Fundamental Principles of Rotary Displacement Meters

Frederick C. Schwarz
Badger / Instromet, LLC.
3731 Briar Park Suite. 100
Houston, TX 77042

Introduction

All rotary piston meters, commonly known as rotary meters, utilize the fundamental 1846 lobed impeller design of the Roots brothers.

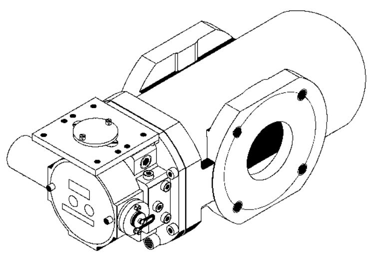

Figure 1

Originally designed for water pump applications, this fundamental style has been parent to virtually all interweaving rotor designs applied to gas and liquid compression, pumping and measurement applications. The first positive displacement rotary meters manufactured for gas applications were built in 1920.

Over time, rotary meters have been continually improved by use of new modular designs, better materials, more precise manufacturing processes and electronics. They have a proven record of accomplishment of high and consistent performance. As compared to orifice, diaphragm and turbine meters. They have better accuracy, larger turndowns and are relatively smaller than other mechanical gas meters. This paper generally describes the fundamental concepts of rotary meters, installation and maintenance.

Operation

As illustrated in Figures 2, 3 and 4, rotary meters feature two counter rotating “figure 8” or lobed impellers. These impellers, or rotors, move as a function of the force of flowing gas and are unaffected by gas density, turbulence and pulsation in the line. The rotor lobes form a defined space between the impeller and the meter wall, hence the term, “positive displacement meter”. Clearance between the rotors and sidewalls is kept to a minimum to minimize leakage.

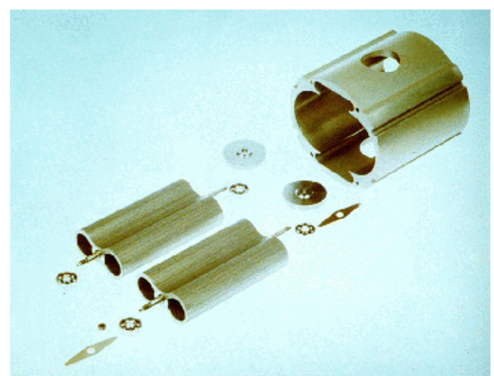

Figure 2

This positive gas displacement is fixed which in turn, traps, and moves four defined volumes of gas per each complete rotor rotation.

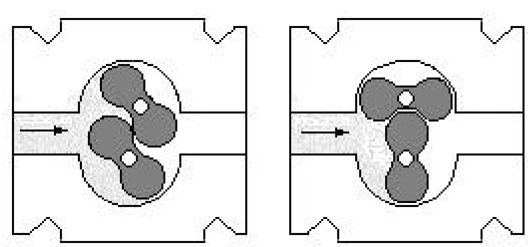

Figure 3

Figure 4

By counting revolutions and by knowing the volume displaced in each revolution, a very accurate gas volume can be measured. The meter's basic counting mechanism indicates uncorrected volume (ACF) and there is a wide variety of transducers available to transmit measurement to volume correctors or flow computers. Examples are direct mechanical coupling (instrument drives), contact closures, optical sensors, magnetic pulsers or proximity detectors.

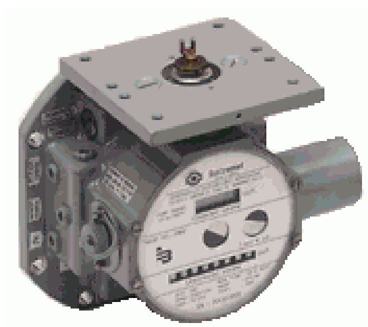

Figure 5

Figure 5 depicts a typical index unit removed from the meter body. The photograph shows typical options; temperature compensation with its associated battery and LCD display, mechanical volume index wheels, instrument drive for use with mechanically driven volume correctors, optical sensor paddles and pulse output connectors. The side-mounted receptacle facilitates low frequency pulse outputs. Standard low frequency pulse outputs do not actually generate a pulse; they cause a contact closure at each revolution of the lowest denomination mechanical index wheel. The volume corrector or flow computer connected to the meter applies a voltage across the low frequency output switch terminals. Each index rotation makes a contact closure thus causing a voltage pulse as the index operates. Depending on the size of the meter, these pulses are normally set one per 10 or 100 ACF. If more resolution is required the pulse rate per given volume can be increased by using different sensors such as proximity detectors or magnetic probes.

The basic meter index produces measurements made at line conditions, that is, in "actual cubic feet". It must be corrected for compressibility effects to achieve the base, standard or reference conditions necessary for billing and custody transfer. Gas flow is effected by factors such as temperature, pressure, composition, and the meter itself. As gas pressure increases, more gas molecules can be compressed within a given space – such as a pipeline. Likewise as gas temperature decreases, more gas molecules can be accommodated. By applying equations considering gas composition, pressure and temperature, correction can be manually computed although it is usually an automated function accomplished by volume correctors, flow computers, SCADA systems, etc. Figure 6.

Figure 6

Mathematics

The equation to calculate the base volume is:

$$\mathbf{V_b = V_l\ (P_l / P_b)(Z_b / Z_l)(T_b / T_l)}$$

Where:
V_b volume at base conditions
V_l volume at line conditions
P_l pressure at line conditions
P_b pressure at base conditions
Z_b compressibility at base conditions
Z_l compressibility at line conditions
T_b temperature at base conditions
T_l temperature at line conditions

An alternative method uses the density at line conditions and the density at base conditions. The equation for this method is:

$$V_b = V_l (\rho_l / \rho_b)$$

Where:
V_b volume at base conditions
V_l volume at line conditions
ρ_l density at line conditions
ρ_b density at base conditions

Accuracy and Rangeability

Accuracy is a function of meter performance compared to a known standard. Depending on the legalities these tests can be performed with bell or piston provers in the meter shop, by field transfer provers or by third parties offering internationally certified test results.

Rotary meters are machined devices and their chamber and rotor dimensions are fixed. There are no mechanical adjustments to enhance the accuracy and rangeability of the instrument although some meters have available change gears which allows the meter's overall performance curve to be raised or lowered in small increments. However, meters having multi-point calibration curves which plot accuracy as a function of flow rate, pressure and temperature can apply appropriate meter factors which mathematically adjusts, or flattens, the meter performance curve for known errors at identified flows. This is spreadsheet function and depends on accurate and reliable proving tests.

The rangeability (turndown) of a meter is normally expressed as a ratio of the meter's maximum flowrate divided by its minimum flowrate in an accuracy band of +/- 1% of value. With the employment of new body designs and modern machining practices, rotary meters can have rangeablities of well over 200:1.

Example:

1000 ACF / 25 ACF = 40:1

Installation

Rotary meters should be installed into a sturdy, vibration free piping system with precisely aligned and fitting flanges. The meter should be properly leveled which provides for correct reading of the oil sight gauges. Improper leveling can not only result in bearing problems but also in oil bleeding into the measurement chamber causing rotor drag. Correct flange alignment is paramount. Use a spool piece to facilitate alignment, never use the meter body as a straightening element for misaligned flanges. Over stressing some meters can result in binding of the rotors against the measurement chamber, which reduces rangeability, accuracy and even blockage, and complete meter failure. Stresses caused directly from initial installation or indirectly from settling or foundation upsets are of serious concern.

Figure 7

Use proper gaskets for the installation. Each ANSI flange rating has a corresponding gasket material to correctly fit the application. Generally, the lower the rating, the softer the material. The higher the rating, the harder the gasket.

Inspect the meter before installation. Check for free and easy rotor rotation. Before the meter is set, the line should be cleaned of valve grease, dirt, welding slag and any other debris that could harm the meter. Strainers and/or filtration is always good practice on new installations. Meters set into low flow conditions at mature sites such as those found in a gas distribution system might be able to get away with little or no protection, but meters set into new installation environments experiencing high flow applications, (such as a gas transmission site), should always have filtration. Meter failure and improper measurement is more expensive than a filter or strainer. Protection is cheap insurance.

Once the installation is complete, gradually pressurize the line to allow for the rotors to spin up properly and avoid excessive differential pressure and over speeding. Use of by-pass piping is recommended for maintenance and testing routines.

Maintenance

Rotary meters are relatively simple to maintain. Assuming that the gas line is clear of oil, grease and debris and no site settling has occurred, little has to be done other than checking for proper oil level in the sight glass, Figure 8.

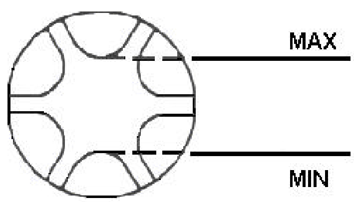

Figure 8

Some meters have a single oil chamber while others feature multiple reservoirs, be sure you are familiar with the particulars of your meter. Use an oil approved by the manufacturer. Use of the correct oil at proper levels can result in years of trouble free operation. Depending on the cleanliness of the gas, most oils have a life of at least five and as much as 15 years, (but if it becomes discolored, change it).

Regular inspections are necessary when using strainers and filters. A clogged or dirty strainer/filter can reduce if not block gas flow. Many high flow units feature differential pressure gauges that are used to indicate the degree of contamination. Even with good filtration, some dirt will still pass through the meter. For this reason, most manufacturers apply a hardened surface to the rotors and chamber walls.

Over time, oil deposits can accumulate on the rotors and measurement chamber walls. This can cause drag and reduce the accuracy and rangeability of the meter. Many operators employ differential rate testing. This test is based on the fact that differential pressure across the meter will increase as a function of bearing wear and contamination. Assuming that the pressure, temperature and gas composition is the same after a period of operation, any increase in differential pressure as compared to start-up must be caused by meter problems such as contamination from valve grease, dirt, worn bearings or excessive oil. Typically, if the differential pressure exceeds 50% of the initial installation value, then the meter requires removal from service and warrants internal inspection. Often the meter only requires cleaning with a solvent such as kerosene and can be immediately returned to service.

The differential test requires a pressure gauge or manometer to measure the pressure drop across the meter and a stopwatch to time the test. Pressure readings should be taken at a minimum of three points between 25 and 100% of meter capacity to insure correct results across the full range of the meter.

Meters using battery powered electronic volume correctors should establish a regular routine for checking the condition of the battery. New extended life lithium units can last several years but unfortunately, operators can become complacent and not verify proper application sometimes resulting in an unexpected failure.

New Developments

The need to produce the very best product available as well as with litigation playing such an important part in our industry, manufacturers have become keenly aware that cost, accuracy, repeatablility, fast and efficient maintenance are paramount issues. Most notably, recent advances include pre-fabricated emergency by-pass assemblies. Portable by-pass piping is now available allowing technicians to perform maintenance on mature meter settings. Some automatic emergency by-pass systems are now being manufactured into the meters themselves, Figure 9. These features protect the end-user from loss of gas service should the meter block.

Figure 9

Pre-fabricated skids now allow complete meter sets to be installed more efficiently. Some manufacturers have redesigned their meters to utilize one central oil reservoir and sight glass. Larger stainless steel bearing use has extended field reliability and new modular designed meters are now available with the introduction of new cartridge style meters, Figure 10. These new designs offer easier maintenance and do not suffer some of the traditional limitations caused by the effects of pressure and temperature.

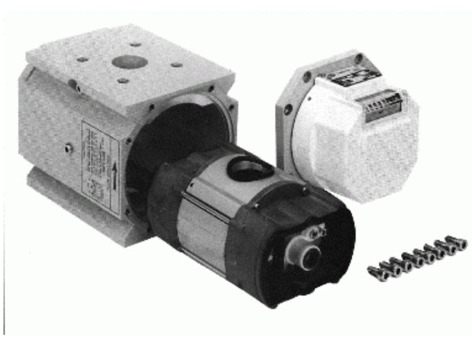

Figure 10

Summary

Rotary meters have been an important part of natural gas measurement in the United States for over 60 years. They have met the test of time for durability, reliability, low maintenance and accuracy. Industry usage has increased exponentially with the introduction of smaller, more compact sizes. Recent advances in modular designs, materials and electronic support have given way to even more interest and acceptance over the past decade. In all respects, they are a cost-effective means of ensuring good measurement.

References:

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