INTRODUCTION

With the increased use of Natural Gas as a fuel, higher natural gas prices, and the new federal regulations, buyers and sellers of natural gas are seriously looking at ways to improve their natural gas measurement and reduce the unaccounted for natural gas. An error in measurement of only one tenth of one percent (0.1%) on 100 million standard cubic feet per day of Natural Gas selling at $3.00/MCF will cause an over or under billing of $109,500.00 in one year. This will more than pay for a proving system.

The BTU in one barrel of oil for example is equivalent to approximately 5,600 cubic feet of natural gas. At $3.00 per thousand cubic feet, the natural gas equivalent of one barrel of oil costs $16.80 or more than the cost of a barrel of oil. In the petroleum liquid industry no custody transfer liquid measurement system would be complete without a method to prove the meter, either as part of the equipment or have connections provided on the measurement skid to connect a portable prover.

Under billing causes loss of revenue, and over billing can cause a future correction that will cost the company millions of dollars. For these reasons gas meter proving is important and necessary to insure precise measurement of natural gas that both the buyer and seller can agree upon.

The gas turbine meter is easy to understand and maintain in the field, and is easy to interface with the new electronics available in the industry today.

REASONS FOR PROVING A FIELD METER

Although the installed field meter has been completely checked and calibrated at the factory, and a performance curve developed, there are many things that can affect a meter on site causing measurement errors.

Any meter system can have changes during operation that will cause errors in measurement. Orifice plates can become damaged, bearings on Turbine Meters can wear, and dirt and trash can accumulate on flow conditioners and in piping. Trash can accumulate on straightening vanes, and Ultrasonic meters and other meters can become dirty causing the meter to error.

The inputs into flow computers and other electronic devices can be changed by mistake causing errors in measurement.

New meter installations can have debris from construction caught on the straightening vanes or in the meter itself. Proving checks not only the meter, but the complete meter system.

One of the more important reasons for meter proving in the case of Custody Transfer is to give both the buyer and seller confidence the volumes they transfer are acceptable to both the buyer and seller, thus eliminating disputes.

METER PROVING DEVICES

There are many different methods and devices available that can be used to prove a Natural Gas Meter. Some of them are calibrated Master Meters, Sonic Nozzles, Bell Provers, and Volume Provers. Each device has its advantages and disadvantages.

These proving devices can be divided into two categories, primary and secondary. A primary measurement device, such as a bell or volume prover is one that has had its volumetric flow rate measurement accuracy checked and verified against measurements for which there are national or international standards (e.g., mass, time, length, etc.) This device can then be used to verify Master Meters. A Master Meter that has been calibrated becomes a secondary standard and can then be placed in series with a field meter to verify the
accuracy of the Field Meter. A secondary device is one that has been checked against a primary device and is then used to prove another meter. An example of a secondary device is an In-Situ Meter Prover using a Master Meter. An In-Situ Meter Prover is the Master Meter and its associated piping that can be either taken to the site of the meter in the field or is installed permanently on the meter skid.

Volume provers which are relatively new, are primary devices and very accurate. They are however very expensive and work best at higher line pressures and lower volumetric flow rates.

Bell provers, which are also accurate, work only at low pressures and cannot be used for large flow volumes. They can be used to calibrate a Master Meter, which can then be used to prove other devices at higher pressures and higher flows. Bell Provers are relatively expensive to build and maintain.

The sonic nozzle is precise, (±0.25% total measurement uncertainty) but can only check a field meter at one flow rate and line pressure. The sonic nozzle also causes a permanent pressure drop of 5% or more in the system.

A calibrated Turbine Master Meter can be used to check the field meter through its entire operating range. It can be used at high and low pressure, and the systems using Master Meters are relatively inexpensive. The Master Turbine Meter can be portable or stationary. However the Master Meter can become damaged in use and lose its precision. For this reason meters with self checking ability such as dual rotor turbines are well suited as Master Meters. Ultrasonic meters can also be used as Master Meters on high pressure proving systems, but care must be taken to insure the transducers and the bore of the Ultrasonic Master meter is kept clean and free of any material build up. Keeping the Master Meter and its associated piping clean also holds true for all meters used as Master Meters.

A Transfer Prover is a proving system that checks the field meter against the Master Meter at Atmospheric Pressure. The Master Meter and its associated piping is placed in series with the field meter and air is drawn through the two meters by an adjustable flow rate blower. Air at atmospheric pressure and at various flow rates is then pulled through the two meters and a comparison is made between the Master Meter and the Field Meter. A Transfer Prover System can be used to calibrate field meters brought into a shop or the Transfer Master Meter Prover can be portable and taken to the field. The atmospheric Transfer Prover is best suited for checking meters operating at lower pressures. Many Flow Meters exhibit line pressure sensitivity that can introduce a measurement bias if they are calibrated at a test pressure significantly different than their field operating pressure.

The higher pressure In-Situ Master Meter Prover is a Master Meter usually placed immediately downstream and in series with the operating Field Meter. It is connected on site and is used for proving at actual operating conditions of flow, temperature, pressure and density. The Master Meter is either mounted permanently on the metering equipment skid or is portable and connected to an existing three-valve manifold when needed.

A Portable High Pressure Proving System consists of a number of different sized parallel turbine meter runs with provisions for installing a field meter for test downstream of the master meter. A sonic nozzle is placed downstream of each of the two meters in series to limit the flow and to verify the accuracy of the Master Meter. Since the Sonic Nozzle is a precision mass measurement device, it works very well to determine the mass flow at a pressure and temperature. It can be used as a check for any variable flow Master Meter.

Since proving with a Master Meter is currently one of the least expensive ways to calibrate an existing field meter we will discuss the various Master Meter systems. It is noted that AGA Report No. 6 on Transfer Meter Proving using Master Meters is presently being updated and rewritten.

FIGURE 2.

PROVISIONS NEEDED ON THE FIELD METER STATION TO CONNECT THE MASTER METER

There are two ways to install a Master Meter on an existing Field Meter skid. One way is to use a three-valve manifold downstream of the existing meter run shown in the P&ID above. Downstream of the field meter is the preferred location because the flow profile into the Field Meter is not disturbed. A Flow Conditioner should be installed upstream of the Master Meter in the Master Meter prerun piping to eliminate any problems in the flow profile caused by the elbows and valves going into the Master Meter Run. If a three-valve manifold is used the inline valve must be a Block and Bleed type valve to insure all the flow is going through the Master Meter Run. As a cost saving, extra valves are not needed going into and out of the Master Meter Run. Blind Flanges can be used to cover the connections. However closing in the Field Meter and bleeding down the pressure to install a
Master Meter without the valves is time consuming and costly.

The second method is to install a Master Meter in series with the Field Meter on the existing Field Meter Skid. With this arrangement it is necessary to provide space downstream of the Field Meter for an additional Master Meter run. The advantage of this system is that no additional valves are required. The disadvantage is the Field Meter run has to be closed in and bled down to install the Master Meter.

Some Meter Systems are designed in such a way that the Master Meter is permanently installed on the Meter Skid. The Master Meter can then be used as the spare meter to be put on line if there are problems with the normal operating meters or if the flow rate exceeds the limits of flow through the installed meters.

EQUIPMENT REQUIRED FOR ONSITE PROVING OF GAS TURBINE METERS

Master Meter

AGA Report No. 7 states gas turbine meters must have a predicted accuracy of ±1% of reading. Therefore the device used to check the meter must have an accuracy that is at least as accurate as ±1% of reading and, preferably 2 to 5 times more accurate. AGA Report No. 7 also states the repeatability of a Turbine Meter normally exceeds plus or minus 0.1% of reading. Some manufacturers state their turbine meters are repeatable to plus or minus 0.05% of reading or 5 parts in 10,000. Flow Computers can take advantage of the excellent repeatability of Turbine Meters by using linearization to improve the precision of the meter calibration.

Flow Computer

The engineering calculations performed in the Flow Computer should follow the procedures described in AGA Report Nos. 6 and 7. The report from the Flow Computer must be presented in such a way that the calculations from raw pulses to final compensated volumes can be verified using hand calculations.

Using modern Flow Computers, the typical meter calibration curve of a Turbine Meter can be linearized. During the meter proof, the stated volume of both the calibrated Master Meter and the field meter being proved can be measured precisely during the prove cycle by using Pulse Interpolation as described in the API Manual of Petroleum Measurement Standards, Chapter 4, Section 6, Pulse Interpolation.

Pressure and Temperature Transmitters

The gas pressure and temperature must be precisely measured at the Master Meter and at the meter being proved. Because of the small pressure drop between the Master Meter and the meter being proved the pressure can best be measured with a Multi-variable pressure transmitter. Using a Multi-variable Transmitter the pressure and calibration error of using two pressure transmitters is eliminated.

The lower the line pressure the more difficult it is to determine the difference in line pressure between the two flow meters. With atmospheric Transfer Meter Prover systems, a differential pressure transmitter can be used to determine the gage pressure at the first meter. The high-pressure port of the Differential Pressure Transmitter is left open to atmosphere and the low-pressure port is connected to the pressure port of the meter. Atmospheric pressure can also be a manual entry based on weather bureau data or a precise atmospheric pressure transmitter can be used.

The gas temperature must be measured at a point in the line at least three pipe diameters downstream of each meter. There will normally be a difference in the gas temperature at the two meter locations.

This difference will be due, in part, to the pressure drop between the meters. Since this pressure drop is very small, typically only a small change in gas temperature will occur. Extremely precise and well calibrated temperature sensors and transmitters must be used to measure this precise differential. Temperature Transmitters that include two temperature inputs are now on the market and are best suited to determine the temperature downstream of each meter. This reduces the measurement error associated with using two separate Temperature Transmitters.

MAXIMUM GAS VELOCITY

An 8-inch turbine meter with a 30-degree rotor can flow 11,234,000 standard cubic feet of gas per hour at 1,440 psig. Dividing 1,440 by 14.73 equals 97.76 divided by the compressibility factor of 1.2461 equals 77.36. 11,234,000 divided by 77.36 equals 145,217 Actual cubic feet per hour or 40.34 ACF/Second at a standard temperature of 60 deg. F.

How long is the eight-inch pipe that will hold the 40.34 CuFt of gas that moves in one second? Eight-inch
schedule 80 pipe has in inside diameter of 7.625 inches. That means 1 foot of this pipe will hold 0.317 actual cubic feet of gas. We can use the formula (pi times the radius squared times twelve inches divided by the cubic inches in 1 cubic foot \(3.813 \times 3.1417 \times 12\) / 1728 = 0.317 cu. ft. in one foot of the pipe). Therefore it will take 40.34 cu. ft. divided by 0.317 or 127 feet of pipe to hold the 40.34 ACF of gas. If the flow rate is 40.34 ACF/sec. it will have to pass through 127 feet of pipe giving a flow rate of 127 ft./sec. or 86.6 miles per hour.

The weight of 0.6 sp.gr. Gas at 1440 psi is 5.727 lbs./cu. ft. the max velocity recommended by API RP 14E is 78 ft./sec.

**PIPING PER AGA 7**

Piping for both the Turbine Master Meter and field meter preruns and post runs should be configured per the recommendations of AGA Report No. 7. The axial lengths of the post-run of the first meter and the pre-run of the second meter (in series) can be combined making the minimum axial length separating the two meters a total of ten pipe diameters. If any piping manifolds, elbows or bends are located upstream of either the Master Meter or the field test meter, as is the case when connecting to a three-valve manifold, a high performance flow conditioner should be installed upstream of the meter in accordance with the flow conditioner manufacturers recommendations.

**IN-SITU PROVING WITH A MASTER METER PLACED IN SERIES WITH THE FIELD METER**

The performance of the Master Meter and the Field Meter should be compared on a mass flow rate basis. For most turbine flow meters, the measured flow rate is expressed in terms of volumetric flow rate. The line pressure (and, probably, the gas temperature) will be slightly different at the two meter locations, so the actual volumetric flow rates measured by the two meters will not be equal. As an alternative to comparing the field turbine meter and the prover on a mass flow rate basis, the volumetric flow rates recorded by the two meters can be adjusted to 'standard' conditions and then compared. Standard volumetric flow rate is essentially a mass flow rate that has been referenced to arbitrary temperature and pressure conditions (e.g., a predetermined pressure and temperature, such as 14.73 psia and 68°F, respectively) for the flowing gas composition. Standard volumetric flow rate is proportional to mass flow rate through the application of standard gas density and is, therefore, conserved from the upstream to the downstream meter locations.

A calibrated Master Meter run of sufficient size and pressure rating is connected to a three-valve manifold located upstream or downstream of the meter to be tested. Tests have shown that most of the commonly-used turbine meters are relatively insensitive to upstream piping effects. However since piping and field conditions may vary it would be good practice to follow the standard piping configurations shown in AGA Report No. 7 for the Master Meter run. The use of a flow conditioner upstream of the Meter Run is recommended if there is the possibility the Master Meter piping might have an adverse effect on the Master Meter. The Master Meter run must be complete with a Flow Computer, and pressure and temperature transmitter. The Master Meter, it’s associated piping, and electronics should calibrated as an assembly. Test at various pressures can be done and correction factors established for any shift caused by pressure.

The field meter to be tested and the pressure and temperature transmitters associated with it are connected to the proving Flow Computer in such a way that the existing measurement is not affected. Normally the pulses from the meter come from a parallel connection and the analog signals from the pressure and temperature transmitters are connected in series. A device that can measure the gas density, either a Gas Chromatograph or a Correlative device also needed to determine the mass flow. With a Gas Chromatograph the density of the gas is determined by it's composition. A Correlative device uses other means such as speed of sound, thermal conductivity etc. to determine the gas density.

**HIGH PRESSURE PROVING WITH INLINE METERS**

High Pressure proving at various flow rates and pressures can be accomplished with a High Pressure Master Meter Proving system. This system is located where there is sufficient pressure and flow to check all the meters in the system individually.

For example the best location for High Pressure Proving in a distribution system is where gas enters the distribution pipeline. The system here can serve two functions. It can measure the gas being purchased and it can be used to prove all the high pressure meters used downstream in the distribution system.

Routing the flow through the other meters in the system can vary the flow rates through the meter being tested.

The pressure in a High Pressure Proving System can be varied as long as the Master Meter System has been proved at that pressure and it does not affect the downstream system.

**CONNECTING A PORTABLE MASTER METER RUN TO THE FIELD METER SKID**

1. Connect the Master Meter Run to the three valve manifold using either new gaskets or gaskets that are suitable for multiple uses.
2. Connect the electrical cables from the Master Meter, Pressure Transmitter and Temperature Transmitter to either the existing Flow Computer or Connect the Field Meter, Field Pressure Transmitter, and Temperature Transmitter signals to the Flow Computer on the Master Meter Run.
3. Slowly fill the Master Meter Run with gas by opening a small valve usually a needle valve or small ball valve that connects the line pressure piping to the Master Meter. As a rule of thumb pressurization of the line should not exceed one PSI per Second. It is also a good practice to check for leaks with an approved leak detection method while the Master Meter Run is filling. Checking at a low pressure first before the line is completely filled and checked at line pressure can save time and gas if a leak is detected.

4. Open the upstream valve connected to the Master Meter Run.

5. Slowly open the downstream valve that connects the Master Meter Run to the Field Meter Run.

6. Slowly close the Block and Bleed valve downstream of the Field Meter on the three valve manifold putting the Field Meter and Master Meter in series with one another.

7. Follow the Master Meter Proving Procedures usually supplied by the Company for Proving a Master Meter.

8. When the Proving has been completed open the Block and Bleed Valve downstream of the Field Meter.

9. Close the valves connecting the Master Meter Run to the Field Meter and slowly bleed down the pressure on the Master Meter Run. One PSI drop per second is a safe pressure drop rate.

10. Disconnect the Master Meter Run from the Field Prover Skid.

**ONSITE MASTER METER PROVING PROCEDURES**

1. After the Master Meter has been properly installed on the three-valve manifold, the system must be checked for leaks.

2. The precision of the Master Meter should be verified before each prove.

3. The manufacturer of the Master Meter will have a procedure on how to verify the meter is still in calibration. When the Master Meter condition is verified its condition should be recorded on the prove report.

4. Enter the tracking information from the Master Meter or select a Master Meter whose information has already been entered into an existing database.

5. Enter all the information for the Field Meter to be proved or enter the serial number for the information to be entered automatically if it already exists in a database.

6. Prove runs are normally done at 10%, 25%, 50%, 75% and 95% of the maximum rated flow rate of the meter to be proved. These are recommendations only. The test flow rates requested by the end user should be used wherever possible. If the required flow rates cannot be obtained the Field Meter must be proved at the available test flow rates.

Proves can be done based on time or on volume. Either method if performed properly, can produce a good prove. In this example we will use proof runs based on time.

7. Set the time and number of proves for the prove run. The number of pulses generated by the meters will determine the time for each flow run. The time must be long enough for a statistically significant number of pulses to be generated by the lowest frequency output. If the Flow Computer is capable of Pulse Interpolation the time of each run can be shortened in accordance with the API Manual of Petroleum Measurement Standards Chapter 4, Section 6, Pulse Interpolation.

8. The number of proofs at a specific flow rate depend on the client. However, it is recommended that a minimum of three runs be made at each test flow rate to determine if the meter being proved is repeatable.

9. Start the prove. The Flow Computer will automatically stop and start each run, based on the time entered into the Flow Computer. On the first run allow time for stabilization of the flow rate through the meters before beginning the data acquisition.

10. When the prove runs for the specified time and the run is successful, the information is saved in the Flow Computer and/or can be printed out. If the flow rate of the station can be changed, it is recommended that the first test run be performed at maximum flow rate setting. If the meter repeats and is within specifications at the maximum flow it is an indication that it may prove at the lower flows. Proves at all flow rates and operating pressures specified must be done to insure the field meter is operating properly.

11. At any time during a prove run or cycle, the prove can be stopped (Aborted). Aborting the prove stops the proving run. An aborted prove report should be stored or printed.

12. When the prove for all flow rates is complete, the flow control valve closes to the meter run closes, the prove report is printed, and all information is saved electronically in a file for that prove.

**CONCLUSION**

Using available knowledge, products and equipment natural gas meter proving in the field and in the shop can be used to verify the accuracy and repeatability of natural gas measurement systems.
REFERENCES


API Manual of Petroleum Measurement Standards, Chapter 4, Section 6, Pulse Interpolation.

AGA. Report No 6, “Methods of Testing Large Displacement Meters.”