Ensuring a High Level Confidence in Sonic Nozzle Test Equipment Used to Certify Domestic Gas Meters

A.J. Cockshott

Landis+Gyr, 50 Cyanamid Street Laverton North Vic 3026, Australia.
E-mail : antony.cockshott@landisgyr.com

Abstract

The validation and verification of sonic nozzle test equipment are typically conducted on an annual basis. This involves the comprehensive calibration of multiple pressure, temperature and relative humidity transmitter's, time measurement and the calibration of sonic nozzle factors to determine the overall system accuracy calibration.

When manufacturing and certifying domestic gas meters to a very tight tolerance, it is common to utilise a check meter to ensure the continued accuracy of sonic nozzle test equipment since its last verification. Analysing the error percentage drift of the check meter over time, allows the organisation to determine the level of confidence of the test equipment between successive equipment verifications. But when considering the uncertainty of the test equipment combined with the repeatability of a check meter, what variation in error percentage of the check meter does one consider acceptable?

This paper analyses the effects of pressure, temperature, relative humidity and time measurement on overall equipment accuracy which has led to the development of an equipment verification system. The equipment verification system is a tool which enables the earliest possible detection of any critical sensor drift which in turn ensures, with a high level of confidence that the sonic nozzle test equipment is working as designed and as close to calibration specifications as possible.

1. Introduction

Domestic diaphragm meters are required to have an initial performance meter error of ±1.5% from 0.2Qmax to Qmax as specified in the Australian Standard AS4647 [1]. However, diaphragm gas meters are manufactured to a much tighter tolerance of ±0.71%. Regular checking of sonic nozzle test equipment is required to ensure, with a high level of confidence, that the equipment is maintaining its accuracy, working as designed and as close to calibration specifications as possible. This is often achieved by utilising a check meter tested on a daily basis.

The test equipment typically has an uncertainty of ±0.3 %, and when considering contributing factors such as variations in the check meter repeatability, temperature, barometric pressure etc. it is not surprising that the check meter method is unable to provide reliable results. A better solution needed to be found.

2. The check meter problem

A check meter is typically the same geometrical shape in which the equipment is designed to test. This allows the meter to fit the automatic clamping mechanisms ensuring that the equipment does not need to be modified, potentially introducing additional errors such as leaks. It also allows for the complete equipment systems to be checked i.e. the test pulse pick up circuitry etc.

Obviously a check meter is chosen on the basis that it has good reliability and repeatability. But the reality is that a check meter is not perfectly repeatable. The uncertainty of sonic nozzles test equipment is typically ±0.3% and a check meter would have repeatability in the order of ±0.2%.

When considering the combination of equipment uncertainty and the repeatability of the check meter, a limit needs to be set to trigger the decision to stop testing and conduct a comprehensive investigation to determine the root cause(s) of the variation in the check meter results.

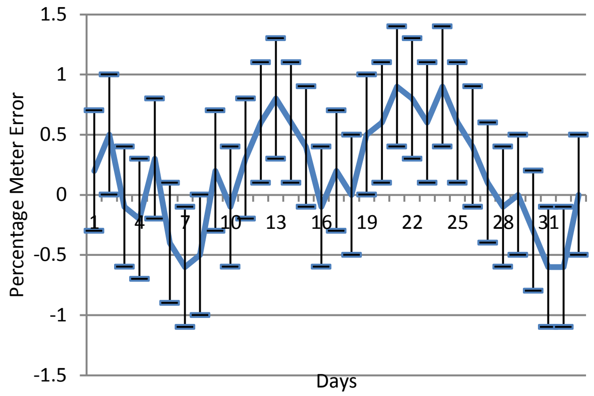

Figure 1: Example check meter results over time.

This so called trigger limit may be an absolute value determined by previous experience, or based on a theoretical value, or even simply an arbitrary limit. The trigger may be when this limit is exceeded once or twice or more. Additionally, each plotted point maybe a single test result or even an average of 2 or more repeated tests.

From Figure 1 above, the error band always overlaps from the test result on the first day through to the last result, 33 days later. The check meter results have varied by 1.5% from -0.6% to 0.9%. Is the cause the meter repeatability, the overall uncertainty of measurement, temperature / pressure / relative humidity sensor fault or some other issue?

3. Sonic nozzle testing

Firstly, we need to understand how the sonic nozzle test equipment works.

Testing using sonic nozzle test equipment involves utilising a vacuum pump drawing air from the temperature controlled test room through both the meter under test and the sonic nozzles. This is shown in figure 2, below. The meter under test is typically left in the test room to acclimatise for a minimum of 8 hours before a test.

Figure 2: Simplified test layout.

Depending on the required test flow rate, one sonic nozzle or a combination of sonic nozzles can be used. The vacuum pump is normally located outside the testing area as it generates both heat and noise.

Sonic nozzles (critical flow venturi nozzles) are designed and manufactured to have a smooth, geometrically symmetrical internal shape with a very smooth rounded inlet section converging to a minimum throat area and diverging along a pressure recovery section. The critical flow venturi nozzles are designed to the requirements as detailed in the Standard EN ISO 9300 [2].

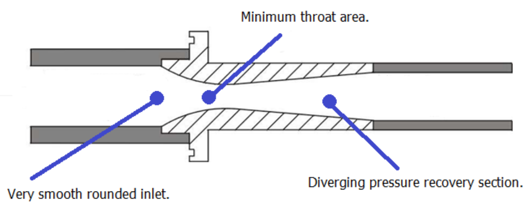

Figure 3: Schematic diagram of a sonic nozzle.

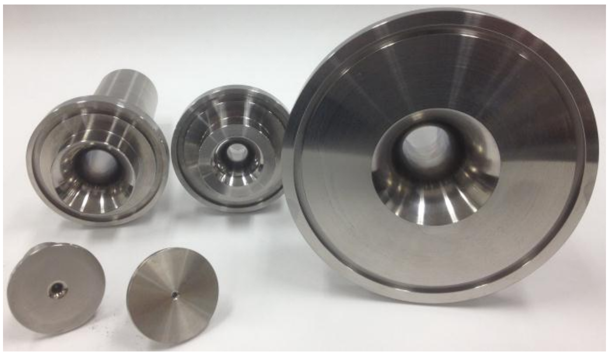

Figure 4: Critical flow venturi nozzles.

As air accelerates through the nozzle, by use of a vacuum pump, the air velocity increases and the density decreases. The maximum velocity is achieved at the throat, where the cross sectional area is the smallest. When the pressure differential reaches a critical point (typically when the outlet pressure divided by the inlet pressure of the nozzle is ≤ 0.8) the speed of the air at the throat reaches the local speed of sound, a Mach number of 1.

This is often referred to as the nozzle being in chocked flow or critical flow. The flow rate at these conditions is unaffected by downstream conditions and the flow rate can be calculated by using the equations detailed in Standard EN ISO 9300 [2].

Put simply the flow rate is primarily dependent on the sonic nozzle throat cross-sectional area, the upstream pressure, temperature, compressibility factor of humid air and the density of the humid air.

The computer software then compares the volume passing through the meter under test (MUT) with the volume going through the certified test equipment using various measurements such as test time, pressure, barometric pressure, temperature, meter pulses and relative humidity.

The percentage meter error of the meter under test, as defined in the Standard AS4647 [1], is calculated from the volume displayed by the meter Vmeter and the actual volume Vref which has flowed through the sonic nozzles.

$$Error\% = \frac{(\text{Vmeter}-\text{Vref})}{\text{Vref}} \; X\ 100 \qquad (1)$$

4. Test measurements

MAPS, which stands for Multiple Automated Prover System, was first put into operation on 4th March 2013. Two MAPS test benches are used, which can test 5 meters each i.e. 10 meters can be tested simultaneously.

Each meter test station is independent of each other, only sharing the same vacuum source. This is to ensure better uncertainty of measurement compared with testing meters in series with only one set of sonic nozzles.

Figure 5: MAPS test equipment.

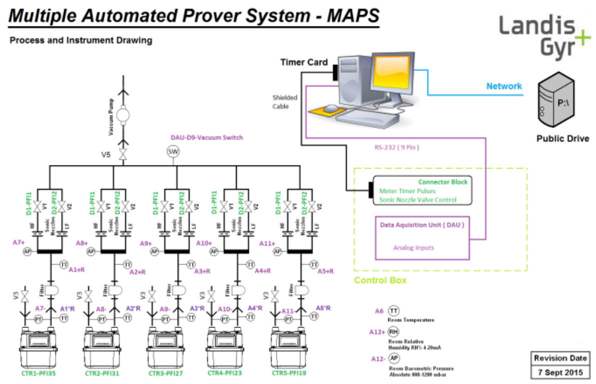

Figure 6: Schematic of the test equipment.

The flow rates at which meters are tested are 20% of Qmax and Qmax which are defined in Australian Standard AS4647 [1]. The volume of the test and hence the total test time is determined by experience in what volume produces repeatable results. During a particular flow tests a number of measurements are made. These measurements are detailed in Table 1, below.

Table 1: List of measurement during a test.

Test variables	Measurement
Meter under test temperature (°C)	Averaged measured variable over the total test time
Meter under test pressure (kPa abs)	
Sonic nozzle temperature (°C)	
Sonic nozzle inlet pressure (kPa abs)	
Test room relative humidity (%)	
Test room barometric pressure (kPa abs)	
Test room temperature (°C)	
Test time (seconds) based on the test volume i.e. the number of meter pulses	Time

5. Effects of test variables on meter accuracy

Many factors can undermine a measurement. Because real measurements are never made under perfect conditions, errors and uncertainties can come from a variety of sources. Some of these sources are shown in Table 2, below.

Where the size and effect of an error are known (e.g. from a calibration certificate) a correction can be applied to the measurement result. But, in general, uncertainties from each of these sources, and from other sources, would be individual ‘inputs’ contributing to the overall uncertainty in the measurement.

Table 2: Sources of Measurement Errors

Source of error	Description
Environment	Temperature, air pressure, humidity and many other conditions can affect the measuring equipment or even the meter being measured.
Meter under test	The meter being measured may not be stable or repeatable.
Measuring equipment	Equipment can suffer from errors including bias, changes due to ageing, wear, or other kinds of drift, poor readability, noise (for electrical instruments), analogy to digital conversion circuits, time measurement error and many other problems.
Imported uncertainties	Calibration of the measuring instrument has an uncertainty which is then built into the uncertainty of the measurements you make.
Measurement process	The measurement itself may be difficult to make, such as meters that have a cyclic capacity volume when divided by the test volume results in a fraction of a cycle of the internal meter volume.

Table 3 below shows the magnitude of an error in a particular measurement in order to impact the meter accuracy result by ±0.2%.

Table 3: Effects of test variables on meter accuracy.

Test variables	+0.2%	-0.2%
Meter under test temperature (°C)	+ 1.17 °C	- 1.17 °C
Meter under test pressure (kPa abs)	+ 0.20 kPa abs	- 0.20 kPa abs
Sonic nozzle temperature (°C)	+ 1.17 °C	- 1.17 °C
Sonic nozzle inlet pressure (kPa abs)	-0.20 kPa abs	+ 0.20 kPa abs
Test time (s)	-0.12 s	+ 0.12 s
Test room relative humidity (%)	-48.3 RH%	+48.3 RH%
Test room barometric pressure (kPa abs)	Not significant > 10 kPa abs	Not significant < 10 kPa abs
Test room temperature (°C)	Not significant < 10 °C	Not significant > 10 °C

What is particularly notable is that the three test room measurements of temperature, barometric pressure and relative humidity have to be considerably wrong in order to impact the meter accuracy result, whereas a small error in the test time and the pressure and temperature measurements of the sonic nozzles and the meter under test have a significant impact on the meter accuracy result.

6. Equipment Verification Equipment

The test equipment typically has an uncertainty of ±0.3 %, and when considering contributing factors such as variations in the check meter repeatability, temperature, barometric pressure etc. it is not surprising that the check meter method is unable to provide reliable results.

The verification of sonic nozzle test equipment typically takes one to two days and involves the calibration of all the measurement transmitters and each individual and combination sonic nozzle flow factor(s). This reverification, being unplanned and possibly unnecessary, means a better solution needs to be found.

This has led to the development of an Equipment Verification System (EVS) where the check meters have been replaced with empty casings i.e. a meter without internals. By using empty meter casings there is stable pressure and temperature at all the transmitters.

The meter pulse output has been replaced with a simulated meter pulse to an accuracy of better than 1 microsecond (0.000001 sec). This generated pulse is sent to each of the 5 test stations simultaneously to ensure that the test is completed under exactly the same conditions.

Figure 7: MAPS test equipment during EVS testing.

Each testing station has different sensors and different sonic nozzle factors so if the same timed pulse is put into each station the percentage meter error will be different. However, the difference in the percentage error between any two stations should remain exactly the same, from one day to the next, unless there is a problem with the equipment.

The EVS test is done on a daily basis. The empty meters are installed and clamped and the EVS test starts with 5 pulses exactly 5.030 seconds apart. At the end of the EVS test the results are scrutinised to ensure that there has been not been any drift day to day for any of the critical sensors.

Should the analysis determine that an error exists the test equipment "locks out" the equipment. Specialised quality control and production engineering personnel receive an email notifying the failure requiring investigation.

7. EVS test criteria

The difference in the percentage meter error between each station shall not exceed 0.2%. In addition, the following rules have been implemented:

7.1. Meter Pressure
The difference between all ten station meter pressure readings must not exceed 0.5 kPa.

7.2. Meter Temperature
Meter Temperature for each station is recorded on the outlet of the meter. There is one meter temperature sensor per MAPS Station (ten in total). The variance between any one of these measurements must not exceed 0.2°C.

7.3. Sonic Nozzle Pressure
Sonic nozzle pressure for each station is recorded from the pressure transducer that is connected to the sonic nozzle inlet manifold. There is one sonic nozzle pressure transducer per MAPS Station (ten in total). The variance between any one of these must not exceed 0.5 kPa.

7.4. Sonic Nozzle Temperature
Sonic nozzle temperature for each station is recorded from the temperature sensor that is connected into the sonic nozzle inlet manifold. There is one sonic nozzle temperature sensor per MAPS Station (ten in total). The variance between any one of these must not exceed 0.2 °C.

7.5. Room Temperature
There is one room temperature sensor mounted on each of the MAPS units, the difference between these two sensor readings must not exceed 0.2 °C.

7.6. Room Pressure
There is one room pressure sensor mounted on each of the MAPS units, the difference between these two sensor readings must not exceed 0.5 kPa.

7.7. Room Humidity
There is 1 room humidity sensor mounted on each of the MAPS units the difference between these two sensor readings must not exceed 5.0 RH%.

Table 4: Summary of EVS Analysis

Sensor / measurement	Unit	Number of checks	Limit
Percentage Meter Error	%	10 Stations	0.2%
Meter Pressure	kPa	10 Sensors	0.5 kPa
Meter Temperature	°C	10 Sensors	0.2°C
Sonic Nozzle Pressure	kPa	10 Sensors	0.5 kPa
Sonic Nozzle Temperature	°C	10 Sensors	0.2°C
Time of Test	s	10 Stations	0.001 s
Room Temperature	°C	2 Sensors	0.2°C
Room Pressure	kPa	2 Sensors	0.5 kPa
Room Humidity	RH%	2 Sensors	5 %RH

8. Comparison EVS vs check meter

In figure 8 below, the test results of a check meter are compared with the EVS evaluation comparing station 1 and 2 are shown.

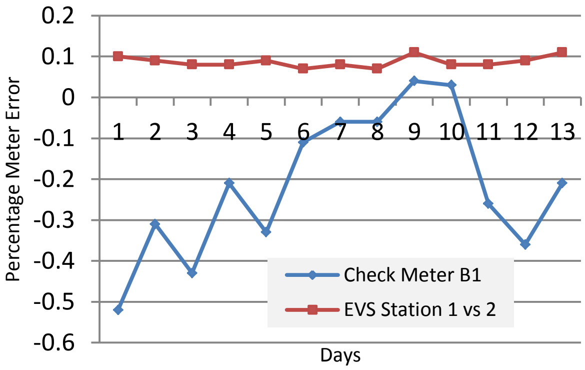

Figure 8: Actual comparison check vs EVS.

9. Flow rate accuracy

The flow of air from the room through the meter under test passes through a filter to ensure the sonic nozzles are not damaged or blocked. The equipment verification system has one basic flaw; it cannot determine if the sonic nozzles are partially blocked.

The reality is that this has never happened as the filters prevent this occurring; however, this is a possibility that could not be ignored.

Every week one test station is tested against the master rotary reference meter. So every 10 weeks each station is individually checked for flow rate accuracy.

10. Conclusion

The old method of utilising a check meter produces an error band exceeding that of the uncertainty band of the equipment. This makes it practically impossible to determine if any variation is due to the errors in the equipment.

The Equipment Verification System method not only produces results that are easier to interpret, but also allows the daily diagnostic checking to be far more sensitive to detecting changes in the equipment. This allows an earlier, more definitive indication if any of the sensor reading(s) have started to drift from their calibrated factors.

11. References

[1] AS4647: *Diaphragm Gas Meters*, 2011.
[2] EN ISO 9300: *Measurement of gas flow by means of critical flow venturi nozzles*, 2005.