Liquid Flow Provers

Class # 4090

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Introduction

The purpose for proving a meter is to calibrate the flow measured by a meter. Usually there are multiple parties involved in any fluid transfer. There is a seller, a buyer, and usually a middle, nonbiased, third party. The necessity of proving a meter depends on the value of accurate measurement for the product being handled. The ability to test a meter's accuracy is vital to petroleum measurement.

The objective of proving a meter is to determine each individual meter's factor.

$$\boldsymbol{Meter\ Factor = \frac{True\ Volume}{Indicated\ Meter\ Volume}}$$

This equation "divides out" the meter indication and "multiplies in" the corrected volume.

Most meters' flow curves are not linear; the calibration of the meter should be done over a range of the meters flow rates. Then the meter factor can be entered as an average over the varying flow rates. The meter factor is known as the "K-factor".

There are two K-factors to consider: Meter K-factor and the Prover K-factor.

- Meter K-factor is design data supplied by the meter manufacturer
- Prover K-factor is the correction for ambient conditions, for example, the factor for a fluid-flow meter to compensate for such conditions as liquid temperature and pressure change.

Calculations for prover design are determined from the meter factor. Most meters are designed to operate within a ±0.5% to ±0.05% accuracy or 'linearity' range. Meters start with a registered volume that is accurate to within ±0.5% to ±0.05% of the actual volume, when operated within the meters design parameters. However most of these meters have a 'Repeatability' of ±0.02%, meaning they will 'repeat' the inaccuracy within 0.02%. See the figure below: Figure 1.

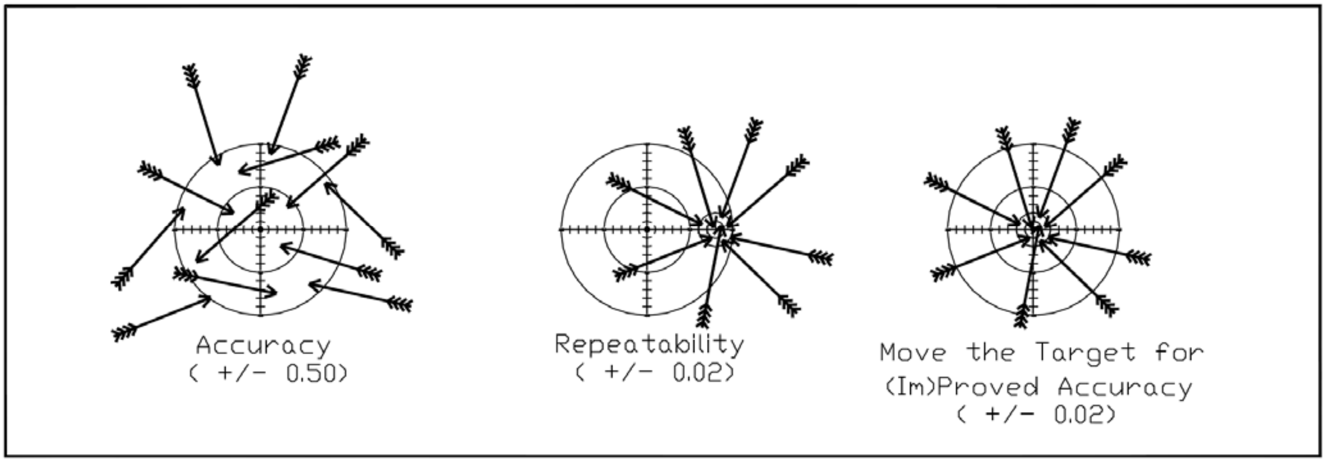

Figure 1

Types of Proving Systems

There are a variety of prover designs to choose from. In making this choice there are many variables when contemplating a prover design. Though cost is usually the most important determinant; overall size of the prover foot print is just as important. Other factors should include prover flow rates, fluid types, and maintenance costs; which are often overlooked. Request for Quotation for Supply of Portable Master Pipe Prover

There are two main classifications of proving: Static Proving and Dynamic Proving.

Static Proving

1. Gravimetric: Using a weigh scale
2. Volumetric: Using a calibrated Tank

Dynamic Proving

1. Volumetric: Using positive displacement meter prover
2. Master Meter: Using a calibrated meter

Of the listed proving types above; the positive displacement meter prover (Volumetric) is the most accurate and convenient to use. One of the considerable advantages to positive displacement meter provers is that liquid flow through the prover is continuous. Continuous liquid flow eliminates errors in starting and stopping the fluid flow; allowing for meter proving under actual operating conditions. Typical operating conditions could include typical temperatures, pressures, and flow characteristics.

Compact Piston Provers: The piston prover for liquid calibration consists of a long, thick walled, portion of pipe that is honed to a precise inside diameter and then lined with an electro-less nickel plating or stainless steel plating. A close fitting piston is used to displace the fluid that is passing through the meter. Optic sensors are used to trip the meter pulse counter. The meter pulses are then used for a known volume to calibrate a meter.

There are two types of conventional pipe provers, these are: Bidirectional Provers and Unidirectional Provers. These operate on the principle of the repeatable displacement of a known volume of liquid from a calibrated section of pipe between two detector switches utilizing a displacer, usually a sphere, which has a diameter that is slightly larger than the ID of the pipe. The displacer trips the detector switch; upon entering the measuring section, and then the flow computer begins to count meter pulses. Meter pulse counting stops when the displacer trips the 2nd detector switch.

Bidirectional Prover: Is designed to have the displacer travel in one direction then reverse back through the measuring section again. The displacer travels in one direction, actuating the first detector at the beginning of the calibrated section, the pulse signal from the meter sends a signal to the prover counter. All of the meter pulses are accumulated until the displacer actuates the detector at the end of the calibrated section, stopping the pulse signal to the prover counter. The displacer stops in a section where the flow can bypass the displacer. A valve assembly is utilized to reverse the fluid flow and sends the displacer back through the loop. The displacer actuates the first detector at the start of the calibrated section, the meter pulse signal is again sent to the prover counter. The counter continues to accumulate pulses until the displacer actuates the detector at the end of the calibrated section.

The bidirectional prover is constructed of pipe; which may be a straight section or folded to various configurations to meet space requirements. The base volume of a bidirectional prover is expressed as the sum of the calibrated volumes between detectors in two consecutive one-way passes in opposite directions, each corrected to standard temperature and pressure conditions. This is repeated x number of times to calculate the meter factor.

Unidirectional prover: This type is able to launch the displacer into a flowing stream and retrieve the sphere from the flowing stream without stopping and/or reversing the flow. A prover interchange is used to launch the sphere into the loop, upstream of the detector switch. The prover counter begins to record the meter pulses. When the sphere actuates the second detector the prover counter is stopped. These accumulated pulses represent the complete prover volume.

The sphere in Unidirectional provers move in one direction; which means, that the displacer only makes one pass through the measuring section. The interchange of the unidirectional prove, launches and receives the sphere;

utilizing a launch tee and a receiver tee. A set of hydraulic cylinders makes the interchange function flawlessly. Upon initiation of the “Prover” command a hydraulic ram retracts a seal. Upon full retraction a “kicker” ram pushes the sphere down to the launch tee. A “hold” ram is fully extended to temporarily prevent the displacer from traveling into the measuring section; this gives adequate time for the seal ram to fully seat. The seal, when seated properly creates a positive seal, at this point the hold ram retracts allowing the displacer to launch into the stabilized and steady flow in the measuring section.

The base volume in a unidirectional prover is the calibrated volume between detectors corrected to standard temperature and pressure conditions.

Prover Selection

Prover design starts with certain criteria, that is defined by the application. Provers can be stationary or mobile. Their design can be compact or spread out. Other criteria might be: Is the prover in-line or is it part of a central system? Is the prover to be in continuous service or isolated from the metered stream? Is the prover above or buried below ground, and does the prover require insulation? Can pulse interpolation be utilized?

Some other design characteristics to consider are minimum and maximum flow rates, temperature and pressure ratings, maximum allowable pressure drop across the prover, fluid properties, and any utilities available.

More often than not the prover selection is based off of past experiences, preferences, and more importantly – cost. The costs include maintenance costs as well.

Prover Sizing

The Volume of the measuring section is the distance between the detector switches, otherwise known as the calibrated volume of the prover. This is determined by the following determinants:

1. Overall repeatability of the proving system (0.05%)
2. Detector switch repeatability
    - The minimum calibrated length between detector switches depends on the accuracy with which the detector switch can repeatedly determine the position of the displacer and the desired discrimination of the prover system during calibration. (>0.02% repeatability)

$$minimum\ calibrated\ section\ length = \frac{displacer\ position\ repeatability\ (detector\ actuations)^2}{desired\ prover\ accuracy}$$

3. Minimum calibrated length

$$minumum\ calibrated\ section\ length = \frac{minimum\ volume\ of\ the\ prover}{area\ of\ the\ prover\ pipe}$$

4. 10,000 unaltered pulses
5. Resolution of meter pulses generator (pulses per unit volume)

$$calibrated\ volume = \frac{10{,}000\ pulses\ min.}{pulses\ per\ unit\ volume}$$

Displacer Velocity Calculation

The velocity of the displacer is dependent upon the internal diameter of the prover pipe as well as the maximum and minimum flow rates of the meters to be proved. The velocity of the displacer can be calculated as follows:

$$velocity = \frac{flow\ rate}{area\ of\ pipe}$$

Displacer velocity for a bidirectional prover is >5$^{f}/_{s}$.

Displacer velocity for a unidirectional prover is <10$^{f}/_{s}$.

Velocity of Displacer at Minimum Flow

The velocity of the displacer at minimum flow rates is also an important aspect of the prover design. The key is for the displacer to travel at a uniform speed in a steady flow. At low displacer velocities, especially in liquid with low lubricity, the sealing friction of the sphere to the ID of the pipe is higher; which could cause chatter, skipping, and/or slippage. Higher velocities might be necessary for liquids with poor lubricity e.g. LPGs and NGLs.

Minimum allowable displacer velocities are 0.5$^{f}/_{s}$ to 1.0$^{f}/_{s}$.

Measuring Section Diameter

Choosing the correct prover pipe diameter is dependent on design flow rate and the displacer velocity.

$$Prover\ Pipe\ Diameter = \sqrt{\frac{0.286\ x\ BPH}{displacer\ velocity}}$$

The selection of the pipe diameter and wall thickness should be based upon a nominal pipe wall thickness that meets the design operating pressure requirements of the system.

Bidirectional Prover

Generally the design of a bidirectional prover, Figure 2, is a “U” shape. Launch chambers are located on each end of the “U”; where the displacer launches from. The chambers can be horizontal (0˚), vertical (90˚), or at any angle in between (usually 22.5˚). The diameter of the launch chambers should be approximately 2 pipe sizes larger than the diameter of the measuring section. The length of the launch tubes is generally (3x) the diameter of the measuring section.
Either elevated launch chambers and/or ball stops can aid in positive launching of displacer into the launch chambers in low flow rate applications. At higher rates elevated launch chambers and/or ball stops may reduce the possibility of damage of the displacer.

In order to properly reverse the flow direction in the prover, while sealing, in a bidirectional prover a diverter valve is necessary. This allows the displacer to alternate its direction of passage through the measuring section. The diverter valve needs to have capabilities of double block & bleed method for positive verification of sealing. Automation of diverter valves can be accomplished using actuators. Actuators can be electric, hydraulic, or pneumatic to cycle the diverter valve.

Pre-run Length of the bidirectional prover is vital to the provers operation; it allows the displacer adequate time to travel while the flow stabilizes; which occurs after the diverter valve seats. Calculations dictate the length in time to where the valve will seat, up to the stable velocity, before the sphere actuates the first detector switch. Pre-run length is determined by this formula:

$$Prerun\ Length = (cycle\ time)x\ (maximum\ velocity)x\ (stabilization\ factor)$$

The stabilization factor is a safety factor; usually 1.25.

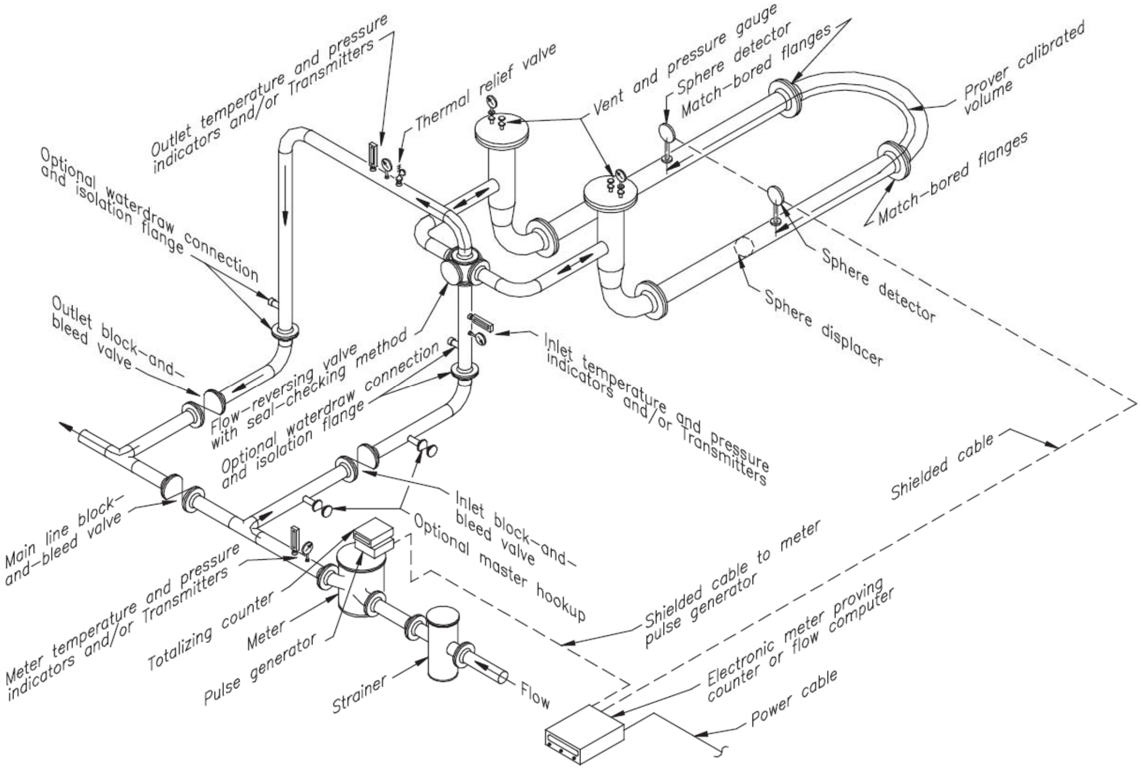

Figure 2

Unidirectional Prover

The unidirectional prover design, Figure 3, is unique in that it has the ability to launch and retrieve the sphere in a flowing stream without disrupting or reversing the flow. The interchange provides the mechanics to input the sphere back into the flow, for the next proving. The interchange utilizes a series of hydraulic rams to transfer the displacer back to the inlet side of the prover.

Hydraulic rams that transfer the sphere to the inlet side is also used to seal the prover. This requires a positive type of sealing. As the displacer travels to the interchange a set of steel ramps decelerates the displacer and guides it to transfer stage.

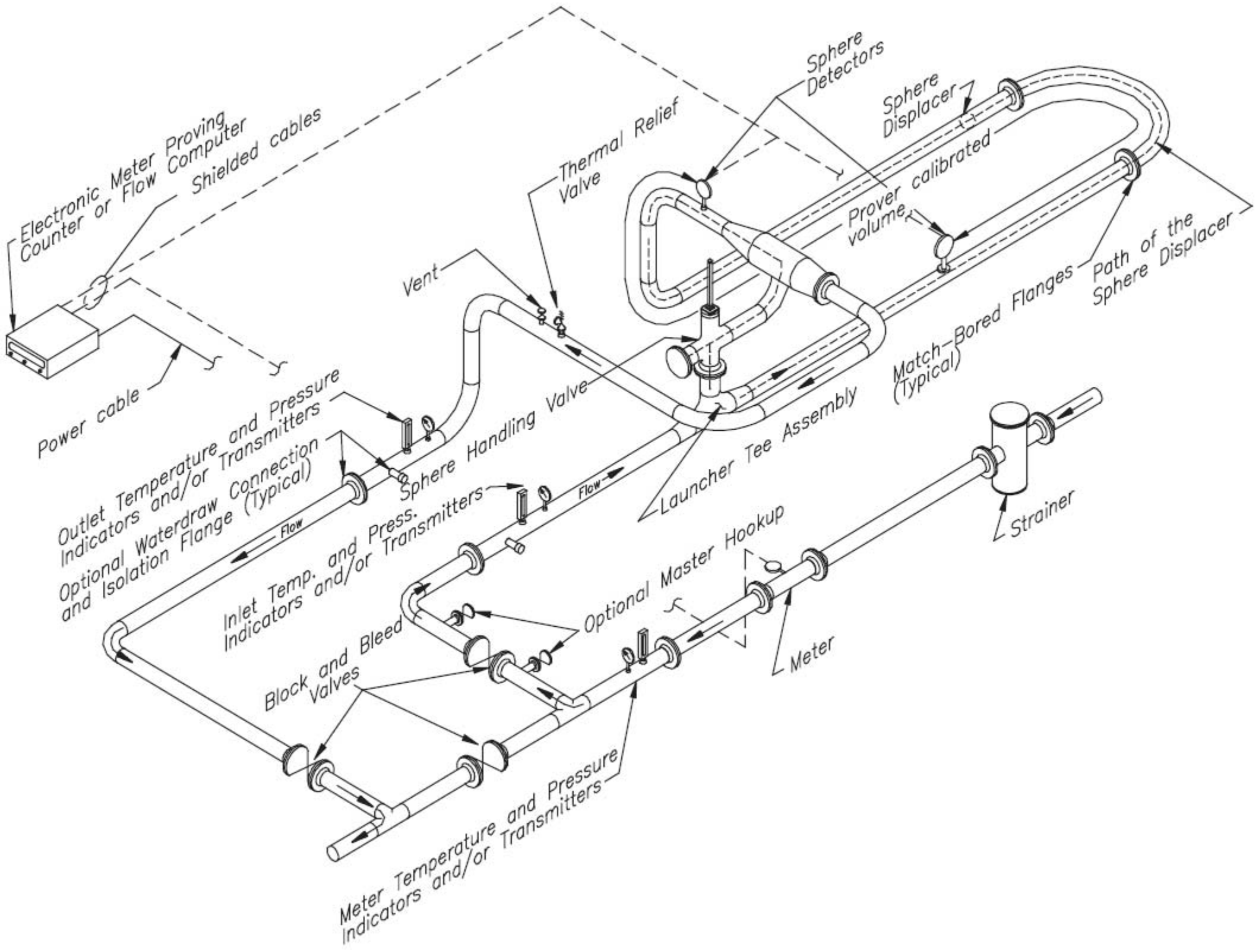

Figure 3

Detector Switches

A detector switch is an externally mounted device on the prover, the converts a mechanical signal to electrical signal, which has the ability to detect and repeat with in close tolerances, the displacer entrance and exit of the measuring section. The amount of fluid between the set of detector switches is the calibrated volume. The detector switches sends an electronic pulse to an electronic meter-proving counter that is connected to a flow meter pulse generator. There are two types of detector switches utilized on meter provers; mechanical and proximity type.

Mechanical Type detectors are normally used in spherical type provers. As the displacer contacts the detector switch plunger, this motion is converted into a signal which is transmitted to a switch. Mechanical type detector switches are inserted into the test liquid and are subjected to the corrosiveness of the liquid, as well as the pressure and temperature.

Proximity Type detector switches are used on piston type meter provers. These operate on an electrical or magnetic field being tripped by a flag. No portion of this style switch is subjected to the liquid.

Internal Coating

Internally coating the prover allows for a smooth passage for the prover displacer to travel. The type of internal coating is selected to provide for a hard, smooth, and long lasting finish which has to endure corrosive materials as well as wear from a sphere traveling inside the pipe.

Application of the internal coating should be done per the manufacturers specifications. The manufacturer will recommend a minimum anchor pattern or media blast specification to prepare the pipe for the internal coating.

External Coating

Externally coating the prover will reduce in corrosion, while prolonging the life of the prover. Applications where the prover is buried calls for a more adept coating solution.

Prover Displacer

The most common type of displacer is the elastomer sphere. It is manufactured of polyurethane, neoprene, or nitrile. It has a hollow center with one or two valves to inflate the sphere. The sphere is typically filled with glycol, water, or a mixture of glycol and water to prevent freezing. Care must be exercised to ensure that no air remains inside the sphere for compressibility purposes and to provide the sphere with negative buoyancy. Once the sphere is filled, it is inflated, generally, to 2-4% over the pipe inside diameter for normal proving operation.

Excessive inflation of the sphere may result in sticking of the sphere, damage to the sphere, excessive wear of sphere or internal coating, and increased pressure drop across the prover. These effects are more pronounced in the smaller diameter provers. Under inflation can result in fluid bypass around the sphere causing inaccuracies in the proving volume.

Calibration

The prover has to be calibrated to establish a known volume between the detector switches. This is normally done with a water draw calibration method according to API MPMS Chapter 4 & 12.