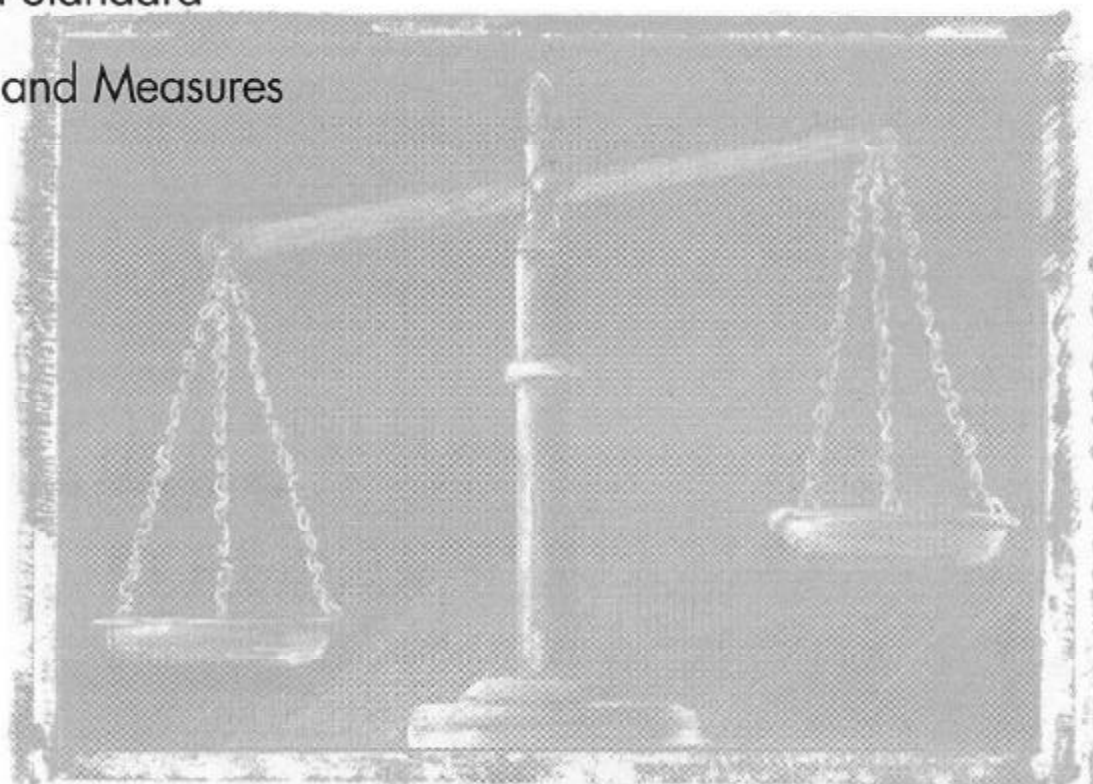


SPECIFICATIONS AND TOLERANCES

for Reference Standards
and Field Standard
Weights and Measures



7. Specifications and Tolerances for Dynamic Small Volume Provers

NIST
Handbook

105-7
1997

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Preface

Small volume provers and associated technology have been in use throughout the world by weights and measures jurisdictions and industry for meter verification (pulse-generating meters) since the 1980's. However, field standard test measures and large volume graduated neck-type provers, as described in NBS Handbook 105-3, are most commonly used as field standards by weights and measures officials in the United States.

The American Petroleum Institute (API) documented the proper design and use of small volume provers in 1988: "Manual of Petroleum Measurement Standards," Chapter 4, Proving Systems, Section 3, Small Volume Provers, and Section 6, Pulse Interpolation. These publications should be referred to for additional information.

A major effort was undertaken by Brooks Instruments in 1992 to obtain recognition of the small volume prover as a field standard. Subsequent field tests were conducted, calibration procedures were developed, and Examination Procedure Outlines for meter verification were modified to address unique capabilities of the small volume prover. This publication is the result of a draft prepared by Timothy W. Scott of Brooks Instruments in 1994.

Favorable results have been achieved through comparison between graduated neck-type provers and small volume provers when used in meter verification. Improvements in the volume measurement system in the United States may be possible through the use of small volume prover technology over the use of graduated neck-type provers. Improvements have been suggested in the following areas:

- 1) Operator safety (ground level operation);
- 2) Environmental safety (closed system, minimized spill, and minimized vaporization);
- 3) Improved efficiency (automated operation and calculations, reduced time required for test);
- 4) Improved accuracy and uniformity (automated calculations and documentation, evaluation of meter linearity at different flow rates, multiple meter factor determination for preset linearization); and
- 5) Reduced uncertainties (elimination of meniscus reading and effects due to level conditions).

Note regarding units of measure:

The SI unit of volume is the cubic decimeter (dm^3) or the cubic centimeter (cm^3). The Twelfth General (International) Conference on Weights and Measures redefined the litre [herein spelled liter] as a "special name for the cubic decimeter," but agreed to permit the continuance of the terms liter (L) and milliliter (mL), except in association with measurements of the highest precision. The commercial measurement system in the United States primarily uses gallons (gal) and cubic inches (in^3). Since commercial applications in the United States use units other than SI or other accepted metric units, this document references common units in current use.

Trade names used in this paper do not imply recommendation or endorsement by the National Institute of Standards and Technology.

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**SPECIFICATIONS AND TOLERANCES
FOR REFERENCE STANDARDS AND FIELD STANDARD
WEIGHTS AND MEASURES**

7. Specifications and Tolerances for
 Dynamic Small Volume Provers

These specifications and tolerances are recommended as minimum requirements for standards used by State and local weights and measures officials and others in the verification of meters used in quantity determinations of liquid commodities.

Key words: field standard small volume prover; K-factor; meter factor; prover pass; double chronometry; pulse interpolation; reference volume; specifications; standards; tolerances; volumetric standards; volumetric specifications and tolerances; weights and measures.

INTRODUCTION

Dynamic small volume provers permit performance testing or verification of commercial liquid measurement devices in an operational line for compliance with the requirements of commercial device requirements without interrupting normal process flow. Use of these standards at all appropriate levels of manufacture, distribution, and weights and measures inspection will help promote accuracy and uniformity in commerce.

Dynamic small volume provers consist of a calibrated precision bore cylinder with a displacer or fluid separation device with precision displacer detectors. Corrections for temperature and pressure are applied to the small volume prover and to the product used during calibration.

These field standards are suitable for use with liquid measurement devices that produce a pulse type output signal. Meter pulse discrimination using pulse-interpolation counter(s) or other approved techniques that increases the resolution is required. Pulse interpolation electronics permit exact time determination and pulse counting which provides high accuracy proving with a smaller volume and a smaller number of flowmeter pulses.

Because small volume provers are comparatively compact in both size and weight, they may be portable, such as truck or trailer mounted.

1 Scope

1.1 “Field Standard” Classification

These specifications and tolerances describe the essential elements of a dynamic small volume prover and provide operating details for the various types of small volume provers that meet acceptable standards of repeatability and accuracy for use as field standards in meter verification activities.

1.2 Retroactivity

These specifications are not intended to make obsolete those field standards fabricated to meet other specifications. All new provers must meet these requirements prior to certification for legal use.

1.3 Safety Considerations

This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Commercial liquid-measuring devices, tested with these small volume provers, are typically used to measure quantities of petroleum products. Petroleum products are known hazardous materials and hazardous wastes. The user is

encouraged to obtain Material Safety Data Sheets (MSDS) from the manufacturer of any product encountered. Federal and local safety and disposal regulations concerning hazardous materials should be reviewed by the user.

Appropriate safety precautions must be followed. Proper venting of air/gases and draining of liquid from the prover shall be performed to meet the department of transportation specifications prior to transporting portable provers on public highways.

2 Reference Documents

2.1 OIML¹

2.1.1 Fourth Preliminary Draft, International Document on Measurement of Volume of Liquids, Hierarchy Schemes, December, 1987.

2.2 NIST²

2.2.1 Handbook 44, Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices, see current edition, published annually.

2.2.2 Handbook 145, Handbook for the Quality Assurance of Metrological Measurements, 1986 or later edition.

2.3 API³

2.3.1 Manual of Petroleum Measurement Standards, Chapter 4, Proving Systems:

2.3.1.1 Section 3, Small Volume Prover.

2.3.1.2 Section 6, Pulse Interpolation.

2.3.1.3 Chapter 12, Calculation of Petroleum Quantities.

3 Terminology

Base Volume. The base volume of a unidirectional small volume prover is the calibrated volume displaced between detectors in a single pass corrected to reference conditions of temperature and pressure. The base volume of a bi-directional small volume prover is the sum of the round trip volumes displaced between detectors corrected to standard conditions.

Detectors. Optical sensors or electronic switches used to start/stop counters and determine the calibrated section of the prover.

Double Chronometry. A pulse interpolation method used in small volume provers to provide for fractional meter pulse counting.

Frequency. The number of signal repetitions or cycles occurring in a time period of one second; this number is represented in hertz.

K-Factor. A value obtained by dividing the number of meter signal pulses collected during the proving sample by the actual volume.

$$K\text{-Factor} = \frac{\text{Meter signal pulses}}{\text{Corrected prover volume}}$$

Meter Factor (MF). A value obtained by dividing the volume of liquid passed through the meter (corrected prover volume) by the registered meter volume.

$$MF = \frac{\text{Corrected prover volume}}{\text{Registered meter volume}}$$

Pressure Rating. The maximum operating pressure the unit is rated in accordance with ANSI standards.

Prover Pass. A single pass of the displacer through the calibrated section.

Pulse Interpolation. A pulse counting technique used to calculate the total number of meter pulses between two detectors; including fractional pulses.

Reference Volume. The calibrated volume of the prover determined by the waterdraw calibration method at a specific reference temperature and pressure.

Tolerance. Maximum permissible error. A value fixing the limit of allowable error or departure from the true performance or value.

Volume Correction Factor. A fixed calculation to adjust the displaced volume due to the effects of pressure, temperature, and API Gravity (or relative density).

Waterdraw. The calibration procedure used to determine the actual reference volume of the small volume prover.

4 Specifications

4.1 Nominal Sizes

Small volume provers are available in a number of sizes based on connection and flow rate capabilities. The measuring section of common sizes are as follows:

20 L (5 gal), 40 L (10 gal), 57 L (15 gal), 60 L (15 gal), 120 L (30 gal), 159 L (42 gal), 250 L (65 gal), 318 L (84 gal), 650 L (170 gal).

The size of a small volume prover is selected on the basis of the maximum flow rate of the meter to be tested.

4.2 Reference Temperature

The temperature at which the small volume prover is referenced during calibration and during use for testing petroleum products is generally 15.56 °C (60 °F). Internationally, petroleum products are generally referenced to 15 °C.

4.3 Materials

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

4.4 Physical and Mechanical Properties

4.4.1 Suitability

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

4.4.2 Components

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

- 1) precision bore cylinder;
- 2) displacer piston, spheroid, or other fluid-separation device (designed such that the displacer velocity will be no greater than 5 feet per second);
- 3) a means of positioning and launching the displacer upstream of the calibrated section;
- 4) a displacer detector or detectors;
- 5) a valve arrangement that allows fluid flow while the displacer is traveling from one position to the opposite position;
- 6) pressure-measurement devices;

- 7) temperature-measurement devices;
- 8) instrumentation with timers, counters, and pulse-interpolation capability;
- 9) provisions for proper venting and draining.

4.4.3 Pressure testing

All prover units shall be hydrostatically pressure tested to 150% of the maximum pressure rating.

4.4.4 Hardware

Hardware, such as seals, valves, flanges, vents, and drains must not contribute to poor operation of the small volume prover. All valves shall operate freely and positively and shall not leak under normal operating pressures. Flanges or other provisions should be provided for access to the inside surfaces of the calibrated and prerun sections. The calibrated volume section of the prover, defined by the prover detector switches, must be designed to exclude any nozzle attachments such as vents or drains.

4.5 Workmanship, Finish, and Appearance

4.5.1 Construction

Design and fabrication of the prover shall insure that no pockets, dents, or crevices will be present which may entrap air or liquid, or impair the operating characteristics such as proper filling or draining of the prover.

4.5.2 Concentricity and Alignment

Care should be exercised to ensure and maintain proper alignment and concentricity of pipe joints.

4.5.3 Fabrication

The prover and associated valves, piping, gage, etc., shall be free of slag, scale, weld or solder splatter, grit, dirt, dents, interior rust, water or product residue, or any other foreign matter before shipment from the factory or before submission for calibration.

4.5.4 Fittings and Connections

All threaded fittings and connections, including plugs and caps, shall be thoroughly lubricated with a suitable nonhardening paste, or pipe joint tape, and shall not leak.

4.5.5 Internal surface

The interior surface of the prover shall be made from corrosion resistant materials or coated with a suitable material which will provide a hard, smooth, long lasting finish will reduce corrosion, will be impervious to liquids for which the prover will be used, and will prolong the life of the displacer or displacer seals in the prover.

4.5.6 Identification

Each standard shall bear, in a conspicuous place at minimum, the following information:

- 1) name and address of manufacturer;
- 2) model number;
- 3) nonrepetitive serial or identification number;
- 4) cylinder material identification;
- 5) material thickness; and
- 6) maximum pressure rating.

This information shall be engraved or permanently embossed on a metal plate which is permanently attached to the prover.

5 Tolerances (Maximum Permissible Errors)

5.1 Zero Tolerance

When small volume provers are calibrated, the actual volume must be reported noting specific reference temperatures and pressures. Since calibration values are available and used in meter verification, the nominal cylinder volume is not used and tolerances are not considered.

To achieve requirements in NIST Handbook 44 that state that the error of the standard be less than one-third of the smallest tolerance applied to the device being tested, the expanded uncertainty of the calibration is used in lieu of a tolerance. See Section 8 for additional information.

5.2 Normal Operation

Normal operation of small volume provers consists of five consecutive passes or round trips that repeat within 0.05 percent for meters whose pulse generation is very close to, or directly from, the measuring elements. Meters having a nonuniform pulse output may require increased number of passes or prover round trips.

6 Verification Requirements

6.1 Legal Requirements

The specifications and tolerances herein specified are intended to permit the use of the equipment in normal field testing operations as standards having assigned calibrated values. When small volume provers are used for commercial applications they must be inspected and verified by a NIST recognized laboratory, using appropriate test methods, with valid calibration reports provided.

In the event that a weights and measures jurisdiction does not have a laboratory with a Certificate of Traceability for that parameter, the jurisdiction may witness and accept calibration reports from other organizations if an on-site assessment is conducted and no deficiencies are identified.

6.2 Traceability

Field standards used for legal metrology shall be traceable to national standards through calibration in a laboratory recognized by NIST for the appropriate parameter, range, and scope.

Application Note: In the case of small volume provers, State laboratories have not established test facilities. Suitable test facilities and traceability must be established prior to use of a small volume prover for legal enforcement activities.

6.3 Calibration Reports

Acceptable accuracy and traceability to national or international standards shall be documented in a calibration report using accepted test methods. After a small volume prover is calibrated, the data sheets shall be used to prepare a certificate of calibration. The certificate shall state the calibration method used, the base volume or volumes, the expanded uncertainty, the reference pressure, the reference temperatures, the calibration medium (should be water), the serial numbers, and the date.

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

6.4 Initial and Periodic Verification

Small volume provers must be verified prior to use and rechecked as often as regulations or circumstances require, especially when damage is known or suspected.

A new small volume prover must be tested prior to use in service and at a 6-month interval thereafter. The calibration interval may be extended or reduced based on historical evidence up to the limit determined by State or local weights and measures regulations, but should not exceed 3 years.

If a small volume prover has not been in continuous use throughout the year and has been stored for more than a month, it is recommended that it be calibrated prior to a series of field tests unless evidence is available to support the stability

of the individual device. Periodic comparisons against calibrated graduated neck-type provers during a meter verification can be used to demonstrate continued stability between official calibrations.

7 Test Methods and References

7.1 “Calibration Kit”

The small volume prover system manufacturer must provide the necessary special accessories required to perform the system calibration.

7.2 NIST Handbook 145, SOP 26

SOP 26, Recommended Standard Operating Procedure for Calibration of Dynamic Small Volume Provers

7.3 API, Manual of Petroleum Measurement Standards, Chapter 4, Proving Systems

Section 3, Small Volume Provers (4.3.7), Calibration, of this API handbook covers the calibration of small volume provers. Much of the following text is taken from the referenced section.

7.3.1 General Considerations

A small volume prover must be calibrated before it is placed in service to determine its base volume (the calibrated volume corrected to standard conditions).

Small volume provers having a single shaft attached to only one side of the displacer will require calibration for both the upstream and downstream volumes as the two volumes will differ. Small volume provers having a single shaft continuous and uniform will require calibration from either upstream or downstream as the two volumes will be equal. Each calibration volume should clearly be stated on the calibration certificate. Small volume prover calibration methods include gravimetric, master-meter, and most commonly, the waterdraw calibration.

7.3.2 Waterdraw Calibration

The ideal environmental condition for the waterdraw process is a stable temperature controlled environment shaded from direct sunshine to allow the prover, field standard, and test liquid to reach an equilibrium temperature with stable conditions.

The ideal medium for calibration is water due to its high heat capacity, low compressibility, and low coefficient of thermal expansion as compared to petroleum liquids. The prover and fill lines must be free of foreign materials to prevent contamination of the water. Any other medium used in test measures changes the surface tension voiding the calibration.

The prover should be free of air and flushed to remove particulate; if necessary, run several passes. The temperature of the prover and the liquid need to be common and steady. Also, it will be necessary to check all valves, seals and displacer security, and ensure there is no leakage from or around the prover.

Temporary valves and small-diameter water lines may be used in calibration; however, quick response automated solenoid valves actuated by detector switches should be used. Precautions should be made to ensure that no water bypasses the field standard. Upon completion, all parties involved in witnessing the calibration shall check and sign the data recording sheets.

8 Uncertainties

8.1 Legal Applications

Uncertainties of the calibration must be evaluated according to the ISO Guide for the Expression of Uncertainties in Measurements,⁴ 1993 to ensure that the three to one accuracy ratio of NIST Handbook 44 is maintained. At this time, the acceptance tolerance for liquid measuring devices is 0.2 percent. Therefore, the relative expanded uncertainty for a small volume prover calibration should be less than 0.07 percent.

8.2 Sources of Variation

8.2.1 Accuracy

To achieve the required proving accuracy and repeatability, the minimum volume between detector switches depends on the uncertainty of the laboratory standard, discrimination of a combination of pulse-interpolation electronics, detectors, as well as flow rate, pressure measurements, and temperature measurements. Small volume prover calibration should utilize only a single field standard, or as few as possible, with a valid calibration report and a maximum expanded uncertainty ($k = 2$) of less than 0.02 percent.

8.2.2 Repeatability

The dynamic small volume prover must be equipped with accurate pulse interpolation electronics to achieve a repeatability of 0.02 percent during calibration. Repeatability problems may be the direct result of a leak in the proving system, which must be corrected before calibration can be completed.

The agreement of the observed volumetric values obtained during calculation is calculated as repeatability using the following equation:

$$\text{Repeatability \%} = \frac{\text{Value}_{\max} - \text{Value}_{\min}}{\text{Value}_{\min}} \times 100$$

API Chapter 4, Section 3, Sub-section 4.3.7.5 Notes: Repeatability is only one component of calibration accuracy. By filling the same field standards with the test runs made at an equal rate, an operator can complete a series of erroneous calibrations as the result of a consistent leak. This hazard can be reduced or eliminated by making an additional run at a rate change of at least 25 percent. With a changed flow rate, a different volume (after correction) that is outside 0.02 percent of the initial runs (after correction) indicates the possibility of a leak in the proving circuit, which must be corrected before calibration can be achieved. All corrected volumes at both flow rates shall agree within 0.02 percent of the minimum volume. This is true of both unidirectional and bi-directional provers.

Notes

1. OIML, L'Organisation Internationale Metrologie Legale, Bureau Internationale De Metrologie Legale, 11 Rue Turgot, 75009 Paris, France.
2. NIST, National Institute of Standards and Technology, Gaithersburg, MD 20899.
3. API, American Petroleum Institute, 1220 L St. NW, Washington, DC 20005.
4. ISO, International Standards Organization, Case Postale 56, CH 1211, Geneva 20, Switzerland.

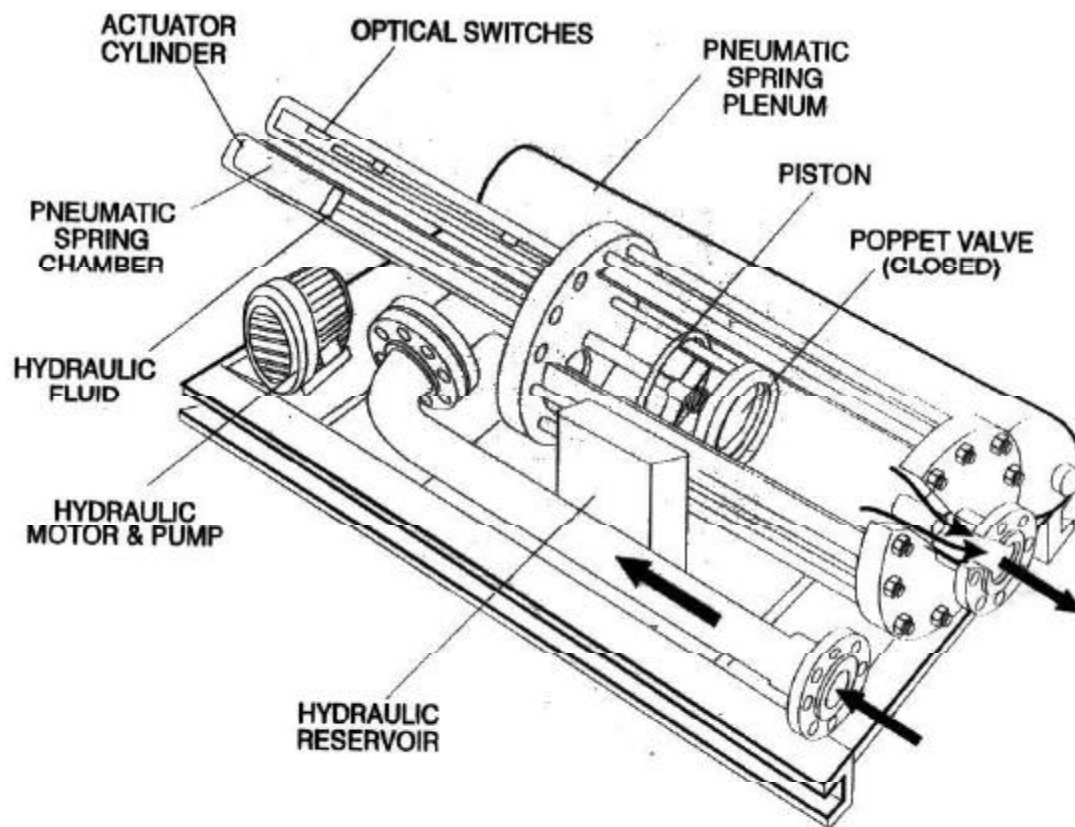


Figure 1. Example 1 of a Dynamic Small Volume Prover.

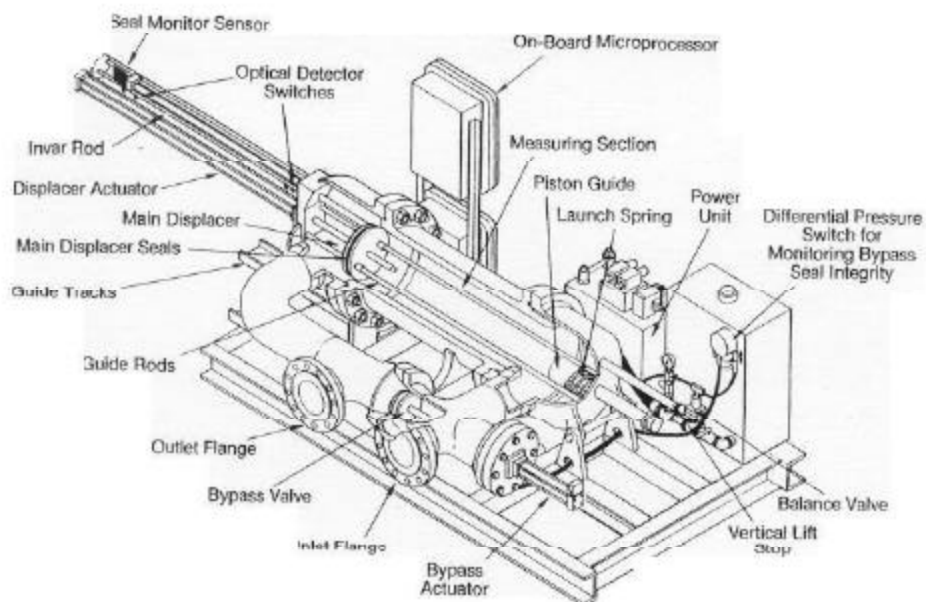


Figure 2. Example 2 of a Dynamic Small Volume Prover.

