FUNDAMENTAL PRINCIPLES OF DIAPHRAGM METERS

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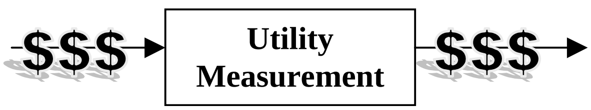
Introduction

Natural gas measurement is the vertebrae of any natural gas utility. Without the ability to measure, it would be impossible to account for the flow of gas from receipt to delivery. Very much like an accountant that labors to keep the ledger balanced, a utility needs metering to balance the gas producer's receipts against the end customer delivery.



The first natural gas utilities did not have the ability to measure their gas deliveries. The initial high costs and slow growth of the industry naturally gave way to the need to measure the delivered energy. Today utilities spend millions of dollars to install, maintain, and upgrade their "cash registers." Meters are placed throughout the transmission and distribution systems all in an effort to balance the inflows and the outflows.

Natural gas measurement today is accomplished through the use of different types of meters. Positive displacement meters measure the actual volume of gas displaced through them. Diaphragm meters are one type of positive displacement meters and will be discussed throughout this paper.

This paper will present basic operation principles, accuracy, rangeability, and benefits of diaphragm metering technologies used throughout the natural gas industry today.

History

In 1792, the process of manufacturing gas from coal was introduced in England. Not surprisingly, the first gas meters were developed in England after the founding of the first gas company in London in 1808.

The first gas company, The Gas Light Company of Baltimore, was chartered in 1816 and gas was introduced commercially to the United States. In those so called "good ole days," meters were unknown and gas was sold more or less on an hourly basis by contract. Each customer was charged equally regardless of the actual gas consumption. Gas company inspectors would tour the city at night and rap on the walk or curbs outside of the homes to indicate to gas light customers that their contract time had expired and the lights were to be extinguished. If the customer ignored the warning, the inspector would turn off the service. This billing structure was not successful. Costs were high and most consumers did not want to subsidize other less responsible end users. The utility also had no way to account for theft and leakage.

This practice was later changed and the gas light customers were charged for the quantity of the gas used based on the number, and possibly the size of light burners in the homes. Thus, the first gas meters developed were rated as "Five Light," "Ten Light," etc. A gas burner was based on a consumption of 6 cubic feet per hour.

Positive Displacement Measurement

Measurement principles relying on positive displacement have been employed for many years. Positive displacement meter are mechanical devices which capture and release a know volume of gas. This cyclical process is repeated and counted on a mechanical device. Two such meters that employ the positive displacement method will be discussed in following sections.

Meter Developments

The first practical positive displacement meter was the revolving drum, water sealed gas meter developed by Samuel Clegg in England in 1815. The wet drum meters were first used to measure gas plant send outs, with meter diameters up to 16 feet with proportional lengths. Particularly in Europe, small size wet drum meters were used to measure consumption of domestic customers. Today the small wet drum meter may be found in laboratories for precision measurement.

Diaphragm Meters

William Richards invented first diaphragm displacement meter in 1843. Thomas Glover later improved upon Richard's design and was erroneously credited with the first displacement diaphragm meter. It came to be known as the Glover two-diaphragm, slide valve, four-chamber meter.

Later, in 1903, Henry Sprague patented a two-diaphragm, three-chamber, oscillating valve, iron case meter, which brought to the American Gas Industry a second meter design. The Sprague 3-chamber and the Glover four-chamber designs are both universally accepted. The principle operation of the Glover type meter has basically not been mechanically changed since 1844. However, major changes in materials, construction, assembly, and testing have improved the life expectancy and durability of the diaphragm meter.

Operating Principles

The action of a Glover four-chamber diaphragm meter is similar to a simple two-cylinder steam engine with cranks at 90º to each other so when one is fully stroked, the other is at mid-stroke. The slide rectilinear valve type four-chamber meter alternately diverts the gas flow from one side to the other side of a flexible diaphragm attached to a diaphragm disc or center pan (Figure 1). The positive increments of volume trapped in this manner are released to the meter outlet. The two enclosed diaphragms mounted on each side of a casting partition form the four chambers of the meter. As the chamber fills, it moves the diaphragm and the gas in the filled chamber on the other side of the diaphragm to be forced out. The filling and emptying of the compartments is controlled or timed by a D-slide rectilinear valve reciprocating over a multi-port valve seat. The motion of the valve is timed to the motion of the diaphragm through the crank, tangent, flag arms and flag rods. The number of turns of the crank is transferred through a worm gear and shaft to the index, which is geared to convert revolutions of the tangent of the volume of gas measured.

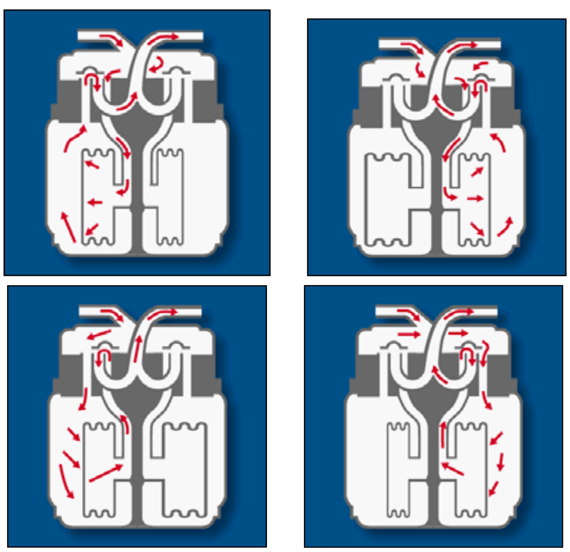


Figure 1

As seen in the diagrams above the movement of the meter is cyclical and repetitive. At the same pressure, each revolution passes the same volume of gas. The force needed to move the whole mechanical assembly is the differential gas pressure measured between the inlet and outlet of the meter. The amount of pressure differential limits the operating capacity of the meter. As stated by ANSI, the base capacity rating of all diaphragm meters is the stated flow rate at 0.5" w.c. However, additional capacity can be obtained by allowing the meter to revolve faster at a higher pressure deferential. As long as an increase in differential pressure does not impair the application, additional flow rates can be obtained with differential pressures of 1, 1.5, or 2" w.c.

Three Chamber Meter

Figure 2 illustrates a three-chamber, two-diaphragm, oscillating valve meter.

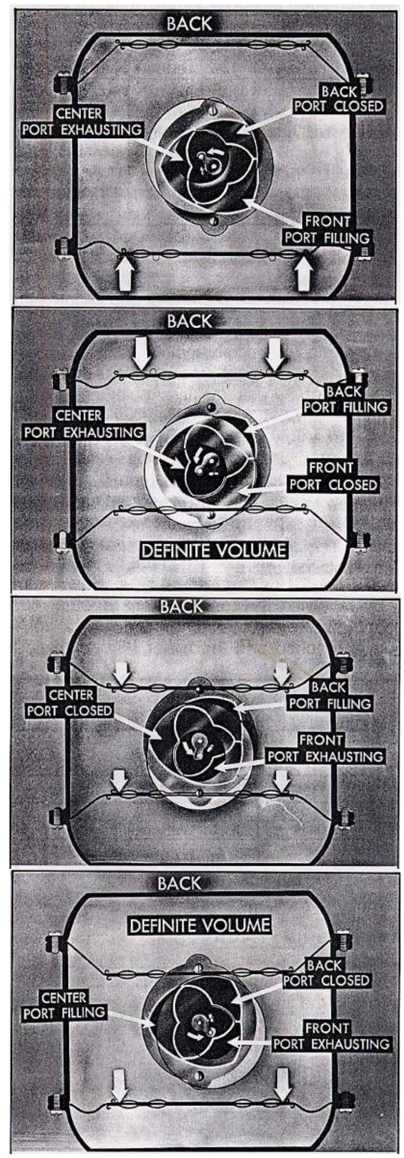


Figure 2

The operation and end results of this meter are similar to that of the Glover four-chamber meter, but are accomplished with a reduced number of moving parts.

The Sprague valve is circular with the outside of the diameter coinciding with the radii of the three inlet valve seat port lands and the inside diameter coinciding with the radii of the common outlet valve seat port lands. The valve moves in a planetary path about the valve center, revolving about itself resulting in a cleaning action.

The three-chamber meter is constructed and consists of a center, a front, a back, a top and an index box. The diaphragms are held between the flanges of the center casting and the front and back cover castings.

The center casting has no center partition and the three chambers are formed by the space between the front cover and the front diaphragm, between the front and back diaphragms and between the back diaphragm and the back cover.

The internal mechanism consists of the diaphragm carrier wires and brackets to support and guide the motion of the diaphragms, the main movement, valve, index drive movement, and index.

Each revolution of the valve is translated to the index through a worm and spur gear reduction in the index drive movement. This gear reduction is determined by the displacement per revolution (C.F.R.) of the meter in relation to the cubic feet per revolution of the proving dial of the index.

Meter Adjustments

All United States manufactured diaphragm meters are equipped with movements, which permit the timing and displacement adjustments to be made from outside of the meters.

Timing Adjustments

The function of the timing crank adjustment is to correct the timing of the valve in relation to the diaphragm position. This adjustment allows the slope of the accuracy curve to be changed.

Normally two flow rates are used for determining the accuracy curve of a diaphragm meter; the “open” rate and the “check” rate. The open rate is the 100% rated flow, and the check rate is 20-25% of the open rate.

By properly adjusting the timing, the two flow rate accuracy points may be set to the customer specifications.

Displacement Adjustment

The function of the displacement adjustment is to raise or lower the accuracy curve in relation to the 100% accuracy point. After the slope of the curve has been properly set by the timing adjustment, the curve may then be set in relation t the 100% point as determined by the customer.

The access to the calibration adjustment devices is different for four chamber and three chamber designs. The four-chamber access is provided by a “hand hole” plate in the top, which is removed to expose the two adjustment screws. The three-chamber has an access hole in the side of the center casting, which allows the operator to adjust the two screws with an adjustment wrench.

Capacity

The original capacity rating of a diaphragm meter was based on the flow of 0.60 specific gravity gas through the meter creating a specific pressure drop of ½” w.c. when tested near atmospheric pressure. ANSI B109.1 indicates the exact piping and position of pressure taps to determine the capacity.

The ½” w.c. harkens back to the days of manufactured gas and the old gasholders, which only supplied low pressure gas in the mains, on the order of a few inches of water column pressure. There was concern that the absorption of pressure by the meter would not allow sufficient pressure to satisfy the appliances downstream.

Today, it is not necessary to restrict the flow rate to only ½” w.c. pressure drop. As long as an increase in differential pressure does not impair operation of the burning equipment, higher flow rates can be utilized with differential pressures of 1” 1 ½” or 2” w.c.

Operation of the diaphragm meter at high pressure will create higher pressure drops across the meter due to the increased gas density. At elevated metering pressures, it is not necessary to limit the meter flow rate, which corresponds to 2” w.c. pressure drop. However, it is not considered good practice to permit a flow or index rate at high pressure as great as the flow or index rate permissible when measuring gas near atmospheric pressure. The high-pressure capacity is therefore a compromise between these conditions, and each meter’s maximum high-pressure capacity should be obtained form the manufacturer. ANSI B109-1 gives this method of calculating this capacity in the appendix. The primary concern is to limit the differential pressure at high pressure to a value that will not wear the valves prematurely.

Expressing Meter Performance

There are various methods of expressing performance of a meter and unless the performance is qualified, great confusion may result. The principle methods are % Accuracy, % Proof, and % Error. The same numerical answers can be given for % Accuracy and % Proof, but their meanings are entirely opposite. For example, 99% Accuracy means the meter is 1% slow, whereas 99% Proof means the meter is 1% fast. % Error must carry the correct algebraic sign, either + or – to designate if the meter is fast or slow.

A "fast" meter is a meter that registers on the index more volume than the correct amount. A "slow" meter is a meter that registers on the index less volume than the correct amount.

The following examples are given as a guide to the various methods of calculating and expressing meter performance. In each case, the meter proving hand will be two cubic feet.

$$\% \text{ Accuracy} = \frac{\text{Meter Proving Hand}}{\text{Prover Scale Reading}} \times 100$$

$$= \frac{2.00}{1.99} \times 100$$

% Accuracy = 100.5% Meter is .5% fast

$$\% \text{ Accuracy} = \frac{\text{Meter Proving Hand}}{\text{Prover Scale Reading}} \times 100$$

$$= \frac{2.00}{2.01} \times 100$$

% Accuracy = 99.5% Meter is .5% slow

$$\% \text{ Proof} = \frac{\text{Prover Scale Reading}}{\text{Meter Proving Hand}} \times 100$$

$$= \frac{1.99}{2.00} \times 100$$

% Proof = 99.5% Meter is .5% fast

$$\% \text{ Proof} = \frac{\text{Prover Scale Reading}}{\text{Meter Proving Hand}} \times 100$$

$$= \frac{2.01}{2.00} \times 100$$

% Proof = 100.5% Meter is .5% slow

$$\% \text{ Error} = \frac{\text{Meter Proving Hand - Prover Scale Reading}}{\text{Prover Scale Reading}} \times 100$$

$$= \frac{2.00 - 1.99}{1.99} \times 100$$

% Error = +.503% Meter is .5% fast

$$\% \text{ Error} = \frac{\text{Meter Proving Hand - Prover Scale Reading}}{\text{Prover Scale Reading}} \times 100$$

$$= \frac{2.00 - 2.01}{2.01} \times 100$$

% Error = -.498% Meter is .5% slow

Conclusion

All diaphragm gas meters have three basic elements in common. They have measuring elements or containers of known volume; a valve arrangement to direct the flow of gas into and out of the measuring elements; and a counter or index to register the number of times the measuring element has been filled and emptied.

A gas meter, in addition to the above, must be a very rugged mechanism to withstand the constant abuse it is subjected to. There is perhaps no other mechanical servant of so much is expected and to which so little attention is given. Occasionally, our mechanical contrivances are given a touch of oil, perhaps tightened up with a screw driver or receive the attention of a service man, but the gas meter is expected to operate under all conditions—indoors and out, withstanding temperature ranges from –40F to +120F, and within the most humid to the driest atmospheric conditions. Its diaphragms and internal mechanisms must withstand the chemical action of many gases, including gummy deposits, grit, and dirt.

The diaphragm meter, by design, is quite an accurate workhorse. The achievable accuracy for a diaphragm meter technology is easily ± 1% with the ability to obtain ±0.5%. The technology also excels with a turndown ratio of 200:1. Nevertheless, the gas meter of today is expected to be on the job constantly for periods from 10 to 30 years and to be instantly ready to measure accurately any quantity of gas. Treat it with great care - it is your cash register.