FUNDAMENTALS AND PRINCIPLES OF DIAPHRAGM METERS

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INTRODUCTION

A diaphragm meter is a positive displacement instrument which is used to measure the volume of gas that passes through it. This is accomplished through the known volume that is displaced for each stroke of the diaphragm. The diaphragm also provides the seal between the measuring chambers of the device. As such the diaphragm meter has proven to be an accurate and reliable means of measurement of gas for many years. This is especially true at low flow rates because of its positive displacement characteristics. This paper includes a brief history of diaphragm meters, an explanation of the operation of the diaphragm meter, a basic review of the function and design of the positive displacement meter, discusses meter ratings and capacity, and introduces temperature compensation.

HISTORY

Diaphragm meters are utilized to accurately measure the consumption of gas. They trace their roots to the wet-type positive displacement meter developed by Samuel Clegg in 1815. His design was improved by John Malam and Samuel Crosley. In 1825, the New York Gas Light Company utilized the wet drum meter for commercial use.

In 1844, William Richards and Mr. Croll patented the dry displacement meter. Their meter had two moving diaphragms, two slide valves, and a dial index. Thomas Glover improved the design. The meter then became known as the Glover two-diaphragm, slide valve type meter. The basic meter Mr. Glover designed is still in use today. Improvements to the meter have been through the use of new materials. The basic design has not been improved.

OPERATING PRINCIPLES

The basic concept of a positive displacement meter can be illustrated as in Figure 1. This figure of a simple piston and valving arrangement depicts a single chamber positive displacement device. It can be assumed that the chamber is a fixed size and shape such that the volume displaced by a stroke of the piston can be easily calculated. As gas enters through the "IN" port the piston is moved toward the top of the cylinder. This is accomplished by the pressure of the gas acting on the projected surface area of the piston. The motion of filling the cylinder continues until the piston reaches the

end of its stroke at which time the valve is closed and the motion is stopped.

The valve is then moved to open the "OUT" port which allows the measured volume of gas to be exhausted from the cylinder; thus returning the piston to the bottom of the cylinder.

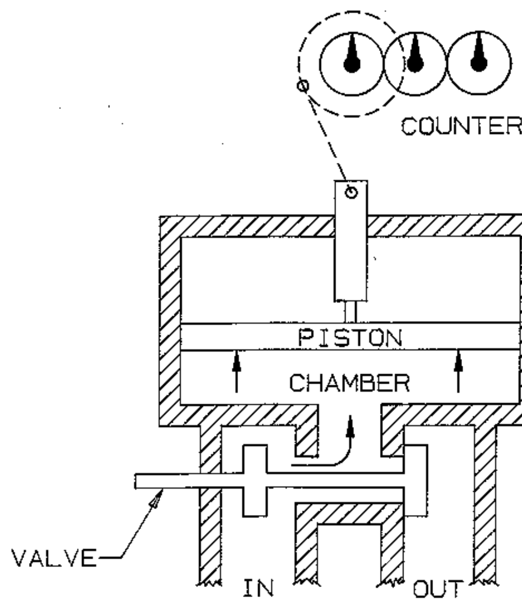

Figure 1

The piston is also connected through a series of links to a counter. The purpose of the counter is to provide a totalized reading of the amount of gas that has been passed through the device. Thus, in effect, the device illustrated in Figure 1 provides for a totalized reading of the amount of gas that has gone through it at any given time by counting the number of cycles through which the piston travels. In order to make the device operate; however, external forces are required to position the valves and assure that the piston motion is controlled.

DIAPHRAGM METER DESIGN

Although the device shown in Figure 1 contains the five fundamental components of a positive displacement meter (chamber, displacement member (piston), valve, counter, connecting linkage), there must be more than two chambers for a diaphragm meter to operate without external power. This is illustrated by plotting the flow through devices with various numbers of chambers as a function of the position within the cycle of operation. This can be seen in Figure 2.

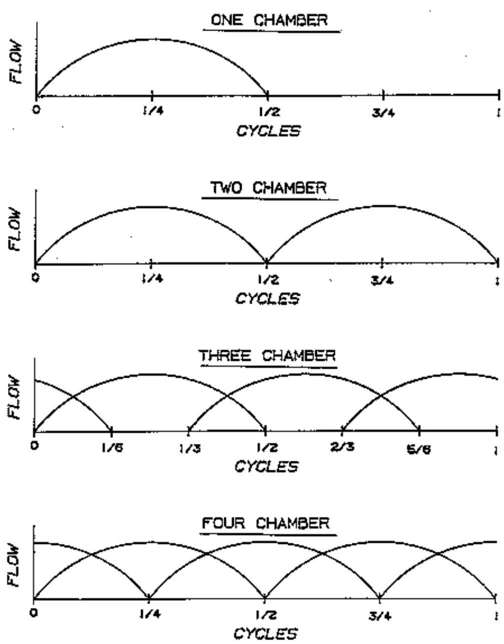

Figure 2

It is obvious from the illustration that a one chamber and a two chamber meter will not operate continuously without some external acting forces to move the devices when they reach a point of zero flow. The three chamber device will operate without the need for external forces to help drive it. It can be seen that as the number of chambers is increased, the summation curve becomes smoother and smoother as does the operation of the device itself.

The four chamber meter is smoother running because the "dead spots" are minimized. This characteristic when seen as some feature of meter performance will manifest itself as a lower operating differential variation; a characteristic that is often referred to as oscillation or fluctuation of the differential pressure across the meter.

The typical diaphragm meter consists of many parts however the five most basic are:

- Housing
- Measuring Chambers
- Valves and Linkages
- Calibration Device
- Index

An examination of each of these elements of the design will enhance the understanding of the operation of the meter.

HOUSINGS

The housing of the meter consists of the cover, body, and the hand hole plate for residential meters and index plate for intermediate and large meters. These components which are typically made of die cast aluminum (residential meters and some intermediate) and permanent mold aluminum castings (some intermediate and large capacity meters) encase the working mechanism as well as partially forming the measuring chambers of the meter.

In the past, housings for diaphragm meters have been made of many other materials including tin, steel, and cast iron.

The integrity of the housings is very important to the operation of the meter, especially in higher pressure applications. It is the housings that create most of the internal to external seal of the meter and it is also the housings, materials and design, which to a large extent determine the burst pressure of the unit. Dependent upon meter size and intended application, the housings are designed for operating pressures of 5 psig to 500 psig (please consult manufacturer's product literature for specific maximum allowable operating pressures per meter type).

MEASURING CHAMBERS

The most common design of meter used today is of the four chamber variety. In this design the body outer walls and the partition create the two large cavities into which the diaphragm pan assemblies are placed. These two diaphragm pan assemblies together with the two volumes outside of them, one on either side of the partition form the four chambers of the meter. The diaphragm pan assemblies consist of the diaphragm, the diaphragm disc, the diaphragm pan, and some type of sealant at the joints.

An important design requirement is minimizing the amount of friction caused by the filling and the emptying of diaphragms. This friction manifests itself as the differential pressure across the meter which is needed to drive the device. Certainly there is a trade off of sorts with these requirements in today's designs. The synthetic rubber diaphragm of today creates a seal and motion that is nearly free of friction; however, the displaced volume may not be as consistent as in the piston and cylinder device. The only friction applied is that of the internal motion of the diaphragm, which is very low. Inaccuracies which may occur because of the inconsistency of the measuring chambers are taken care of through the calibration device and are also minimized through time by the selection of the diaphragm material and the shape of the molded diaphragm itself.

As constructed each of the diaphragm assemblies must pass a leak test which is conducted at about six inches water column. This differential pressure across the diaphragm is many times what is normally seen in use. The diaphragm itself is molded into a specifically designed shape and is made by forming a piece of material consisting of a woven fabric coated on each side by a synthetic rubber material. This material is especially selected so as to give the required performance under all conditions that the meter might be subjected to. This includes retention of both its volume and its flexibility for the entire usable life of the meter.

As the valves open and close the various ports to the diaphragms and the cavities into which they are mounted, the diaphragm sees the pressure differential shift from inside to out. The diaphragm also is allowed to fill and empty which is the measuring function of the device. As the differential across the meter is increased by a greater downstream demand for gas flow, the filling and emptying of the diaphragm happens at greater and greater speeds. As the speed at which the diaphragms move increases so also do the forces to which it is subjected.

It is apparent that all of the parts of the meter must work together to produce the desired results. However, the diaphragm has been shown to be such an important member that it is often referred to as the "heart of the meter".

VALVES AND LINKAGE

In much the same way that the valves in the engine of a car control the flow of fuel into and out of the cylinders, the valves in a meter also control the flow of gas into and out of the measuring chambers. If the metering process is thought of as a sequential filling and emptying of "bucket"; it is the valves that control the filling and emptying. Valves may come in many different shapes and sizes depending upon the individual designer, but they can basically be classified as either reciprocating/slide valves or rotary/oscillating. The difference between the two designs is clear from the names; one slides back and forth on a grid and the other rotates about a center point on a grid. While there is no clear perfect choice for the type of valving used, the majority of today's meters are of the slide type design, as seen in Figure 3. This is presumably because that design has shown itself to be better in the presence of dirty gas, grease, and oil.

To relate again to the engine valves in a car; it is very important that the positioning of the valves remain constant so that the timing of the unit can be maintained. Precise timing of the valves in the diaphragm meter is also very important, for it is the valves that control the timing of the meter as well. Proper positioning of the valves not only promotes smoother operation because of reduced dead spots in the motion but it also reduces the pressure pulsation's which manifest themselves as fluctuations or oscillation in the meter differential. It is also important that the contact area of the valves with the seat grids be maintained as small as possible without causing strength problems. This is so that if there is a buildup of grease and dirt on the grids it will not noticeably drag down the valves.

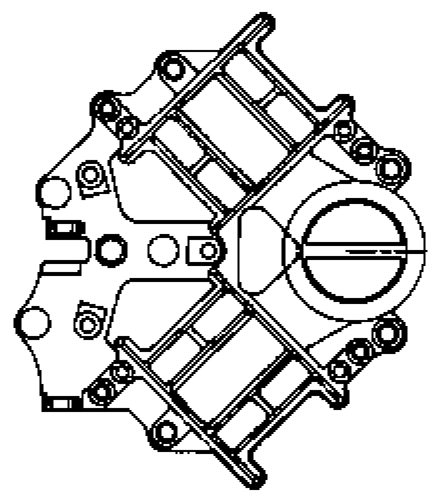

Figure 3

The design of the linkage that connects the diaphragms to the valves is also very important. The linkage design, that is the length of the various components and the angles at which they operate, will greatly influence the efficiency of the power transfer from the diaphragms to the rest of the meter. The greater the power there is available to drive the unit; the greater will be its resistance to such slowing forces as dirty valves. Figure 4 shows a common linkage design.

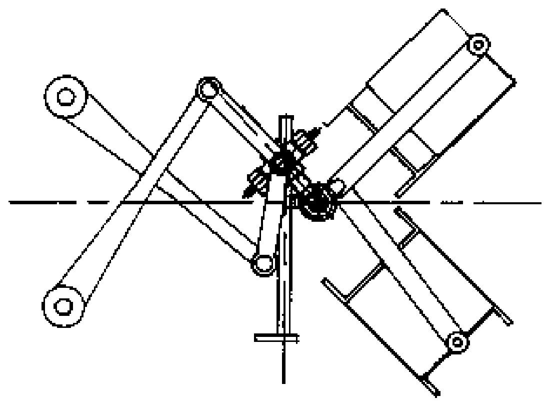

Figure 4

CALIBRATION DEVICE
As is the case with all high accuracy instruments, a calibration device is necessary in the diaphragm meter. This device, known as a tangent, is used to adjust diaphragm displacement and diaphragm to valve sequencing. The main purpose of the tangent or any calibration device is to adjust out all the effect of all the small tolerances that have accumulated through production of the device.

The most common type of tangent used in gas meters today is the X-Y type. The X-Y type allows calibration movement only along the x-axis and y-axis or 90 degrees to each other. This means that the adjustments cannot be made independently unless the tangent post is exactly in line with the crank center; that is along the center of the speed arm.

The calibration process involves relating a known volume from some standard to that volume recorded by the meter. In essence you are adjusting the speed of the meter. If the meter is "fast", that is, it records more than passes through it, then the tangent needs to be adjusted by increasing the radius. If on the other hand the meter is measuring less than the standard has passed through it, then the radius of the tangent needs to be decreased.

There is also a requirement for timing adjustment of the meter. This is done to assure that the diaphragms and the valves are in the proper relationship one to the other. Typically the proving or calibration of a meter is done at two different flow rates. While there are many names and values given to these flow rates the most common are: open flow (100% of rated capacity) and check flow (20% of rated capacity). Individual utilities will have different values from time to time but those stated above are standard in the industry. Timing adjustments are made to adjust for the differences between these two readings. As can be seen in Figure 5, adjusting the speed on the X-Y tangent also affects the timing. This can be seen by the difference in angle Θ.

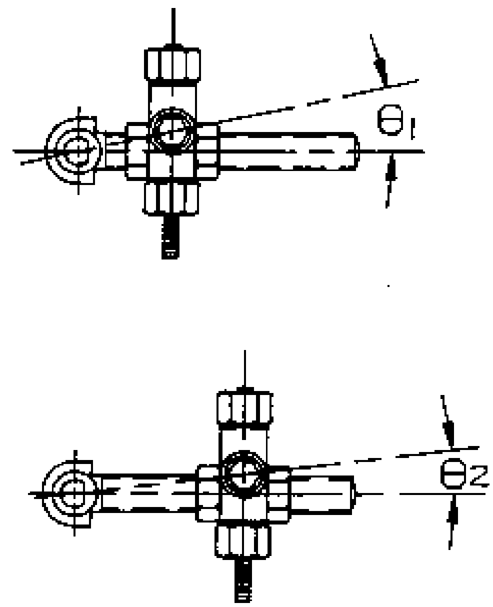

Figure 5

INDEX
Once the gas has been measured and passed through the meter it is necessary to totalize and record the total amount that has gone through the meter. This is commonly done using a register or an index. The index is driven through some type of connecting linkage which is most commonly a worm, wormwheel, and stuffing box shaft. The stuffing box shaft, which transmits the motion from inside the meter to the index outside the meter, is important in that it is the only dynamic seal of the meter's internal pressure.

There are a wide variety of indexes available such as standard or temperature compensating, circular read or direct read, English units or metric, brass or plastic, remote or local read. No matter what type the sole purpose of the index is to provide a totalized quantity that has passed through a particular meter in a given period of time.

<u>TEMPERATURE COMPENSATION</u>
Many gas meters are located outside where they are exposed to the temperature variations that exist for a given climate. These temperature variations affect the density of natural gas which in turn impacts upon the accuracy of the meter. This is because most

gas is billed at what are called "standard conditions", 4 ounce pressure and a 60 °F base temperature. Any departure from these conditions will produce error in meter reading since the standard measures only so many cubic feet of gas passed through it at the pipeline conditions. This variation in the density of natural gas with temperature has been called Charles's Law. This law states that at a constant pressure the volume of gas will be directly proportional to the absolute temperature change. This law can be stated mathematically as:

$$\frac{V1}{T1} = \frac{V2}{T2}$$

where V1 and T1 are the volume and temperature of the gas at the first conditions and V2 and T2 are the volume and temperature of the gas at the second conditions. As the temperature of the gas decreases in order to maintain the accurate registration of 60 °F gas it is necessary to decrease the volume displaced by the diaphragm. This is done through the use of a temperature compensating (TC) tangent. The TC tangent, as it is called, is constructed using a piece of bimetallic material. As the temperature changes the bimetal changes the distance from the crank center to the tangent post to accommodate the temperature. This movement in turn changes the stroke of the diaphragm to allow for proper displacement of volume.

METER RATINGS & CAPACITIES

Diaphragm meters are generally designated by class. Each meter must meet or exceed the specified capacity for its class. ANSI defines the classes in the B109.1 and B109.2 specifications. The capacity is arrived at by measuring the volume of gas passed by the meter at a given pressure drop. The “drop”, also known as the differential, is the amount of pressure loss from the inlet to the outlet of the meter. The pressure loss is the amount of energy required to power the meter. The pressure loss is normally expressed in inches water column (27.7” w.c. = 1 psi).

The normal standard for residential diaphragm meters is 1/2” w.c. Therefore, a 250 class meter must pass 250 cubic feet of natural gas per hour, at 60 °F and 4 oz. pressure (standard conditions), with a maximum pressure loss of 1/2” w.c. This does not mean that the meter cannot pass more gas per hour, it can; however, there will be a larger pressure drop across the meter. The practical limit for a diaphragm meter is based upon the accuracy and meter life required. The higher the volume of gas the meter must pass, the faster the meter must operate. As the meter moves faster and faster, the valves and other components wear, reducing accuracy.

Larger diaphragm meters are typically rated at both 1/2” and 2” w.c. drops. Once again, the meters are rated at standard conditions. The advantage of this method of rating meters is that it enables the user to decide which of two pressure drops is acceptable. The larger the pressure drop, the greater the capacity. Normally, the capacity of a meter can be doubled by increasing the pressure drop to 2” w.c. from 1/2” w.c. In many industrial applications, the 2” w.c. drop will not affect the customer; whereas, a 2” w.c. drop normally will cause significant problems for a residential customer.

CONCLUSIONS

The diaphragm meter has been used for many years as a reliable means of measuring the amount of gas that flows through it in a given time period. Although the basic design has not changed over more than 100 years, many changes have been made to improve the life of the device, decrease its cost, and include special features. Since it is a positive displacement device, it is very accurate even down as low as a pilot light flow.

REFERENCES

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