LIQUID FLOW PROVERS (Conventional)
Class Number 252

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Introduction

Flow meters need to be calibrated for accurate measurement! To understand this statement simply consider the equipment used and applications where accurate metering is demanded.

Positive displacement (PD) meters measure product flow by displacing discrete ‘parcels’ of product with each revolution of the meter. Turbine meters measure product flow by inferring volumetric throughput based on the assumptions that volumetric flow is proportional to average stream velocity, and average stream velocity is proportional to rotor angular velocity.

Manufacturers achieve defined performance characteristics by producing meter component parts to specific tolerances. Tolerances equate to uncertainty and, therefore, a manufacturer can only claim a ‘nominal’ throughput per revolution of a non calibrated metering device.

Uncertainty is further compounded by affects of product and process characteristics. High viscosity products affect meter performance differently than low viscosity products. Thicker, more viscous products can benefit P.D. meter performance by reducing slippage through meter clearances. Yet the same products produce reduced performance in turbine meters by creating a larger boundary layer buildup on pipe wall surfaces and meter internals which reduces the effective cross-sectional surface area and increases product velocity. Consequentially, meter rotor angular velocity increases registering a higher throughput than actual. Temperature and pressure variations cause expansion or contraction which affects both the product and meter equipment components. The presence of foreign matter or entrained air in product further increases the uncertainty of measurement.

To reduce uncertainty, it is necessary to ‘prove’ meter performance. Ideally, this is achieved under actual operating conditions. Proving is accomplished by comparing a meter’s actual registered throughput to a known reference volume. The ratio of known volume to registered volume is a dimensionless number called “meter factor”.

A typical meter/prover arrangement is shown in *Figure 1*. Product flowing through the meter is routed through the proving device before being returned to the main flow line. Utilizing an arrangement of valves, a pulse generator and gating devices (detectors) a comparison of metered throughput to known volume can be obtained.

Meter proving can be carried out using a variety of proving devices, including tank provers, master meter provers, small volume provers and pipe provers. This paper focuses on key design considerations for conventional pipe provers. API defines conventional pipe provers as “volume standards for proving liquid meters that generate at least 10,000 unaltered pulses during a proving pass.”

Uni-directional and bi-directional provers are the two most common types of conventional prover. Both typically utilize a sphere to displace the known prover volume to compare to the registered volume of a flow meter.

In a uni-directional prover the displacer makes one pass, traveling in a single direction to complete a prove run. The prover inlet and outlet are fitted with a launching tee and separator tee respectively. These assemblies are connected by an interchange valve which functions to receive, hold and launch the sphere at different phases of the prove cycle *(Figure 2).* In a bi-directional prover the displacer makes two passes, traveling in the forward and then reverse direction to complete a prove run. A four ported diverter valve connects the prover launch chambers which are located at the beginning and end of the prover piping. Cycling the diverter valve reverses the flow direction through the prover piping while maintaining the physical prover inlet and outlet connections.

There are four primary design criteria to consider for conventional pipe provers:

Displacer Velocity
Prover Volume
Diverter Valve Sizing
Pre-run Pipe Length

Displacer Velocity

The maximum recommended displacer velocity is 5 feet per second for bi-directional provers, and 10 feet per second for uni-directional provers.

Lower velocities are required in bi-directional provers to prevent hydraulic shock from occurring when the diverter valve is cycled to reverse flow direction. The 5 feet per second limit is based on empirical data. Higher velocities can be achieved in bi-directional pipe provers if additional consideration is given to dampen the effects of hydraulic shock by increasing the diverter valve cycle time and decelerating the displacer at the end of a prover run.

Since flow direction is not changed in uni-directional provers higher velocities are permissible. The 10 feet per second limit is also based on empirical data. Above this limit problems associated with increased pressure drop can be experienced. Turbulence through the interchange valve can also cause the displacer to remain in buoyant suspension making it difficult to launch.

Low end velocities can also present operational problems when frictional forces become more dominant and cause the displacer to "jitter". This can be particularly problematic for low lubricity products such as LPG, and where the prover construction includes a lot of pipe bends. As a general rule, low-end velocity should be limited to 0.5 feet per second.

Displacer velocity is determined by dividing product flow rate, expressed in cubic feet per second, by the internal cross-sectional area of the pipe, expressed in square feet, or:

$$\text{Maximum Velocity, fps} = \frac{BPH \text{ x } 0.286}{(\text{I.D. inches})^2}$$

Prover Volume

Two key criteria apply for determining prover volume. Firstly, to achieve 0.02 percent (± 0.01 percent of average) repeatability during calibration, based on number of pulses generated between detectors. Secondly, the distance between detector switches should be sufficient to provide 0.02 percent repeatability based on detector switch resolution.

To determine prover volume based on generating 10,000 unaltered pulses it is necessary to know the nominal pulse output per unit volume (K-factor) for the meter being proved. The ratio of 10,000 to nominal K-factor yields the required prover volume, e.g. a 6 inch turbine meter with a nominal K-factor of 1050 pulses per barrel requires a minimum volume between detectors of 9.52 barrels (10000/1050 = 9.52).

This volume can be converted to linear feet by expressing it in cubic feet and dividing by the internal cross-sectional area of pipe, expressed in square feet, or

$$\text{L (Linear distance between detectors), ft} = \frac{\text{Barrels x } 1029.88}{(\text{I.D. inches})^2}$$

To verify that the length between the detectors is sufficient to achieve 0.02 percent repeatability based on detector switch resolution it is necessary to consider the maximum possible difference in length that can occur for a round-trip. The maximum distance traveled on a single run is defined as $L + 2r_d$. The minimum distance traveled is $L - 2r_d$. Subtracting these values provides the largest possible difference ($4r_d$) on a round-trip. To achieve 0.02 percent repeatability, based on detector switch resolution, the minimum length between detectors is calculated by dividing $4r_d$ by 0.02 percent (0.0002). *Figure 3* provides an example based on a switch resolution of 1/64".

The theoretical calculation of detector resolution r_d is a function of switch protrusion through the pipe, detector plunger diameter, the tangential relationship to displacer surface, and switch actuation repeatability. This complex relationship is compounded with other variables such as displacer durometer, pipe and fittings tolerances, and pipe configuration to affect prover repeatability. As is often the case, empirical results based on field experience can be used to supplement theory. In general, 30 feet is considered an acceptable distance between switches for achieving repeatability. At this length the allowable error for detecting displacer location inside the pipe is close to 1/64-inch. The allowable error reduces proportionally as the length between detectors is reduced, making it more difficult to achieve repeatable performance. Shorter distances between detectors can be utilized on conventional pipe provers if careful consideration is given to prover design and construction.

Diverter Valve Sizing

The diverter valve is the main component of a bi-directional prover. Its selection impacts flow capacity, pressure drop, and prover pre-run length.

Diverter valves should be selected based on limiting product velocity to 15 feet per second across the valve. Velocity can be calculated using the simplified formula,

$$\text{Max Velocity } = \frac{\text{BPH x } 0.286}{(\text{I.D. inches})^2} \leq 15 \text{ fps}$$

In addition the manufacturer's published sizing data should be consulted when selecting a diverter valve. Information is typically provided on flow rate limits, pressure drop, torque, and turn requirements. Diverter valves can be fitted with a variety of actuators including mechanical, electrical or hydraulic types. Actuation times can be enhanced using speed-increasing gearboxes. Diverter valves should incorporate a means to verify seal integrity during proving to ensure no leakage occurs across the valve seats. Manual cavity bleed systems or differential pressure sensing devices can be used to accomplish this check.

Uni-directional provers utilize an interchange valve instead of a diverter valve. The interchange valve assembly includes a suitably sized seat ring to allow passage of the displacer during the transfer process. Like a diverter valve the seat ring should include a means to verify seal integrity during proving. The valve assembly usually includes access for sphere handling.

Pre-Run Pipe Length

The diverter or interchange valve must be completely cycled and seated prior to the start of a prove run to ensure that all metered product is being compared with the prover's reference volume. The pre-run pipe length should be sized to allow this to happen. The pipe configuration should also provide stable velocity conditions prior to the displacer reaching the detector.

Pre-run piping is only required at the inlet end of a uni-directional prover. Its length is dependent on maximum sphere velocity and the speed of operation of the launching mechanism.

For a bi-directional prover, pre-run piping is required at both ends of the prover. Its length is determined by multiplying half the valve cycle time by the maximum product velocity. Designers often add a factor of safety to be conservative when defining pre-run length. This may include adding an additional ½ second to the valve cycle time or adding extra pipe length.

$$\text{Bidi pre-run length} = \left(\frac{\text{cycle time}}{2} + 1/2 \text{ second} \right) \text{x Displacer Velocity}$$

If diverter valve cycle time is 5.4 seconds and displacer velocity is 4.97 feet per second, pre-run pipe length should be 15.9 feet.

$$\text{Bidi pre-run length} = \left(\frac{5.4}{2} + 1/2 \right) \text{x } 4.97 = 15.9 \text{ ft.}$$

For bi-directional provers, pre-run pipe is measured from the point where pipe diameter reduction occurs at the launch chamber to the centerline of the detector *(Refer to Figure 4).*

In addition to the four design criteria discussed above, there are five component design considerations that require attention to ensure proper application of conventional pipe provers.

Pipe Schedule
Launch Chambers
Detector Switch
Displacer
Internal Coating

Pipe Schedule

Selection of pipe schedule is based on the process parameters defined for the proving application, and the specific design code to which the prover must be built. The designer must calculate the required pipe wall thickness in order to determine displacer velocity and prover measuring section volume. Design codes typically follow industry standards such as ANSI B31.4 - Liquid Transportation Systems, ANSI B31.3 - Chemical Plants and Petroleum Refinery Piping, or are specific to a particular company standard. Company standards tend to be more conservative than industry standards.

Launch Chamber

Launch chambers provide an access point for installing and removing the displacer in bi-directional provers. They also facilitate displacer launching at the start of a prove and deceleration of the displacer at the end. They are typically sized at two pipe sizes larger than the measuring section pipe, and can be mounted vertically, inclined or horizontally. The enlarged flow cross sectional area causes the displacer to decelerate as the product flows around it. Gravitational forces contribute to displacer deceleration and launching, particularly when mounted in the vertical plane. Launch chambers are typically three displacer diameters in length but this may vary based on the orientation of the chamber, and whether other accessories are part of the design. Horizontal launch chambers require a inclined ramp device to aid the launch process. The incline ensures the displacer rolls to the prerun end of the chamber prior to launching.

Launch chamber design should also incorporate a deflector device at the nozzle opening to the diverter valve to prevent the displacer from being "pulled" into the nozzles by the flowing product. Launch chamber quick opening closures should be fitted with a safety mechanism to prevent them from being opened when pressurized.

Uni-directional provers utilize a separator tee and launch tee rather than the launch chambers described above for the bi-directional prover. The separator tee is located at the outlet of the prover. Typically, liquid velocity through the separator tee should not exceed 5 feet per second. The launch tee is located at the inlet of the prover. It should be designed to provide a smooth piping transition into the prover. The assemblies should be designed to ensure dependable separation and launching of the displacer from/to the flow stream for the complete flow range of the prover.

Detector Switches

Two detector switches are required to define the prover volume, one located at each end of the prover measuring section. Additional detectors may be installed to provide redundancy and/or added flexibility to the prover for calibrating meters with different performance characteristics. Detectors may also be installed to signal displacer location at the end of a prover run. Detectors should have a highly repeatable actuation point to ensure that displacer location is detected within 0.02 percent of the volume between the detectors.

Altering detector actuation depth changes the position at which the displacer is located, and consequentially affects prover volume. For bi-directional provers the round trip (2 way) displacer travel compensates for a change in actuation depth. This is not the case for uni-directional provers, and it is recommended to recalibrated them as soon as practical after changing a detector.

Displacers

Sphere type displacers are most often used with conventional provers. Material selection is based on compatibility with the product being metered. Manufacturers' data sheets should be consulted for verification of material suitability. Consideration should also be given to quantities and types of additives (MTBE) present in the base product.

Polyurethane, nitrile and neoprene are three common sphere displacer elastomers. For low temperature applications where suitable sphere material is not available, a piston type displacer can be designed with appropriately selected mechanical seals. Piston provers are designed as straight runs of pipe since the piston cannot pass around a pipe bend.

Prover spheres range from 2 inch to 36 inch in diameter. Sizes above 2 inch tend to be inflatable to provide the resilience for the displacer to handle pipe bends and irregularities in concentricity. Inflation rates are usually 2 percent to 4 percent above the internal diameter of the measuring section pipe. A mixture of glycol and water should be used when inflating the sphere to provide a more stable medium, less prone to the affects of temperature changes. Air should be completely evacuated from the sphere cavity to avoid problems with compressibility when the sphere is subjected to the product line pressure. The presence of air can also increase sphere buoyancy making it difficult to launch in light products like LPG.

Sphere displacers should be properly stored to prevent deformation of shape, and exposure to direct sunlight or chemical attack. They should be hung in a sling or supported in a cradle to distribute their weight and prevented flat spots occurring.

Internal Coating

Provers are primarily coated internally to protect against pipe corrosion which can lead to a change in the prover's calibrated volume and sealing integrity. The coating also reduces frictional drag on the displacer which results in smoother travel and less wear on it. Provers constructed of stainless steel or applications where exposure to corrosive environment is avoided (i.e. prover packed with product) are sometimes supplied without an internal coating.

Two types of coating are commonly applied: an air dried epoxy phenolic or a baked on phenolic. Both provide a tough durable coating when applied correctly. The air dried epoxy gives greater flexibility to a manufacturer since it does not require access to an oven for curing. Phenolic coatings are capable of higher temperature services than the air dried epoxy. Customers preference based on experience is often the driving force when specifying the internal coating.

Calibration

The waterdraw method is the preferred calibration technique for conventional provers. It involves displacing or "drawing off" the volume of water between the prover detectors into field standard test measures which are calibrated traceable to a national standard. *Figure 5* shows a typical waterdraw setup. Clear, deaerated water is selected as the test medium because of its stable characteristics, availability, and the relatively low effect its viscosity and surface tension has on drain time through the field test measure.

The base volume between detectors is obtained by adding the volumes from each test measure filled during the prove pass. The observed volume of each test measure is individually corrected to its actual volume at 60°F to obtain the prover base volume. For bi-directional provers base volume is defined as the round trip volume.

Calibration repeatability is achieved by obtaining two or more consecutive runs, after correction, within 0.02 percent of the average base volume. A third run at a 25 percent change in flow rate should be carried out to verify the absence of a consistent leak.

Where waterdraw calibration is impractical due to remote conditions, the master meter calibration technique may be utilized for prover calibration. Using a master meter and water or the actual product the pulse output from the meter is gated by the detector switches to register the prover volume. This method adds one extra link in the traceabilty chain back to the national standard. Inherently it is a less accurate method for calibrating conventional provers.

Conclusion

Flow meters need to be calibrated for accurate measurement. For over forty years the conventional pipe prover has been the primary calibration device for proving liquid flow meters. Its reliability, relatively simply construction and ease of use continue to make it the device of choice for calibrating petroleum liquid flow meters under actual operating conditions. The design consideration summarized in this paper have evolved from the experiences of a field proven device. Implementing them will ensure the repeatable and reliable performance expected of conventional pipe provers.

References

Jakubenas, Peter P. “Liquid Flow Provers (Conventional)”, ISHM Proceedings 1998.

Mentz, Charles J. “Liquid Flow Provers (Conventional)”, ISHM Proceedings 1994.

Manual of Petroleum Measurement Standards, Chapter 4 – Proving System, Section 2, Conventional Pipe Provers.

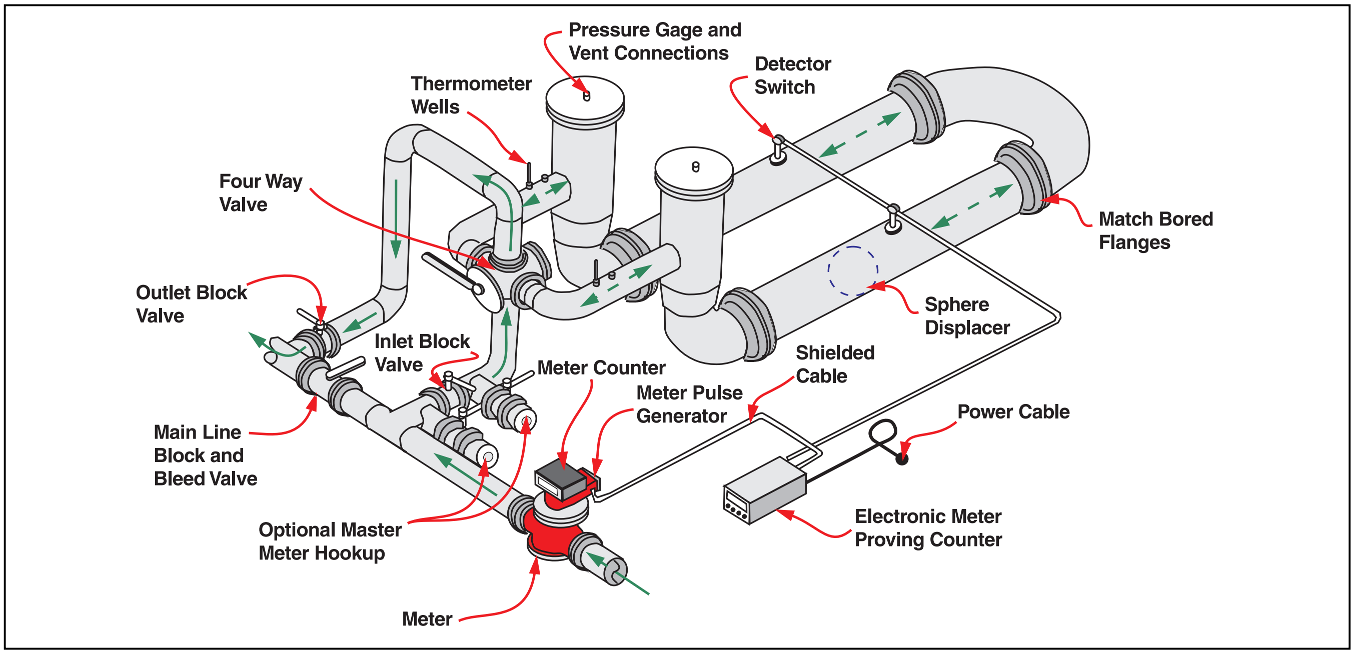


Figure 1

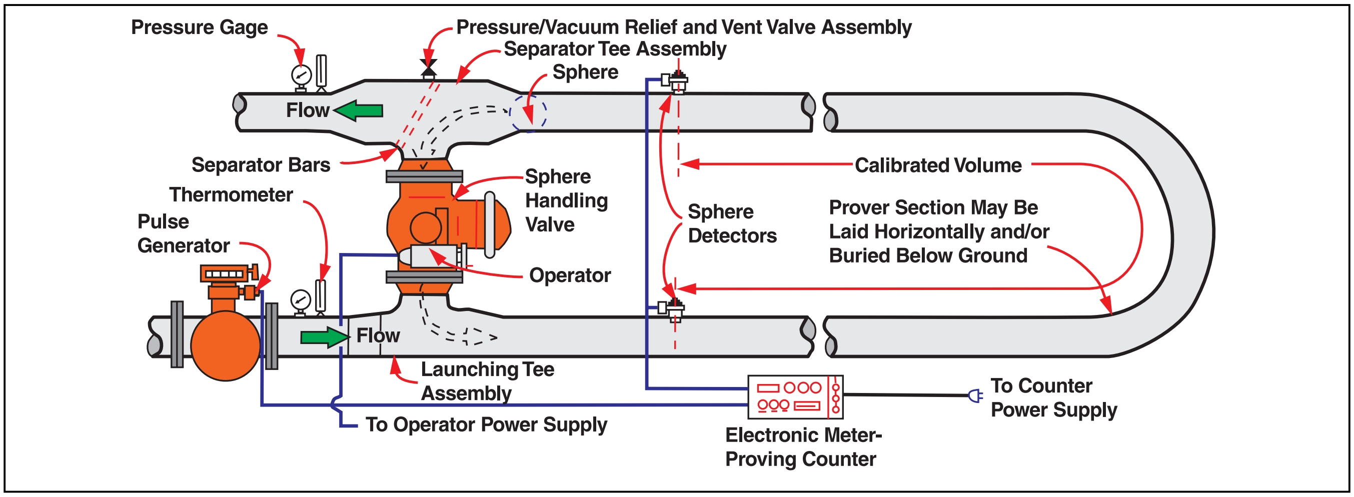
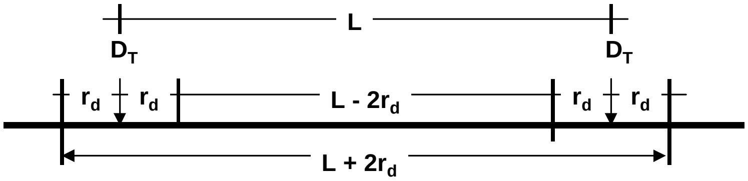


Figure 2



Max. Possible Difference in Length for Round Trip is $4r_d$ $\left(L + 2r_d\right) - \left(L + 2r_d\right) = 4r_d$

For 0.02% Repeatability $L = 4r_d/0.0002$

$= 20{,}000r_d$

If r_d = 1/64" Then $L = \frac{4 \times 0.015}{.0002 \times 12} = 25$ Ft.

Figure 3

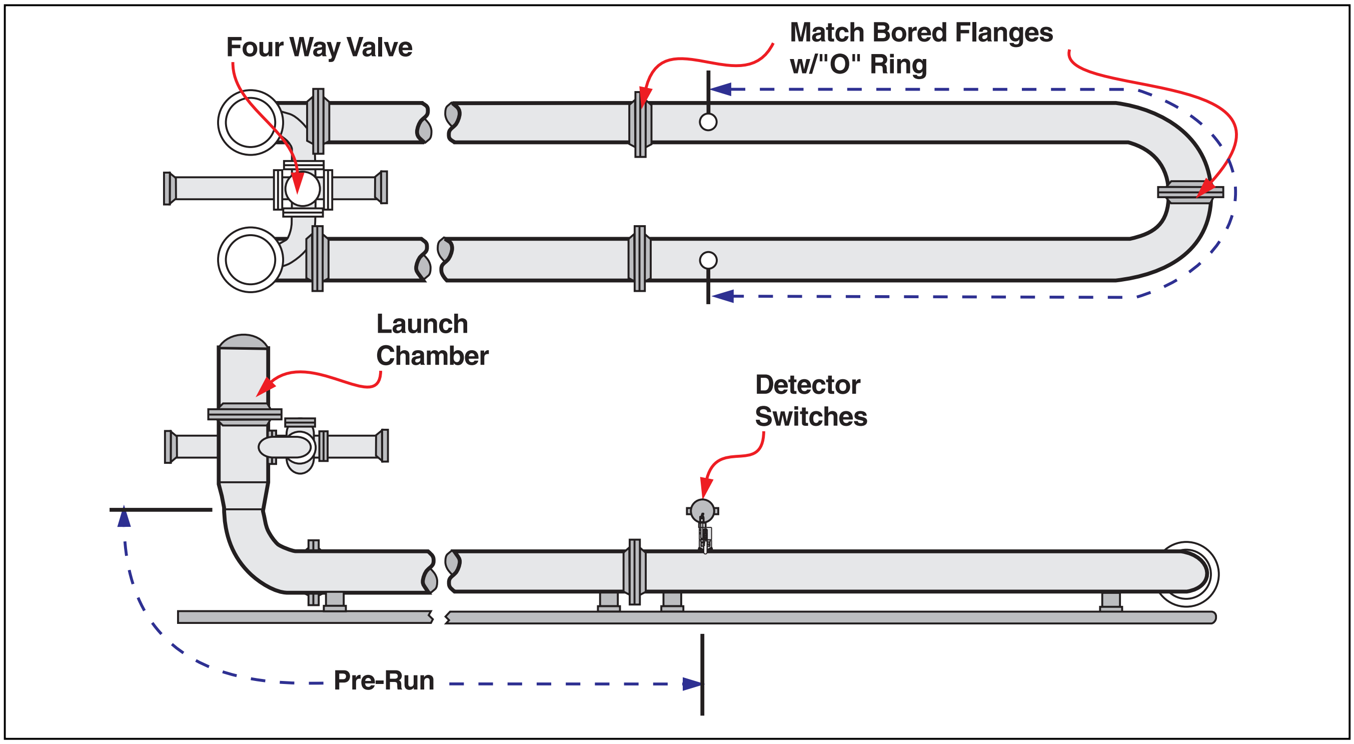


Figure 4

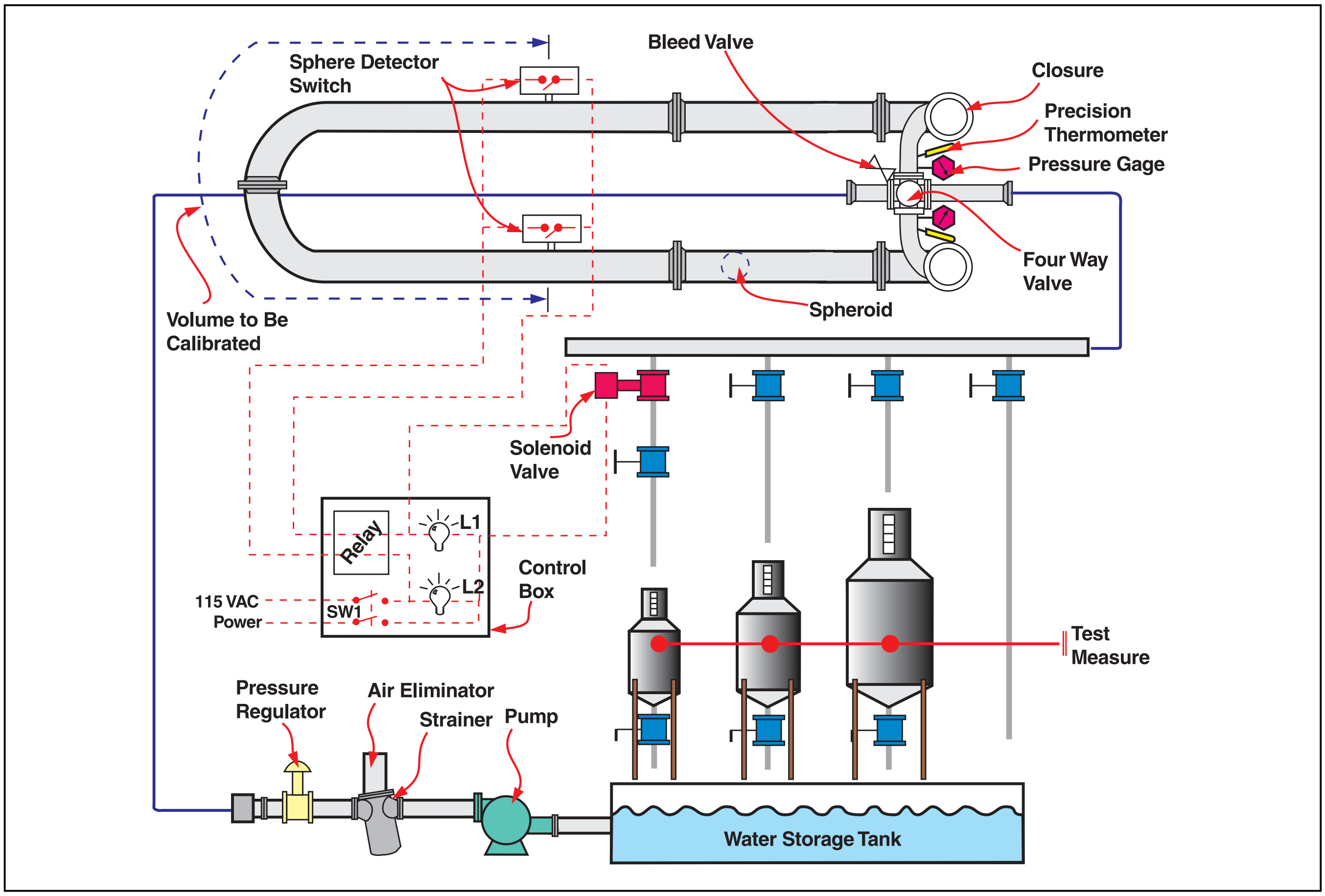


Figure 5