for LPG under pressure

[Comment by TC 8: This figure corresponds to Figures 12 of the present R 119 with the following changes. Measuring system' was indicated clearly. Piping around the back-pressure gauge was modified.]

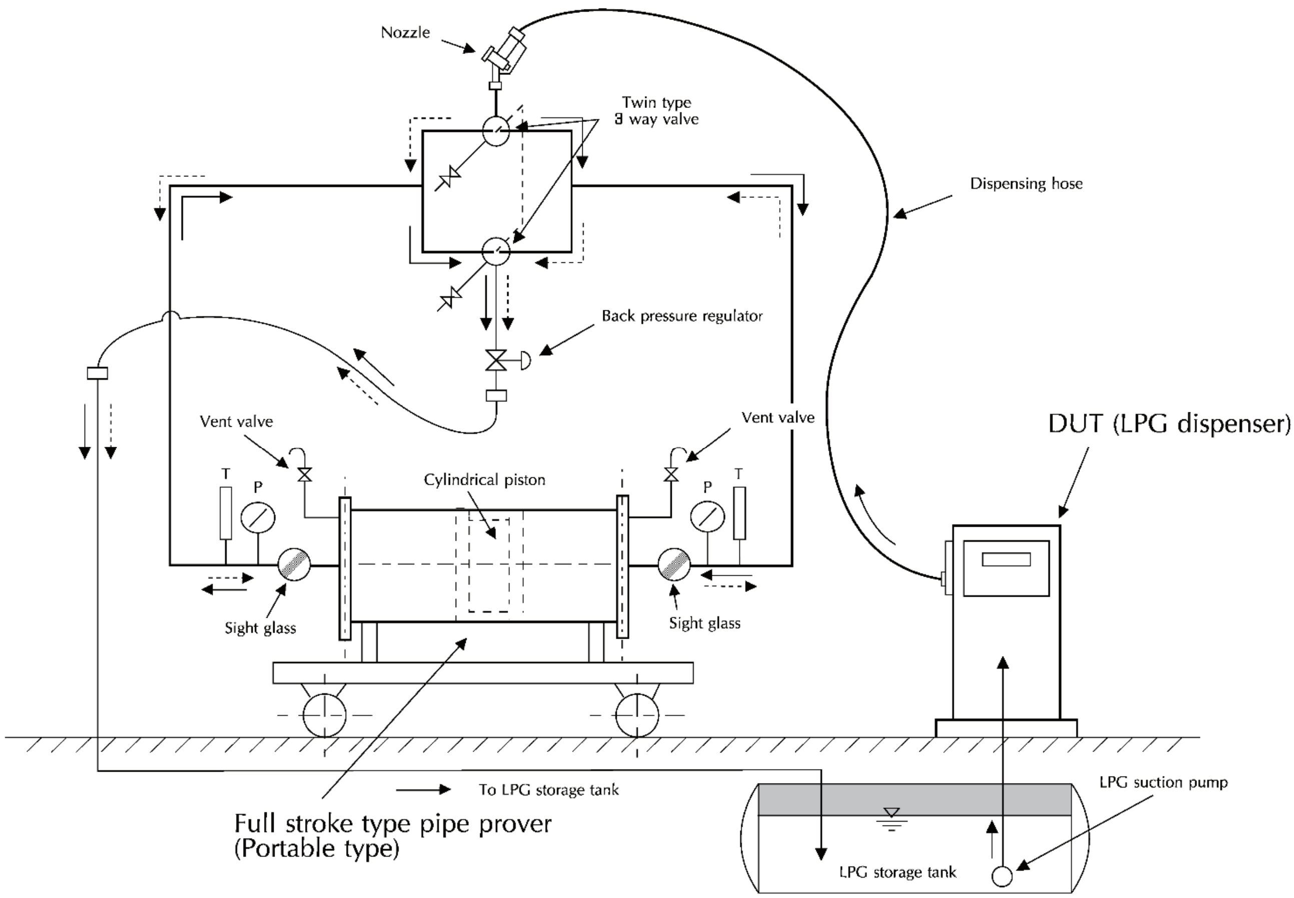

Figure 11 Verification of LPG dispensers

[Comment by TC 8: This figure corresponds to Figure 13 of the present R 119. Figure 14 in R 119 with an application to fuel dispensers was removed as it is not used frequently.]