

# Effects and Control of Pulsation in Gas Measurement

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## Introduction

Pulsation created by compressors, flow control valves, regulators and some piping configurations are known to cause significant errors in gas measurement.

In recent years the Pipeline and Compressor Research Council (PCRC) now known as (GMRC) Gas Machinery Research Council, a subsidiary of the Southern Gas Association, commissioned and funded various pulsation research projects at Southwest Research Institute (SWRI) in San Antonio, Texas.

This research culminated in the publication of several technical papers, including the April 1987 PCRC report 10.87-3 titled "Pulsation and Transient-induced Errors at Orifice Meter Installations" and a report, "An Assessment of Technology for Correcting Pulsation Induced Orifice Flow Measurement" dated November 1991.

The PCRC sponsored research programs concluded that pulsation induced measurement errors fall into two broad categories:

- 1) Primary Element Error: which includes square root averaging error (SRE), inertial errors, and shifts in the orifice coefficient?
- 2) Secondary Element Errors: which consist of gauge line distortion and gauge line shift, together commonly referred to as gauge line error (GLE).

This paper will concentrate on methods to determine Square Root Error, Gauge Line Error, and suggest several techniques to reduce these effects on natural gas measurement. However, because pulsation is a frequent cause of gauge line error, it is important to review the causes of pulsation induced SRE.

## Square Root Error

Most of the natural gas measurement in the United States is performed with orifice plates.

The gas flow rate (Q) is calculated using the basic formula  $Q = K\sqrt{\Delta PXP}$ . The fixed orifice coefficient (K) is derived from a formula found in the latest edition of AGA Report Number 3. Differential pressure ( $\Delta P$ ) and line pressure (P) are measured with mechanical chart recorders or electronic transmitters.

Under steady-state flow conditions, gas volumes can be accurately measured with current state-of-the-art equipment. However, inaccurate measurement occurs when the  $\Delta P$  modulates, or changes, at a frequency greater than the frequency that the measurement system extracts the square root of the  $\Delta P$ .

Pulsation from gas compressors, control valves, pressure regulators, and some piping configurations are one source of frequent  $\Delta P$  modulation. Figure 1 illustrates the amplitude and frequency of pulsation generated by a reciprocating compressor and a control valve.

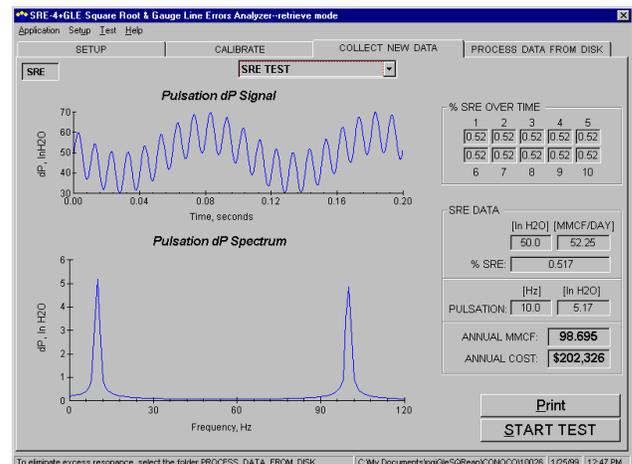


Figure 1

The compressor is causing the pulsation between 0 and 50 Hz, and a control valve is creating the pulse at 100 Hz.

The measurement error referred to above is called Square Root Error (SRE). It is the calculation of unsteady flow using the square root of the average  $\Delta P$  versus the average of the square root values of the instantaneous  $\Delta P$ .

Because SRE is directly related to flow measurement error, it is a very important topic to those who buy and sell natural gas.

In a paper presented at the 1989 Gulf Coast Gas Measurement Short Course in-Houston, Texas titled "Pulsation Effects on Orifice Metering Considering Primary and Secondary Elements", Mr. Robert J. McKee of SWRI states, "a mathematical definition of SRE can be developed from the fact that the average flow is proportional to the Avg.  $\sqrt{\Delta P}$  as opposed to the  $\sqrt{\text{Avg. } \Delta P}$ !"

The formula developed by SWRI to determine the severity of SRE is illustrated below:

$$\%SRE = \frac{(\sqrt{\text{Avg. } \Delta P} - \text{Avg. } \sqrt{\Delta P}) \times 100}{\text{Avg. } \sqrt{\Delta P}}$$

An illustration of a %SRE calculation of a series of six  $\Delta P$  readings taken from a pulsating flow is shown below:

Reading	$\Delta P$ 's (in.wc.)	$\sqrt{\Delta P}$ (in. wc.)
1	75.0	8.660
2	30.0	5.477
3	47.5	6.892
4	52.2	7.225
5	26.1	5.109
6	71.6	8.462
<b>Total:</b>	<b>302.4</b>	<b>41.825</b>
<b>Avg. <math>\Delta P</math>:</b>	<b>50.4</b>	
<b><math>\sqrt{\text{Avg. } \Delta}</math>:</b>	<b>7.099</b>	<b>6.971</b>

$$\%SRE = \frac{(7.099 - 6.971)}{6.971} \times 100 = +1.84\%SRE$$

Note that %SRE is a positive number; mathematically it is impossible for %SRE to be

negative. In addition, %SRE increases with pulsation amplitude, and is inversely proportional to  $\Delta P$  (for a given pulsation amplitude %SRE will be greater at low  $\Delta P$  than at high  $\Delta P$ ).

## Other Primary Element Errors

Though SRE is the largest component of pulsation induced primary element error, under extreme pulsation conditions inertial error and coefficient shift will both increase in magnitude. A brief explanation of each follows:

**Inertial Error:** Pulsating gas flow will tend to remain in motion due to its inertia. As a result, flow velocity changes lag behind  $\Delta P$  changes. Inertial errors are insignificant unless pulsation amplitude and frequency are both relatively high.

**Coefficient Shifts:** Though difficult to quantify, test data indicates that pulsation levels above 1.5% SRE contribute to shifts in the orifice co-efficient.

## Measuring %SRE

When the %SRE at operating conditions is quantified, it can be used to approximate the primary element error induced by pulsation and to determine whether or not corrective action is necessary.

Percent square root error is measured with a device called the Square Root Error Indicator produced by PGI International. This analytical instrument utilizes a high frequency response  $\Delta P$  transducer and special software to calculate %SRE according to the formula developed by SWRI shown earlier.

The PGI SRE Indicator is an analytical instrument used to determine the severity of pulsation and calculate %SRE. Because other primary element errors (inertial error and co-efficient shifts) are not measured, %SRE should not be used to correct flow measurement readings, but to determine if corrective action is necessary.

## Reducing Pulsation

Because of the potential measurement error, many buyers will not accept delivery of natural gas from producers if the %SRE exceeds specific contract limits. %SRE allowed by contract may vary

depending on daily volume, and could be as low as 0.20 %SRE.

The simplest method of reducing pulsation induced SRE is to raise the  $\Delta P$  by changing the orifice plate. Unfortunately, this may also limit the operating range of the measurement system.

In some cases, the piping system can be modified or the pulsation source moved to reduce SRE. This can be time consuming and costly.

Another popular 'cure' for high SRE is to install a device, such as a restricting orifice, between the pulsation source and the measuring station. The negative effects of restricting devices are increased cost of compression and a limited flow range.

%SRE can also be reduced by installing an acoustic filter to remove most of the pulsation. Though more costly than a restricting device, a properly designed acoustic filter will operate over a much wider flow range with a lower pressure drop.

If %SRE is above your contract limits, it is a good idea to contact an expert such as SouthWest Research in San Antonio, Texas for more extensive testing to determine a solution.

## Gauge Line Errors

Gauge Line Error (GLE) exists when the  $\Delta P$  at the taps does not equal the  $\Delta P$  at the end of the gauge lines. GLE may be caused by pulsation or flow phenomena.

The gauge line starts at the orifice taps and ends at the transmitter, flow computer, or chart recorder connections. It includes any pipe fittings, valves, valve manifolds, tube fittings, instrument tubing, and condensate chambers or bottles that may be installed between the orifice taps and the measurement device.

Based upon research conducted by SWRI, it has been determined that gauge line error has two components:

- 1) Gage Line Distortion: defined as the amplification (increase) or attenuation

(decrease) of the pulsation amplitude in the gauge lines. Gauge line distortion is similar to the noise created when playing a flute or blowing across the top of an open bottle.

- 2) Gauge Line Shift: defined as the actual shifting of the average pressure along the length of the gauge line. Gage line shift may be created by pulsation rectification effects, which occur when the  $\Delta P$  signal is transmitted through changing inside diameters of gauge line created by multiple instrument tubing sizes, bottles or condensate chambers, shut-off valves with a smaller ID than the instrument tubing, or male-to-female NPT connections.

Other causes of gauge line shift include gas oscillation at the mouth of the gauge line, and density changes caused by pressure and temperature fluctuations in the gauge line.

## Measuring Gauge Line Errors

In 1990, a GLE indicator was developed by PGI International. In 1996, improvements to the earlier model included the capability to perform both %SRE and GLE tests. (shown in Figure 2). The Indicator was developed by PGI International to indicate and quantify both gauge line error and square root error. Used extensively over the past five years, it has proven to be quite useful in the study of gauge line and square root error.



Figure 2

The GLE indicator is designed to compare the  $\Delta P$  at the orifice taps to the  $\Delta P$  at the end of the gauge lines. If the two signals are not the same, the difference will be due to gauge line error.

The GLE Indicator consists of two (2) Rosemount 3051C "SMART"  $\Delta P$  transmitters and the necessary mounting hardware to install one 3051 C directly at the orifice taps, and the other at the end of the gauge lines.

A PCMCIA A/D converter changes the analog output signals from each 3051C transmitter into a digital signal. Which is then analyzed by special software in a portable, battery operated lap top computer. All software is Windows and Windows 95 based for ease of operation.

Operation of the GLE Indicator is straight forward. Station and test data are entered as shown in Figures 3 and 4.

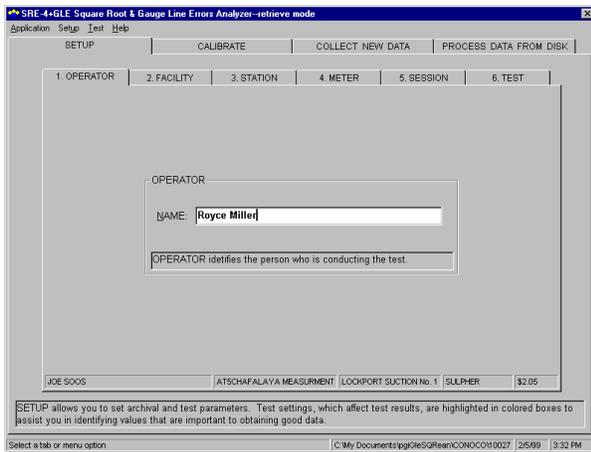


Figure 3

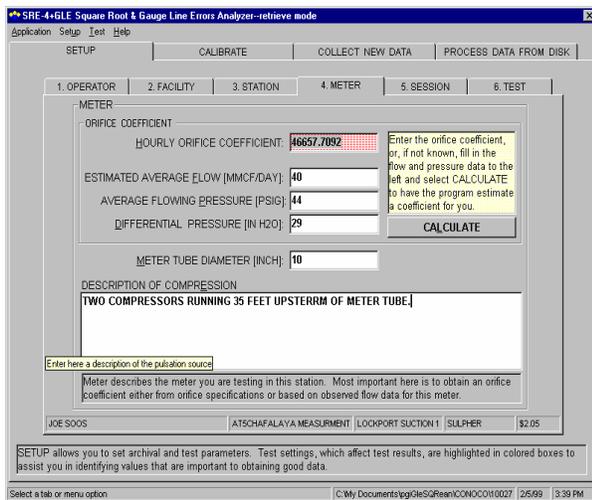


Figure 4

A calibration procedure corrects any output signal deviations at shown input differential pressures (see Figure 5).

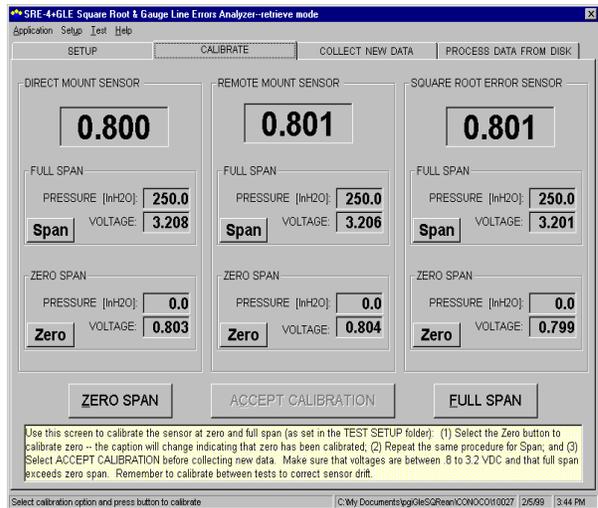


Figure 5

A "noise test" is then performed to determine system error (see Figure 6). During the "noise test," both 3051 C's measure the same differential pressure, which is manually modulated using a hand pump. The noise test will show that the 3051C's and the Validyne are reading the same and no outside electrical interference is present.

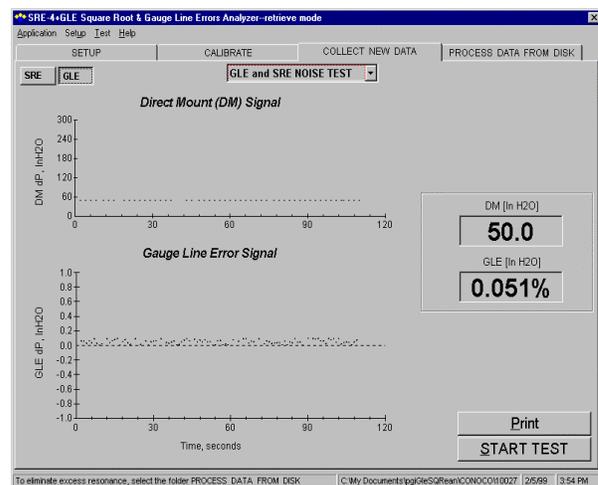


Figure 6

The 3051 C transmitters are then installed as in Figure 2, pressurized to line pressure and re-zeroed to correct for transmitter position and static pressure zero shift.

During the timed GLE test, the  $\Delta P$  of each 3051C is sampled at a frequency of 250 times/second. A flow calculation for each transmitter is performed once each second using the average of the  $\Delta P$ 's.

The GLE Indicator graphically indicates the true  $\Delta P$  at the orifice and the actual gauge line error. Average gauge line error in inches of water and %GLE are also displayed. At the conclusion of the test, the flow calculated from each transmitter is compared. Any difference in the two volumes is displayed in annualized MMCF of gas and dollars of gain or loss. The dollar amount is calculated based on the user's price of gas per MCF at the time of the test.

Numerous GLE tests can be performed at various flow rates. All gauge line and square root error tests are automatically stored to the hard disk for future analysis or printing.

## Testing Results

Extensive field testing with the GLE Indicator confirmed the research conducted at SWRI by PCRC. In the following test examples, "DM" represents the  $\Delta P$  of the reference 3051C that was direct mounted on one side of the orifice fitting.

GLE-Test 1: In this test, gauge line error was measured at the outlet of a small bore (0.187") 5 valve manifold connected to the orifice fitting with 4.5 ft. of 3/8" O.D. tubing. A pair of 3/8" I.D. ball valves was installed at the taps. %SRE at the taps was .997% as shown in Figure 1. Gauge line error was negative 0.102 wc. at 30.7 inches wc.  $\Delta P$ . Annualized, this would result in a measurement error of \$31,503.00 as shown in Figure 7.

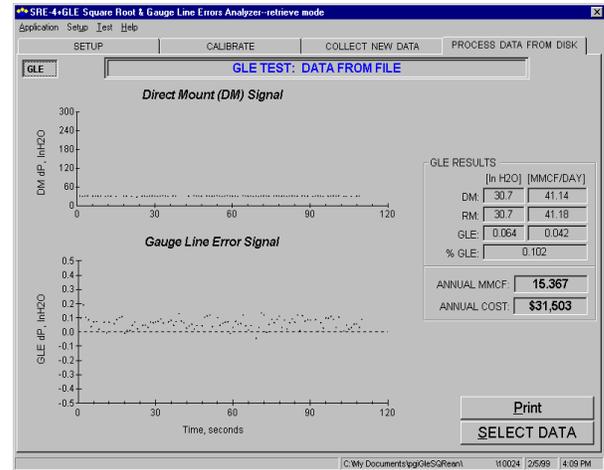


Figure 7

GLE-Test 2: In this test, gauge line error was measured at the end of the 3/8" O.D. gauge lines 5 ft. from the orifice taps. Block valves on the 6" Daniel Senior Fitting were conventional 0.187" soft seat needle valves. GLE measured negative 0.386 in. wc. at a constant 36.07 MMCFD flow rate. Based on gas at \$2.00 per MCF, the annualized error was a negative \$132,309.00 as shown in Figure 8.

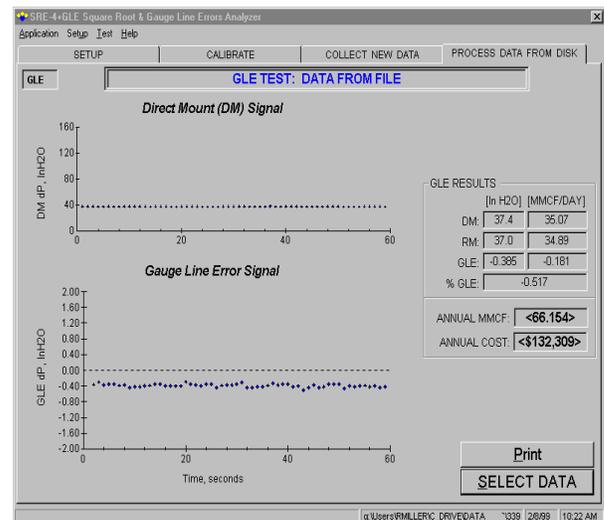


Figure 8

GLE-Test 3: A Honeywell  $\Delta P$  transmitter was connected to a 16' Daniel Junior fitting with 15 ft. of 3/8" O.D. tubing, a small bore (0.187") 5 valve manifold, and 1/2" ball valves at the orifice taps. At a constant flow of 30.19 MMCFD, gauge line error measured a negative 0.192 in. wc. Annualized this would result in a measurement error of \$143,529.00 as shown below in Figure 9.

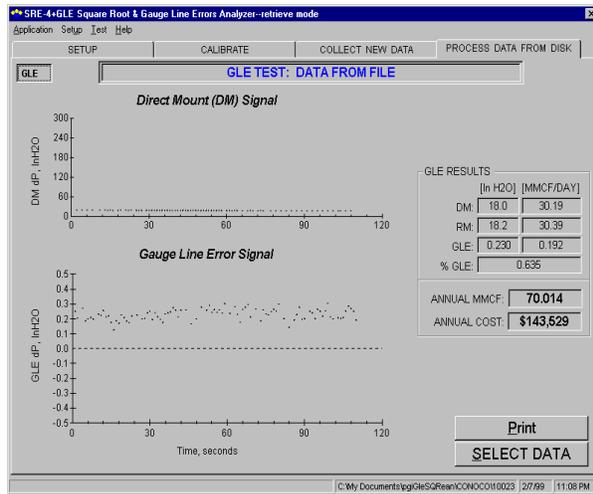


Figure 9

## Eliminating or Minimizing GLE

As mentioned previously, numerous gas contracts now include pulsation magnitude clauses. Many transmission companies require the installation of acoustic filters to minimize pulsation levels and %SRE.

Testing has shown that in some cases gauge line error may continue to be present after the installation of an acoustic filter and when % of SRE readings are very low - in some cases 0.1 % SRE.

Because of the many variables involved in gauge line error, such as pulsation levels, gauge line lengths and/or diameters, operating pressure, gas density, and gas velocity, it is extremely difficult to observe a measurement location and predict what gauge line error, if any, will be present. The only way to determine the presence of gauge line error is through testing.

An alternative to testing for gauge line error at each installation is to install the transmitter

and/or EFM in a manner that will minimize or eliminate gauge line error.

To minimize gauge line error when pulsation or flow phenomena are present, a differential measuring device should be close coupled to orifice fittings with equal lengths of large bore (0.375" I.D. or greater) constant diameter gauge lines.

This can be accomplished using a short length of 1/2" O.D. instrument tubing and full opening ball valves on the orifice fitting and measurement device. However, in this type of installation the numerous matting of female NPT connections create small 'volume chambers,' which could produce gauge line shift (pulsation rectification effects).

If the full port 1" ball valves are used, it is very easy to shock one side of the measurement device with full line pressure. When this occurs, it may create a significant static shift in the calibration of the transmitter not detectable under normal calibration procedures.

A more feasible method is the Direct Mounting System as shown in Figure 10. With over 10,000 installations currently in service, this method of close coupling transmitters or a self-contained EFM to the orifice fitting continues to gain wide acceptance within the industry.

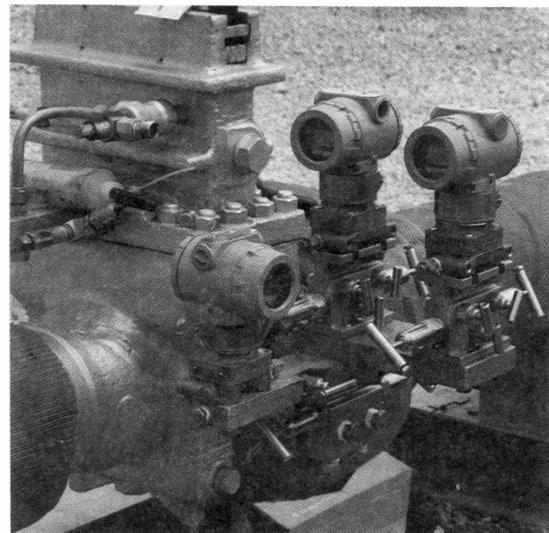


Figure 10

Utilizing a pair of stabilized connectors for safety, and roddable large bore (0.375" I.D.) soft seat instrument manifolds, the transmitters are located as close as

possible to the orifice taps, typically within 13 inches or less.

Flanged connections with Teflon® seal's eliminate the "volume chambers" found with NPT connections. Multiple turn valves prevent "shocking" of the measurement device when opened.

Frequent valve stem packing adjustments are eliminated by a dynamically loaded stem seal that is guaranteed leak-free under fluctuating pressure (vacuum to +10,000 PSI) and temperature (-40° to +450°F).

Protection of the electronic transmitters from cathodic protection currents and possible transients is provided through the use of dielectric isolators, rated to 2,500 volts DC, located between the stabilized connectors and the manifold.

## Summary

- Pulsation created by compressors, flow control valves, regulators, and some piping configurations may create unacceptable levels of SRE and/or GLE.
  - %SRE is always positive, never negative, and increases with pulsation amplitude.
  - To reduce pulsation to an acceptable level, the source of the pulsation must be eliminated, piping systems modified,  $\Delta P$  increased, a restricting device installed, or a properly sized acoustic filter installed.
  - Whenever pulsation is present there is a high probability that GLE will exist.
  - Even though %SRE readings may be within acceptable limits, low amplitude/high frequency pulsations may create significant GLE.
  - Volume chambers, such as condensate pots, bottles, and bellows housings of different volumes greatly affect GLE.
  - Numerous measurement devices connected to the same set of orifice taps may create GLE.
- Unlike %SRE, GLE can be either positive or negative. It may be of a greater magnitude than %SRE.
  - To minimize or eliminate GLE, the transmitters or EFM should be close coupled to the orifice taps with equal length, large bore (0.375" I.D. or greater), constant diameter gauge lines.
  - Minimizing or eliminating GLE by close coupling the measurement device to the orifice taps will not reduce %SRE.

## References

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