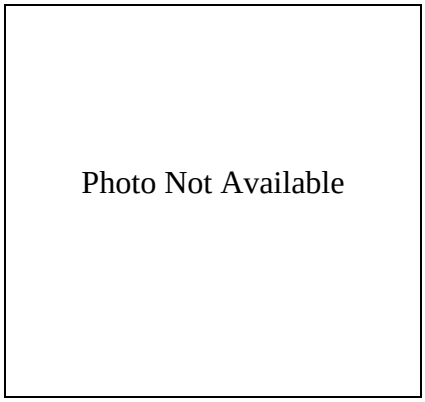
2013 Western Gas Measurement Short Course
Reno, NV

DISTRIBUTION GAS METER PROVING: THE EQUIPMENT AND METHODOLOGY USED TODAY IN THE NATURAL GAS INDUSTRY

GREGORY A. GERM
NORM MUSSETT
ELSTER AMERICAN METER



INTRODUCTION:

To determine the accuracy of a natural gas meter, a known volume of air is passed through the meter, and the meter registration is compared against this known volume. The "known" volume of air originates from the meter prover. In earlier times, the gas meter prover was a stand-alone device (usually a bell-type prover), manually operated without any electronics or automation. Today, the majority of gas meter provers are fully automated; computer controlled and operated, and responsible for other job functions besides the proving of gas meters. The bell-type meter prover – though still commonly used in the industry – is not the only kind of meter prover used today. The advancements and developments in electronics and computer technology has lead to an evolution of meter proving equipment – far from the manual proving methods that were commonplace only a few decades ago. Many utilities have replaced the bell-type prover with sonic nozzle and transfer provers. Provers can now store and retrieve information from a utility's meter management system, reduce the human error factor in the proving operation, and provide self-diagnostics to assist the prover operator in maintenance and in troubleshooting problems.

With the advancements made in gas meter provers, there exists the need to understand gas meter proving "basics". The gas meter prover determines the accuracy of a gas meter.

Although there have been advancements made to the gas meter prover, the prover itself still has measurement uncertainties that can attribute to measurement errors in meter proving. The gas meter prover today may be more accurate than proving equipment in the past, but the proving room environment hasn't changed much – this proving room environment is also responsible for measurement variations and uncertainties.

This discussion will focus on the proving "basics" and terminology commonly used today in the industry. In addition, the three most common types of gas meter provers will be discussed, as well as the means in which they are calibrated and certified. Finally, the factors that attribute to meter accuracy variation - such as prover limitations and environmental conditions – will be addressed, as well as corrective means to reduce these measurement uncertainties.

METER PROVING BASICS:

As stated in the Introduction, the "proving" of a gas meter determines its accuracy. Once the accuracy of the meter is obtained, the meter can be adjusted or repaired accordingly. The meter accuracy can be defined three ways: Percent Proof, Percent Accuracy, or Percent Error. Percent Proof is defined as the known volume (or the standard volume) over the test volume. In the days of strict manual bell-type proving, percent proof was used extensively; due to the fact that the meter proof could be read directly from the bell prover scale (no calculations were necessary in converting the bell scale to a meter proof). Percent Accuracy (the inverse of proof) is defined as the test volume over the standard volume. Percent Error is Percent Accuracy subtracted by 100. Percent Error benchmarks the test results to zero (in other words, a "perfect" meter result would equal 100% proof, 100% accuracy, and 0.0% error). To summarize:

- Percent Proof = $\{V_{standard} / V_{test}\}$ x 100
- Percent Accuracy = $\{V_{test} / V_{standard}\}$ x 100
- Percent Error = $[\{V_{test} / V_{standard}\}$ x 100] - 100

A meter test result will commonly be described as "slow" or "fast". A "slow" meter means that the gas meter is registering LESS volume than what was actually passed through the meter. The end result being that the customer receives more gas than what was billed. Conversely, a "fast" meter means that the gas meter is registering MORE volume than what was actually passed through the meter, meaning that the customer receives less gas than what was actually billed.

To increase accuracy in meter proving (reduce measurement uncertainty), Boyle's Law and Charles' Law can be used to make corrections to changes in air temperature and pressure between the volume standard (the prover) and the test meter. Consider the following equation:

$$(P_{std} * V_{std}) / T_{std} = (P_{test} * V_{test}) / T_{test}$$

Where,

P = Pressure (absolute)
V = Volume (cubic feet)
T = Temperature (absolute)
"Std" = standard, or prover volume
"Test" = test volume (meter)

Meter test results can then be represented in the following manners:

$$\text{Percent Proof} = [V_{std} / V_{test}] * [P_{std} / P_{test}] * [T_{test} / T_{std}] * 100$$

$$\text{Percent Accuracy} = [V_{test} / V_{std}] * [P_{test} / P_{std}] * [T_{std} / T_{test}] * 100$$

$$\text{Percent Error} = \{[V_{test} / V_{std}] * [P_{test} / P_{std}] * [T_{std} / T_{test}] * 100\} - 100$$

At the very least, all proving equipment used today in the industry should be making the necessary corrections in volume pressure and temperature between the standard and test meter. These corrections alone reduce a considerable amount of measurement uncertainty. Certain types of provers – such as sonic nozzle provers – make additional corrections to the standard volume passed through the meter. These additional corrections will be addressed later.

Repeatability of test results is just as important as meter accuracy. Repeatability is defined as the closeness of agreement between any number of distinctly observed values. In other words, how often is the same proof result generated from a meter test? Advanced meter provers produce repeatability in meter test results within +/- 0.1%. Better repeatability helps in

troubleshooting prover issues and measurement errors. Assuming that a prover is well maintained and calibrated, non-repeatability may be attributed to an errant gas meter. A lack of confidence in a prover's measurement condition will create questions regarding repeatability – is the meter or the prover in error? In addition to repeatability, standard deviation is commonly used in the proving environment. By definition, the standard deviation is a measure of how widely values are dispersed from the average, or mean, value. Standard deviation is commonly used in meter sampling programs – newly purchased meters and retrieved meters from an installed distribution base. Reliable, accurate proving equipment – properly maintained and calibrated – will generate smaller standard deviations.

A gas meter prover is used in many different test applications. Provers can be used to test brand new meters purchased by a utility. Meters are normally "sample" tested. In other words, a percentage of the recently purchased meters are tested across a prover. If the sample "passes" the utility's accuracy and statistical criteria, the entire shipment is accepted. Provers are also used to "in-test" meters that have been changed out in the field. An in-test is a simple "as found", or "as is" test. Based on in-test results, age, and physical condition of the meter, the prover will help identify if the meter should be repaired or removed from the distribution population. Repaired gas meters can be tested and adjusted across a prover, prior to final pilot and leak test.

PRIMARY PROVING EQUIPMENT:

There are three main types of proving equipment used today in the gas industry. These provers are:

- Bell-type Provers
- Sonic Nozzle Provers
- Transfer Provers

This section will address each type of prover, the fundamentals of their operation, and the limitations and uncertainties each prover inherently possesses.

Bell-type Provers:

The Bell-type prover is the oldest gas meter prover used today in the industry. Records have shown that bell-type provers have been used by utilities since the early 1900's. The bell-type prover consists of an open cylindrical metal tank filled with oil. A smaller cylindrical metal tank (called the "bell") operates within this outer oil-filled tank. The "bell" is open at the bottom, dome-shaped at the top, and can be raised or lowered within the outer tank. The oil inside the outer tank acts as a seal and prevents air from entering or leaving the bell. Air inside the bell escapes through a standpipe (called the dry well) which extends from the outside of the prover tank, runs underneath the outer cylinder, and up inside the tank to a point slightly above the oil level.

The bell is guided by two sets of rollers at both the top and the bottom of the bell. These rollers revolve against guide rails attached inside the prover tank, and above the prover tank. The guide rods above the prover tank are fastened to a wheel assembly above the prover. This wheel assembly supports the axle of the large counterbalance wheel and the cycloid lever arm, and rotates in brackets mounted to the wheel assembly. The weights that "counterbalance" the prover bell are attached to a chain, which is carried over the large counterbalance wheel and fastened to the bell by an additional set of three smaller chains. Weights may be added or removed from the counterbalance to change the air pressure inside the bell. The cycloid lever arm attached to the counterbalance wheel has a

smaller weight attached to it, which keeps air pressure inside the bell constant as the bell descends into the oil. Variations in bell pressure depend on the size of the bell, and should be kept to a minimum to insure proper bell operation.

A bell prover can be filled with air using two different methods: supply air may be piped in to the bell from a secondary source (such as an air compressor), or the bell may be manually filled with air by opening a circular slide valve on top of the standpipe and pulling down on the counterbalance chain. Once the bell has been raised to the desired level, the slide valve is closed off.

A bell scale – in increments of cubic feet – is fastened to the outside of the bell or to one of the three columns supporting the wheel assembly. As the bell descends into the oil, a pointer – either attached to the bell or to the outer tank – reads the volume of air passed by the bell.

Bell-type provers can be used to test a wide variety of gas meters – including transmission meters (large rotary and turbine meters). Larger bell provers hold a larger volume of air. The flow rate of air traveling from the bell is controlled using "rate caps". These rate caps are commonly placed downstream of a gas meter, and an orifice is drilled through this rate cap to allow the prover air to escape through. The size of the orifice is a function of the bell prover pressure. In other words, bell provers with greater air pressure require a smaller orifice than bell provers with less air pressure – to generate equal flow rates.

The operation described above assumes that the gas meter is downstream of the bell prover. The weighted bell prover (under slight pressure) pushes air from the bell through the gas meter, at a specific flow rate controlled by the rate cap (attached to the meter's outlet). Bell Provers can be used under slight "vacuum" conditions. In this vacuum application, the gas meter is upstream of the bell prover. The bell prover counterbalance is weighted so that the air inside the bell is at a pressure slightly below atmospheric. The rate cap is placed on the meter inlet (as opposed to its outlet), and atmospheric air is allowed to travel through the rate cap, through the test meter, then into the bell prover. The bell prover is "filled" in this application, as opposed to being "emptied".

Assuming a positive pressure application, the following procedure describes how a meter is tested using a bell-type prover:

The bell is filled with air and a gas meter is placed downstream of the bell. The meter is attached to the bell prover outlet using a piping assembly or a proving hose. The outlet of meter is closed off, and the bell prover observed for any leaks in the system. Once the meter has passed its leak test, a specific rate cap is placed on the meter outlet. This rate cap equals the meter's "open" rate (normally its badge rating at a 0.5 inch WC differential) or a "check" rate (20 to 30% of its badge rating). Open and check rates vary, depending on the utility and state utility

commission requirements. The meter index is observed for complete rotation. As air leaves the bell, it is passed through the meter and the index starts to rotate. Once the meter index completes one or more full rotation, the prover scale is read to determine how much air has passed from the bell. This "known" volume is compared to the volume registered by the meter, and the meter accuracy can then be computed.

If a bell prover is used "manually", the operator is responsible for starting and stopping the test at the same point on the meter index, and for reading the prover scale. Normal manual bell operations do not take into account changes in temperature and pressure between the bell prover and the gas meter. For this reason, climate control is extremely critical, in that the gas meter and the bell prover must be at near equal temperature (within 1^{o} F). Additionally, the pipe or hose between the bell and the gas meter inlet must be of sufficient diameter, so that pressure losses between bell and meter are minimized. For every one-degree difference in temperature between the bell prover and the gas meter, measurement error increases +/- 0.2%. For example, a five-degree difference in prover and meter temperature results in a measurement error of 1%. Therefore, climate control and proper meter acclimation is critical for manual bell-type proving operations.

In the 1960's and 1970's, manual bell proving was replaced with automation. Bell prover controls – such as bell "filling", leak testing, exercising, and meter proving (bell emptying) – were automated to decrease meter test time and operator involvement. Electronics were incorporated in to the proving system to measure bell and meter temperatures, as well as bell and meter pressures. By correcting for Boyle's and Charles' Law between the bell and meter, measurement uncertainty decreased. Additionally, a bell encoder was incorporated to read bell prover volume. As the bell prover descends into the oil, the bell shaft encoder rotates. The number of revolutions of the bell encoder is translated into distance traveled of the scale – this "traveled" distance is then converted to bell prover volume. An optical pick-up assembly was incorporated to read meter volume. The optical pick-up not only reads the meter volume, it also is used to start and stop the proof test. Automated bell provers can also select between open and check rate caps (usually piped in parallel downstream of the meter).

The bell-type prover is a true volume-to-volume proving device. In other words, the prover contains a known volume of air, and this contained air is passed through the gas meter. Other provers, such as sonic and transfer provers, are dynamic provers in that these standards measure a flowing quantity of air, as opposed to physically containing a known quantity of air. The bell-type prover, however, has many limitations that increase measurement variation and uncertainty.

- The bell-type prover is mechanical, and friction plays an important role in accuracy and repeatability. Dirt and contaminants will effect bell prover travel, and lead to non-repeatability between consecutive proof tests.

- The bell encoders will wear over time. As an encoder ages, the high-density pulse beads contained within the bell encoder tend to deteriorate and become damaged. This damage changes the bell encoder "pulse" value (cubic feet of scale read per revolution of the bell encoder) and can lead to measurement error.

- The test time across a bell-type prover is much longer than more modern, sonic nozzle provers. Complete rotations of the meter

index are required to obtain a meter proof result. Additionally, the bell prover has to be filled between open and check rates. Another form of meter gating a test – called "pulse" proving – decreases test time. "Pulse" proving monitors the meter's differential pressure, and this characteristic is converted into smaller volumes passed by the meter diaphragm (revolutions per cubic feet of each diaphragm rotation). A smaller test volume can be used to calculate meter proof. "Pulse" proving, however, has limitations. Older meters with more wear and less predictable differential pressure curves may not prove accurately using "pulse" proving. Repeatability also becomes a factor when using "pulse" proving on older meters.

- The size of the bell prover limits the types of meters that it can test. Two cubic foot and five cubic foot bell provers are usually limited to testing residential meters up to class 500. Larger bell provers (ten and twenty cubic foot bells) can test light commercial and industrial meters (to class 5000). Larger size meters – specifically transmission meters – can only be tested across bell provers greater than fifty cubic feet in size. The meter index, as well as the prover piping, dictates the size of the bell prover necessary for proper proving.

- Even though an automated and fully computerized bell prover makes corrections for temperature, strict climate control and proper meter acclimation is critical. The bell prover sealant – usually mineral oil – changes temperature much slower than the air inside the bell. For this reason, tight climate control is required within the proving room, so that rapid temperature fluctuations are minimized.

- The bell-type prover is highly sensitive to vibrations. Mechanical "noise" created by conveyors, compressors, and other shop machinery must be located away from bells isolated for floor vibration. These vibrations will cause non-repeatability in the bell encoder readings and the position of the meter index sensor.

- Bell provers are no longer made. Some of the antiquated electronics used on first and second generation automated bells of the 1970's and early 1980's are no longer available, which can lead to considerable "downtime" in the event of a prover failure.

Sonic Nozzle Proving:

Over the past fifteen years, sonic nozzle provers have been replacing stand-alone and automated bell provers as the choice for proving smaller class gas meters (residential and light commercial meters). Not only are sonic nozzle provers more efficient and smaller than their bell prover counterparts, their measurement uncertainty is half of automated bell proving systems.

The sonic nozzle provers use sonic nozzles, or critical flow "Venturi" nozzles, as the volume standard. A sonic nozzle is a rounded edge orifice that converges into a small diameter called the "throat". As fluid (or air) passes through the inlet portion of the nozzle, thermodynamic properties allow one to calculate the pressure and temperature conditions at the throat. If a sufficient pressure drop is created between the inlet and the exiting throat portion of the nozzle, the local speed of sound is reached at the throat. In essence, the velocity of air, multiplied by the cross-sectional area in which the air is passing through, is equal throughout a certain length of travel. Air moving from a larger cross-sectional area will have a smaller velocity than the same air

as it passes through a much smaller cross-sectional area (much higher air velocity). Once the local speed of sound is reached at the throat, the volumetric flow through the nozzle is held constant, as long as the fluid traveling through the nozzle remains "attached" to the inside wall, and the pressure differential between nozzle inlet and outlet is maintained.

Early nozzle designs required a pressure differential of approximately 53% between nozzle inlet and outlet. This large differential requirement limited the nozzle's use in gas measurement. Experimentation by NASA in the 1960's determined that the required pressure differential across the nozzle could be reduced by using a "recovery cone". This recovery cone – attached downstream to the nozzle throat – preserves the nozzle throat plane and allows the fluid (or air) traveling through the nozzle to remain attached to the inside wall. Static pressure is "recovered" as fluid travels through the cone, allowing sonic velocity to exist at the throat with a much smaller pressure differential (between 80 to 90% required at the outlet, as opposed to 53%). The following statements can be made regarding the use of sonic nozzles in gas measurement:

- The sonic nozzle element restricts upstream volumetric flow by achieving local sonic nozzle velocity (speed of sound) at the nozzle throat. Once sonic velocity is achieved, the mass flow rate through the nozzle is held constant. By knowing the properties of the fluid traveling through the nozzle (specific gravity and thermodynamic), the volumetric flow rate of the air can be calculated.

- The sonic nozzle can operate within a wide range of pressures and temperatures, as long as a sufficient pressure drop across the nozzle is maintained (between 80 to 90% of the inlet pressure).

- The ASME/ANSI standard "Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles", and the AGA technical note "The Theory and Operations of Meter Shop Sonic Nozzle Provers for Residential and Commercial Meters", are noteworthy references for advanced knowledge of using sonic nozzles and the equations used to derive sonic flow conditions.

A sonic nozzle can be used as a proving device by simply placing one or a number of nozzles immediately downstream of a gas meter. A number of nozzles in parallel can be used to generate a variety of flow rates. A vacuum source downstream of the sonic nozzles creates the necessary pressure differential across each nozzle to produce sonic flow. Atmospheric air from the proving room is pulled through the gas meter and through the sonic nozzles. A complete sonic nozzle proving system incorporates the following:

- A solenoid valve upstream of the test meter inlet closes off to perform system leak testing prior to proving.

- Meter differential pressure, and differential pressure between the meter inlet and the nozzle plenum is measured for Boyle's Law correction.

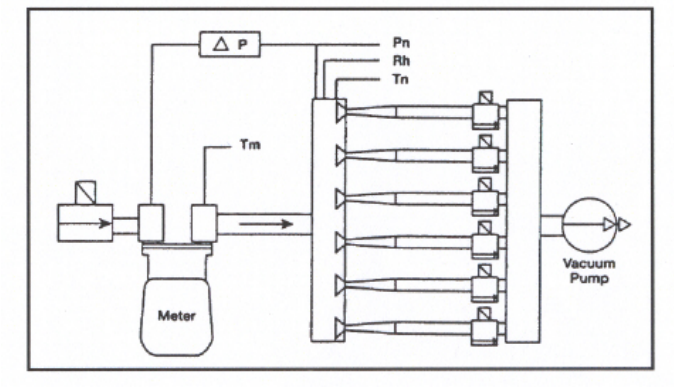
- Meter and nozzle plenum temperatures are measured to calculate Charles' Law correction between meter and nozzles. The recorded nozzle temperature, as well as the nozzle absolute pressure and the relative humidity, is also used to determine local speed of sound at each nozzle throat, and therefore the actual flow rate traveling through the prover.

- A filter element is normally placed between the meter outlet and the nozzle inlet plane to

remove dirt and contaminants that may exist within the meter.

- Solenoid valves are located immediately downstream each nozzle to create the desired flow rate.

- Further downstream, a vacuum source generates the flow medium.



Meter shop provers usually contain between four and seven sonic nozzles, and can vary flow rate between 25 and 2000 cfh. The sonic nozzle prover provides an adjustable table for small and light commercial meter testing, a monitor for interfacing between the prover and the operator, and a state of the art computer enclosure that monitors and controls all proving and data collection operations.

A typical meter test across a sonic nozzle prover may be described as follows:

- The operator selects the type of meter to test and its test requirements, and enters specific meter information into the prover (such as serial number, index reading, etc…).

- The sonic nozzle prover performs a system leak test between the test meter and nozzle block.

- The meter is exercised for a pre-determined period of time (or a preset volume), then an open and check rate test is performed.

As the open and check rates are running, the prover computer samples meter and nozzle temperature, nozzle pressure, pressure differentials, and relative humidity. The averages of these readings are computed during the length of the test, and after a preset volume has passed through the meter, the meter proof result is calculated.

- After open and check rate testing, the operator can choose to re-run the test, accept proof data, adjust the meter tangent, accept the data, and/or classify the meter for repairs or retirement. The prover software prompts all of the above choices. Sonic nozzle provers can also be programmed to detect operational problems with the unit, such as insufficient vacuum for sonic flow, errant temperature readings, meter leak, high pressure drop between meter and nozzle block, or inaccurate meter signal detection.

A sonic nozzle prover uses three types of methods to gate and compute meter volume. A magnetic sensor assembly can be used on aluminum case meters. This magnetic sensor assembly measures the deflections of the meter's diaphragm during a test. By knowing the meter diaphragm revolutions per unit volume, the meter volume can be computed. The magnetic sensor assembly is a very accurate method of computing meter volume, and meter tests can be performed in one-third of the time it takes the same meter to be proved across a bell-type prover using an optical index sensor. "Pulse" proving is also an

option with sonic nozzle provers. Similar to "pulse" proving on bell-type provers, the meter differential pressure curve is closely monitored, and spikes in meter differential pressure are equated into a registered meter volume. Similar to bell proving, however, "pulse" proving may not be accurate with older, more worn gas meters. If a tin or iron-case meter cannot be proved accurately using the "pulse" proving method, then an optical index sensor can always be used to measure meter index rotations.

Sonic nozzle provers have several advantages over conventional bell proving systems:

- Proof test time is dramatically reduced using the magnetic sensor assembly or "pulse" proving.

- The sonic nozzle prover can operate over a wide range of temperatures and ambient pressures. The sensitive electronics can accurately measure slight changes in environmental conditions through the course of a meter test, and a sonic nozzle prover does not require the strict climate controls and near-constant environmental conditions that bell provers need.

- The sonic nozzle prover itself is compact, close-coupled, and portable. If necessary, the prover can be moved to various locations within a proving room. The close coupling of the prover allows for less piping between meter and nozzle block.

- Sonic nozzle provers aren't limited to the meter shop. Pilot tests have proved that residential meters can be proved accurately "in the field" using a modified sonic nozzle prover. A "curb-side" prover can be used as a portable meter shop, where the prover is actually taken to the meter, instead of taking the meter to the field. The portable meter shop contains the sonic nozzle prover, as well as a mini proving room environment with modest climate control and tools necessary to perform minor meter repairs. The curbside prover automatically acclimates the meter until the thermal gradient between the test meter and the sonic nozzles has stabilized. This automatic acclimation routine reduces measurement uncertainty created by temperature.

With all of the advantages to sonic nozzle proving, there are a few minor concerns. Sonic nozzle provers aren't cheap – a utility can expect to pay as much as $40,000 for a state of the art sonic nozzle prover with a variety of options. This investment, however, is worth the money, considering the increased accuracy and efficiency a sonic nozzle prover provides over bell-type provers. The required vacuum source also poses a concern. The greater the capacity of the sonic nozzle prover, the larger the vacuum source that is required to pull the necessary flow. These large vacuum sources can become very expensive, especially when a sonic nozzle prover is

considered for testing larger industrial and small transmission meters. For this reason, many utilities choose to test larger industrial and small transmission meters using transfer provers.

Transfer Provers:

The concept of transfer proving has been around for over forty years, and it provides a means for utilities to test larger class gas meters without using a very large bell prover (20 cubic foot or greater), or large sonic nozzle proving system. Transfer provers can be used inside the gas meter shop or in the field, depending on the particular make-up of the prover. The test meter registered volume is compared to a known volume passing through a "master meter". This "master meter" is a certified meter that has been tested across another prover standard, usually a large bell-type prover. The phrase "transfer proving" was created because the test meter is being proved using another meter, where the standard has been transferred from the bell-type prover (or the standard in which the master meter was proved across) to the master meter. Transfer proving systems range from 10,000 cfh up to 80,000 cfh. Master meters can range in size from 2M capacities to 80M capacities.

Master meters are usually built to tighter tolerances than normal production or usage meters. These tighter tolerances, combined with high pulse outputs for registering its own meter volume, allow these meters to be used in a proving environment. Most transfer proving systems operate under a slight vacuum. The test meter is placed upstream of the transfer prover. Meter differential and meter to master meter differential pressure are recorded, as well as test meter and master meter temperature. As the case with other proving methods, the transfer prover will calculate the necessary Boyle's and Charles' Law corrections between the test and master meter. Test meter volume can be gated using one of two primary methods – an optical sensor can observe meter index rotations, or a low-density volume encoder can be used on the meter index wriggler. Transfer provers can be modified to read electronic outputs from meter correctors, increasing the prover's testing abilities.

The transfer prover computer and software can control flow rate electronically. Older style transfer provers allow the operator to set the flow rate. A flow rate indicator is provided with these older transfer provers to help gauge the rate of air through the prover. Newer transfer provers use an electrically actuated gate valve to set the flow rate. These newer transfer provers will also perform the entire test – without operator assistance – after pre-set parameters have been entered into the prover. The preset parameters include test meter volume registration (index drive), test volume, selected master meter (assuming a "piggy-back" style transfer prover is being used), number of runs, number of different flow rates, and meter output (uncorrected of TC compensated).

A typical test procedure using a transfer prover may be described as follows (assuming the prover is being used at the utility meter shop):

- The operator connects the test meter to the prover, as well as all hosing and sensor connections. The test meter has already been purged of natural gas prior to testing.

- The operator enters all necessary preset parameters into the transfer prover computer, as described above.

- The transfer prover will check all pressure sensors, to make certain all differential pressures have been zeroed properly, and a leak test routine may be performed on the meter at this time.

- The transfer prover will start the test by setting the open rate and watching meter and master meter temperatures. Once stabilization has occurred with the flow rate adjustment, and thermal gradients between test meter and master meter are held constant, the prover will initiate the open rate.

- After performing one or more open rate tests, the prover will reduce the flow rate, wait for stabilization, and perform the check rate test.

- After all testing, the prover provides options to the operator, such as re-testing or saving of data.

Transfer provers used in the field follow similar procedures to the above description, with some changes to the prover set-up. Most meters tested in the field remain piped to the meter set. The meter is isolated from line conditions by closing off its inlet and outlet valves, and opening the by-pass valve (for continued customer consumption). After the meter has been purged of natural gas, the transfer prover hose is attached to the meter outlet piping. The meter is then proved in a similar manner to the in-house meter test.

The advantages to transfer provers are their compact and portable design, low cost, and ease in testing larger class gas meters. However, there are several disadvantages to the transfer prover that affects meter measurement uncertainty. Of all three primary proving methods, the transfer prover is the least accurate. Most transfer provers have measurement uncertainties of +/- 0.5%. When compared to typical sonic nozzle prover uncertainties of +/- 0.15%, one can see just how much more accurate sonic nozzle proving systems are over transfer provers. The master meter – though built to tighter tolerances – is vulnerable to damage. Strainers are normally placed between the test meter outlet and the master meter inlet, but these strainers normally do not remove fine dirt particles. Over time, dirt can accumulate inside the master meter measurement chamber, and lead to errant proof results. Transfer provers that use an impeller-type master meter may see measurement uncertainties due to flow pulsations between the test meter and master meter. Certain types of test meters may create a downstream resonance at specific flow rates. These impeller-type master meters are sensitive to flow resonance, and the end result is fluctuating master meter volume registration and increased measurement uncertainty. Some manufacturers have actually recommended specific length of piping and dampeners between the meter outlet and the master meter inlet to help reduce flow resonance. Finally, test times are lengthy with transfer proving (most of the time), as the prover has to use a test volume that equals a full rotation of the test meter's index drive.

CALIBRATION / CERTIFICATION OF PROVING EQUIPMENT:

Measurement uncertainty and variations in meter test results can be minimized and controlled as long as the proving equipment is properly

maintained, calibrated, and certified on a regular basis. Maintenance of a prover involves minor upkeep and enhancements to keep the prover functioning properly on a day-to-day basis. Calibration of a prover includes the accuracy of sensing equipment (pressure and temperature sensors) and volume recorders. Certification of a prover – mandated by state public utility commissions – are a necessity to regulate accuracy in the entire proving system and verify the use of the prover as a standard for gas meter testing.

Calibration and Certification of Bell-type Provers:

On an automated bell-type prover, calibrations should be performed regularly on the following components: bell prover and test meter temperature probes, bell absolute pressure transducer, bell to meter and meter differential pressure transducers, and the bell prover encoder. Calibrations of these sensors should not go unchecked for more than a year. During the calibration process, the bell prover pressure should be checked to make certain the bell is balanced throughout its scale range. Bill prover fill and empty solenoid valves may also be checked for proper operation. All flow rate caps should be checked to insure that the various caps are passing the desired flow rate. A flow rate cap should be sized within +/- 5% of its stamped rate value.

As far as bell prover certification goes, there are two distinct methods of certification. These methods are "bottling" and "strapping". Most state public utility commissions recognize both methods as a means to certify bell provers. Bell provers may be certified once every two years up to five years, depending on the state.

The "bottling" of a bell prover is a direct volume-to-volume comparison between a cubic foot standard and the bell prover. A cubic foot bottle (stand alone or a Stillman portable bottle) is connected to the bell prover. The bottle itself acts like a mini bell prover, but the certification of the bottle is directly traceable to NIST (The National Institute of Standards and Technology). Air from the bell is passed into the bottle, or air can be pushed from the bottle into the bell prover. Once the bottle has filled or emptied, the bell prover scale is observed between cubic foot increments. Perfect bell prover scales will show no volume deviation when observed after bottling. Bell prover scales that are "shorter" than one cubic foot will read a volume greater than one cubic foot. In other words, if the bell prover scale is being bottled from 0 to 1, and the pointer on the bell prover is above the one cubic foot line after the bottle has been emptied, then the bell prover scale is short, which may result in "slower" than expected meter proofs. Conversely, bell prover scales that are "longer" than required will show a pointer reading below the one cubic foot line, resulting in "faster" than expected meter proofs.

Bottling of a bell prover is a highly subjective test. Usually the bell prover scale is observed using the naked eye. More accurate readings may be measured using a high-powered scope centered on the bell prover pointer, so the bell prover scale around the cubic foot is magnified. Bottling is sensitive to temperatures. Since the bottling certification is a volume-to-volume comparison, accuracy in certification depends on how closely the bottle air temperature is to the bell prover temperature. For this reason, bottles are normally set up a day in advance – next the bell prover – of the certification. Bottling certifications should not be performed if the bell prover oil and the bottling oil temperatures are over a degree apart, due to changes in air volume based on Charles' Law.

Most bell provers are certified by the Strapping method. Strapping of a bell prover

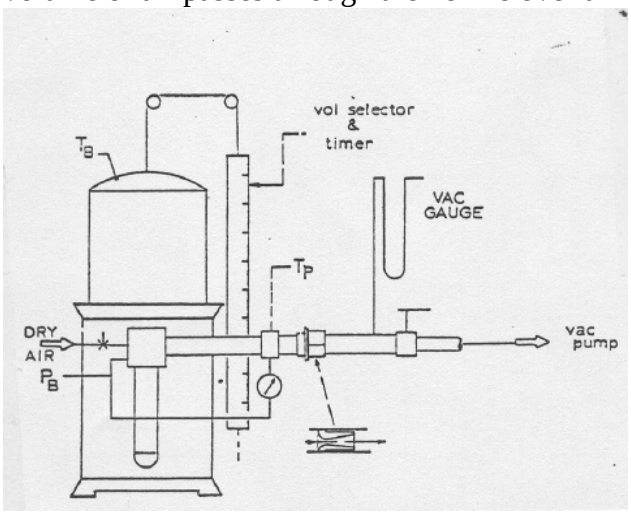
measures physical properties of the bell, such as the diameter of the inside bell cylinder, the oil displaced by the bell as it travels into the oil sealant, the annulus width of the oil sealant that is being displaced by the bell, and the bell prover scale. Based on bell diameter and oil displacement, an "ideal" scale length is computed for the bell. This ideal scale length is compared to the actual scale length of the bell, and therefore the percent error of the prover scale is known. The proving room temperature is not critical when bell prover strapping is performed. Also, strapping provides a calculated error of the bell prover scale, whereas bottling is a subjective error. Strapping should always be used if the bell prover is a master bell prover used for sonic nozzle bell interfacing (this will be described later). Strapping, however, is not a good means for bell prover certification if the bell cylinder is slightly damaged or dented, as the bell diameter measurement may not be accurate.

The strapping or bottling of a bell prover, combined with proper calibration of the shaft encoder and sensors, provides a certification of the entire proving system.

Calibration and Certification of Sonic Nozzle Provers:

As the case with bell type provers, the calibration of a sonic nozzle prover is separate from its certification. Most sonic nozzle provers allow sensors (such as nozzle and meter temperature, differential pressure, absolute pressures, and relative humidity) to be calibrated "on-screen" using a two-point calibration. During the calibration process, simple maintenance issues, such as the cleaning of nozzles and solenoid valves, as well as replacement of the nozzle inlet filter element, should be considered. The magnetic sensor assembly should be checked for proper voltage deflection, and the meter differential pressure transmitter must be accurately calibrated, as this sensor is used for "pulse" proving applications.

The sonic nozzles themselves are factory-calibrated using a bell prover. The calibration of each sonic nozzle element determines how much volume of air passes through the nozzle over time.



A sonic nozzle should be calibrated as close to its operating pressure as possible. If the sonic nozzle element is used in a vacuum proving application (like the majority of sonic nozzle provers), the calibration of the nozzle should be performed at or near atmospheric pressure. The nozzle element is placed downstream of a master bell prover (of known scale accuracy). Since the bell prover pressure is usually set at 1 ½ inches of water column (for most residential meter applications), the sonic nozzle flow rate results can be standardized to a base condition of 14.696 psia. The bell prover scale is "gated" per volume increment with the use of a photo-optic sensor.

The time it takes for the nozzle to evacuate a known volume of air is also recorded. After making corrections for the ideal gas laws, compressibility, specific gravity, and Reynolds Number (the nozzle's discharge coefficient), one can compute the "time constant" of the nozzle, also called its "T_S" value. The time constant is

time – in seconds – it takes for one cubic foot of air to pass through the nozzle, standardized to a base condition of atmospheric pressure, dry air (0% relative humidity), and 60 ^{o}F. Standardizing the time constant to these conditions allows the nozzle to be used at a variety of pressure, temperature, and humidity conditions.

Over time, the entire sonic nozzle prover can be certified against a master bell prover by "bell interface". To perform a bell interface, a utility's master bell must first be certified using the strapping method. As stated earlier, the strapping method determines the percent error of the prover scale. Each individual nozzle is then "proved" using the master bell. The sonic nozzle prover is married to the master bell, and the bell is proved as if it were a gas meter, except the accuracy of the bell prover is known. The scale error becomes the "target" proof of the bell interface. Each nozzle is individually opened to the bell prover, and the bell prover volume passes through the selected nozzle. The sonic nozzle prover will then record an interface proof result. This proof result should be within +/- 0.1% of the bell prover's target proof. Any deviations greater than +/- 0.1% tell the user that the nozzle is slightly out of calibration, and it's T_S value may be corrected to the bell prover target proof. It is important that ALL sonic nozzle prover sensors are properly calibrated prior to the bell interface test, and each nozzle is thoroughly inspected and cleaned, if necessary. Many public utility commissions accept the bell interface as an accurate method for verifying sonic nozzle prover accuracy and certification.

Calibration and Certification of Transfer Provers:

Transfer Provers are calibrated and certified in a similar manner to sonic nozzle provers. The transfer prover temperature and differential pressure sensors are calibrated separately using individual standards. Test meter volume generators and the master meter high-density volume encoder should be checked for proper operation and should be free from binds, drag, or "slippage".

The transfer prover's master meters are certified separately, usually using a bell-type or a piston-type prover. The master meter is removed from the transfer prover, inspected, cleaned, and flushed. The meter's measurement chamber is timed for proper operation, and its bearings may be replaced. The meter is then tested across the standard (again, of known accuracy and proper certification) at a large number of flow rates. Test flow rates can range from sixteen to thirty separate flows, encompassing the entire range ability of the master meter. The meter's accuracy curve is recorded over its range ability, and these accuracy results translate into its new "presets". These master meter presets are programmed in to the transfer prover, so that the transfer prover can make proper volumetric corrections to the test meter. Public utility commissions require transfer prover to be certified usually once every five years.

For all type of gas meter proving equipment, it is good common practice to test several reference test meters (or "correlation meters") across the prover after calibration and certification. These correlation meters are kept in excellent condition by the utility, and are used solely for verification of meter proving equipment. Correlation meters have a relatively known accuracy value that doesn't change over time, due to the fact that they are not used much by the utility. In addition, correlation testing provides a benchmark for each prover, after calibration and certification. Correlation meters should be tested across each prover daily or weekly, to verify that sensor calibrations haven't drifted and to verify the accuracy in proof results.

FACTORS THAT AFFECT PROVING RESULTS:

During a typical day of using meter proving equipment, there exist a number of operational and environmental factors that may increase measurement uncertainty. The proper calibration and certification of proving equipment is vital for measurement accuracy, but even the most recently calibrated and certified proving equipment may calculate false meter proofs due to these operational and environmental factors. The majority of these factors deal with the proving room itself, and the conditions that exist around the prover and the handling of gas meters. The primary factors that lead to measurement uncertainty are ambient temperature conditions, meter acclimation, material handling, and prover operational error.

Ambient Temperature Conditions:

Temperature variation between test meter and prover is the greatest contributor to measurement uncertainty. If bell-type provers are commonly used, the ambient temperature within the meter shop must be maintained to strict tolerances. If bell-type provers use compressed air to fill the bell in-between meter tests, this fill air must also be properly acclimated to the proving room environment. When possible, temperature variations between test meter and prover should be within +/- 1 ^{o}F. If the temperatures between the two are greater (which can be the case with sonic nozzle proving), then the thermal gradient, or difference between the test meter and nozzle plenum or master meter (transfer proving) must be held constant to insure minimal measurement uncertainty. A compromise in the meter shop climate control system – especially with bell-type provers – will lead to less accurate meter proof results. To reduce the effect of temperature on meter proof variation, all type of proving equipment should be located away from direct overhead lighting, open windows or doors, and direct sunlight. Provers should be located away from air-handling diffusers, so as the warm or cold air coming from the climate control system is not blowing directly on the prover. These diffusers should be deflected away from proving operations. Temperature controls should be left on at the end of each day and over the weekend, and should not be turned off for any other short periods of time. If a temperature control system is turned off for an extended period of time, then meter proving operations should not begin immediately when these systems are turned back on. Time is required for the proving room temperature, the meter provers, and the test meters to balance out. Good meter shops perform regular temperature audits of the proving environment using chart recorders or thermal readouts.

Meter Acclimation:

Within the gas industry, there exists the misconception that gas meters do not have to be acclimated prior to sonic nozzle proving. This is completely untrue. Regardless of the type of meter prover, all gas meters should be acclimated close to the temperature of the prover. If a gas meter is not properly acclimated, then as air flows from the prover through the gas meter (or from the meter to the prover, as the case with sonic nozzle and transfer proving), the thermal gradient, or the difference in temperature between the prover and the gas meter, will change rapidly. The prover will calculate an average meter and prover temperature during the course of the proof test. If the thermal gradient is large, the average temperature values will not be accurate, and measurement variation and non-repeatability in consecutive meter tests will result. For sonic and transfer proving, a temperature difference may exist between meter and prover, so long as the

thermal gradient is held constant and is not changing rapidly over time.

Good practice is to allow gas meters to acclimate within the meter proving room overnight. As long as the proving room's thermal controls are operating properly, overnight meter acclimation will eliminate temperature variance as a source of measurement uncertainty. Gas meters should not be placed directly on the floor. The floor itself is usually cooler than ambient conditions, and may alter the temperature within the meter chamber. Meters that are packaged require more time to acclimate, because the package material will act as an insulator. Also, palletized gas meters will take longer to acclimate than separated, individual gas meters. Separated gas meters have more surface area exposed to the ambient temperature than palletized meters. One can visualize a number of small ice cubes taking less time to melt than one large ice cube. The proving room should not be filled with a large number of meters, as the temperature of these meters may cause the climate control system to operate harder than expected.

Material Handling:

The gas meter is the utility's "cash register", and should be treated as such. Mishandling of gas meters may lead to meter damage and non-repeatability in meter proof results. Simply, great care should be exercised when handling and transporting meters in to and out of the proving room, as well as all aspects of meter repair and inventory.

Prover Operational Errors:

Each individual type of meter prover may experience operational problems that will lead to measurement uncertainty. Though there are countless small problems that may exist with a prover, below are a few of the problems and concerns encountered with each type of prover that will lead to significant measurement uncertainty.

Leaks:

Besides temperature variation, leaks are the second major cause of measurement uncertainty with manual bell-type provers. All gas meters should be system leak-tested across a manual bell prior to proving. Most automated bell provers, as well as all sonic nozzle and most transfer provers, will automatically perform a system leak test prior to proving. System leaks will affect the check rate test result more so than the open rate, since there is a smaller flow rate traveling through the system. Meter check rate results will show significantly "slower" readings than then open rate.

Excessive Prover Wear:

Bell encoders will wear over time, leading to false bell prover counts. An automated bell prover uses encoder counts to calculate bell volume. If the encoder is worn, then the bell encoder may not be "counting" the correct number of turns or rotations of the encoder, which will ultimately lead to proof uncertainties. If sonic nozzle prover filter elements aren't properly cleaned and replaced over time, then dirt will form on the inside of the nozzle at the throat. The dirt will actually reduce the effective throat diameter, and theoretically alter the nozzle time constant. Dirt and foreign matter will result in slower meter proof results, due to a slightly longer than required test time. For transfer provers, dirt may damage the measurement chamber of the master meter, which will then change the meter presets. The transfer prover will then falsely correct the master meter volume, resulting in errant proofs. Failing master meter bearings will affect the timing of the master meter, also leading to errant proofs.

Improper Valve / Control Operation:

For automated bells, if bell fill and empty solenoid valves aren't working properly, then changes in actual volume traveling through the test meter may result. If a bell "fill" solenoid valve doesn't close off properly, then fill air will travel through the test meter, falsely showing "fast" meter proof results. For sonic nozzle provers, a faulty nozzle solenoid valve that doesn't close properly will cause air from the gas meter to travel through a nozzle not intended for use, resulting in fast meter proof results. Conversely, if a nozzle solenoid valve doesn't open properly, then meter proof results will be "slow", due to the fact that sonic velocity may not exist at that particular nozzle.

Flow Rate Errors:

Gas meters do not have a true flat-line curve in meter accuracy versus flow rate. If the wrong flow rate is selected as the open or check rate, the meter may be performing differently than expected. Additionally, if a gas meter manufacturer provides proof results at different flow rates than the utility is testing the meter at, then correlation errors may exist between manufacturer and utility. It is critical that communications exist between manufacturer and utility, so that equal flow rates are used for new gas meters. Transfer provers may have difficulty in setting specific flow rates, due to flow pulsations and flow resonance.

As stated in the previous section, correlation meters should be used daily across all proving equipment, to insure proper calibration and operation and various flow rates and test conditions.

CONCLUSIONS:

Proving is a critical part of a gas utility's operation. Meter proving results are translated to all aspects of a utility's data management, inventory, and billing system. Sacrifices should not be made to the quality of meter proving equipment, equipment maintenance, and the environment in which the provers operate. Understanding the limitations of meter proving equipment and the fundamentals of the equipment's operations reduce human error in gas meter testing, maximizes meter shop efficiency, and reduces measurement variation and uncertainty. Internal audit procedures for daily and weekly reference meter correlation testing should be followed to guarantee accurate prover performance, and insure proper prover calibrations. If possible, the prover manufacturer should be contacted in the event measurement uncertainties develop to a point that can no longer be addressed by the utility itself. Meter shop personnel should attend prover manufacturer workshops, participate in hands on classes and training courses, and thoroughly read and review owner's manuals. Preventative maintenance and a solid understanding of gas meter proving will also help guarantee measurement confidence in determining the accuracy of the utility "cash register".