Pulsation Induced Flow Measurement Error Diagnostic with Intelligent Differential Pressure Transmitter

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Introduction

In custody transfer applications it is common to use orifice plates in combination with differential pressure (DP) transmitters to indicate volumetric flow and to serve as the "cash register." Due to this, Emerson Process Management customers demand reliable, high accuracy devices. Independent of the quality of the measurement device, several sources of error exist within the pipeline that may negatively influence the accuracy of the flow measurement. Two examples include Percent Square Root Error (%SRE) and exceeding the American Gas Association (AGA) pulsation environment recommended limits.

When using DP to determine flow rate, the square root of the DP is proportional to flow and is considered to be a very accurate measurement when operating under steady-state conditions. When the process is unstable, for this example due to pulsations caused by pumps, compressors or control valves, the output will indicate a higher than actual flow rate.

Prior work on identifying %SRE has taken the form of methods to significantly increase the rate at which DP is sampled to achieve a virtual instantaneous DP reading. This technique effectively eliminates the square root error through its ability to report the average of the instantaneous square root of the DP, considered by industry to be an accurate representation of true flow rate. Previously no device was available to provide both a reliable and accurate pressure measurement as well as offer an indication of the presence of process pulsation until now. The 3051S equipped with a diagnostics feature board satisfies both of these needs.

Typical flow applications will take the square root of the average of several DP readings as an artifact of sampling rate when using a Distributed Control System (DCS) or flow computer. In addition, damping, averaging over a period of time, is often used to mitigate overreaction to brief process anomalies. This, however, increases the susceptibility to over report flow rates when exposed to elevated pressure pulsations. Equation 1 illustrates how %SRE is calculated. The AGA standard for an acceptable pulsation environment is shown in Equation 2.

$$\%SRE = \frac{\sqrt{Ave\Delta P} - Ave\sqrt{\Delta P}}{Ave\sqrt{\Delta P}} * 100$$

Equation 1: Formula to Calculate Percent Square Root Error (%SRE)

$$\Delta P_{RMS} / \Delta P_{AVE} \leq 10\%$$

Equation 2: AGA-3 Standard for Acceptable Pulsation Environment

Background

Emerson developed a new generation of Differential Pressure transmitters with a unique, scalable architecture. This new pressure transmitter platform, called the Rosemount 3051S, provides best in class performance and reliability and also features advancements in power management that allows the easy addition of advanced functionality to the base pressure transmitter. This functionality, embodied in a feature board, can be ordered as part of the transmitter or simply added to an existing transmitter already installed in the field.

Making use of this advanced functionality, Emerson has developed a unique patented technology that provides a means for early detection of abnormal situations in a process environment. The technology, called Statistical Process Monitoring (SPM), is based on the premise that virtually all dynamic processes have a unique noise or variation signature under normal operation. Changes in these signatures may signal that a significant change in the process, process equipment, or transmitter installation will occur or has occurred. For example, the noise source may be equipment in the process such as pumps, agitators or the natural variation in the DP value caused by turbulent flow or any combination thereof.

The sensing of the unique signature begins with a high speed sensing device such as the Rosemount 3051S Pressure Transmitter equipped with patented software resident in a HART® Diagnostics or FOUNDATION™ fieldbus Feature Board. This powerful combination has the ability to compute statistical parameters that characterize and quantify the noise or variation and represent the mean and standard deviation of the input pressure. Filtering capability is provided to separate slow changes in the process due to intentional setpoint changes from inherent process noise which contains the variation of interest. The transmitter provides the statistical parameters to the host system via HART or FOUNDATION fieldbus communications as non-primary variables. The transmitter also has internal software that can be used to baseline the process noise or signature via a defined learning process. Once the learning process is completed, the device itself can detect changes in process noise and will communicate an alarm via the 4 – 20 mA output or alert via HART or FOUNDATION fieldbus.

With the design of this transmitter and feature board complete, Emerson initiated a test program to determine if this technology could be applied to the prediction of square root error in DP flow applications.

Test Program Description

The ability to predict pulsation induced measurement error was evaluated using three data sets consisting of simulated model-based data, data taken at the Micro Motion facility in Boulder, Colorado and data obtained using a flow test bench at the Emerson facility in Chanhassen, Minnesota.

The simulated data set was created using a sinusoidal model allowing for the inclusion of up to two noise inputs being able to manipulate the frequency and amplitude of each source over various flow rates. In this model, the DP was sampled at 45 ms intervals (22 Hz) to mimic the output of a typical transmitter.

The 3051S DP transmitter is bandwidth limited both mechanically and electronically. Inherent to its design consisting of an oil filled three spring system, pulsations above approximately 25 Hz are damped out. Configuring the transmitter to sample at the maximum 45 ms rate limits DP sampling to below 22.22 Hz. It is important to note that in almost all cases, regardless of the frequency, the DP transmitter has the ability to detect pressure pulsations and will translate this into changes in standard deviation.

On December 4, 2006 testing was conducted at Micro Motion's (MMI) inclined flow test stand. A 405P 0.65 beta orifice plate was used with water at mass flow rates varying from 170 to 500 lb/min. Each test run was performed for a minimum of 60 seconds. The DP signal was measured using a 250" Rosemount 3051S Differential Pressure Transmitter. The transmitter had FOUNDATION fieldbus outputs and was configured to output pressure data at the maximum rate of 22 updates per second. The data from the 15 test runs were recorded using standard PC FOUNDATION fieldbus tools and analyzed post test using standard Excel spreadsheets and MiniTab.

Additional data were collected on April 23, 2007, at the Emerson facility using a Daniel 0.67 beta orifice and a 3051S DP transmitter configured as described above. A total of 17 test runs were conducted with flow rates ranging from 3.4 to 22.6 lb/min of water each lasting a minimum of 60 seconds. As before, the data were collected using PC FOUNDATION fieldbus tools and later analyzed with Excel and MiniTab.

Test Results and Analysis

Data from all three sources, the process pulsation model, the Micro Motion inclined flow bench and the Rosemount flow loop, were consolidated and plotted in Figure 1. Regardless of test setup, flow conditions or noise characteristics, all data lie on one continuous curve. This confirmed relationship would allow for the prediction of %SRE using the standard diagnostic feature board output of coefficient of variation.

As shown in Figure 2, the relationship between the coefficient of variation and the AGA-3 pulsation limit value is clear and virtually mimics that of the coefficient of variation and %SRE. In both instances, pulsation induced errors are related to an increase in noise relative to the fundamental pressure signal (the coefficient of variation) and have been demonstrated to be an excellent tool to represent pulsation induced errors.

Conclusion

Pulsation induced flow measurement errors are a concern for any flow operation, particularly custody transfers where flow accuracy is critical. Emerson has identified a means by which to provide two unique indications of process pulsation, %SRE and the AGA standard for acceptable pulsation environment while continuing to output a highly reliable and accurate pressure measurement. This technology is resident in HART and FOUNDATION fieldbus versions of the Rosemount 3051S Pressure Transmitter, and can provide early warning of process, equipment and installation problems related to process pulsation.

References

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Figures

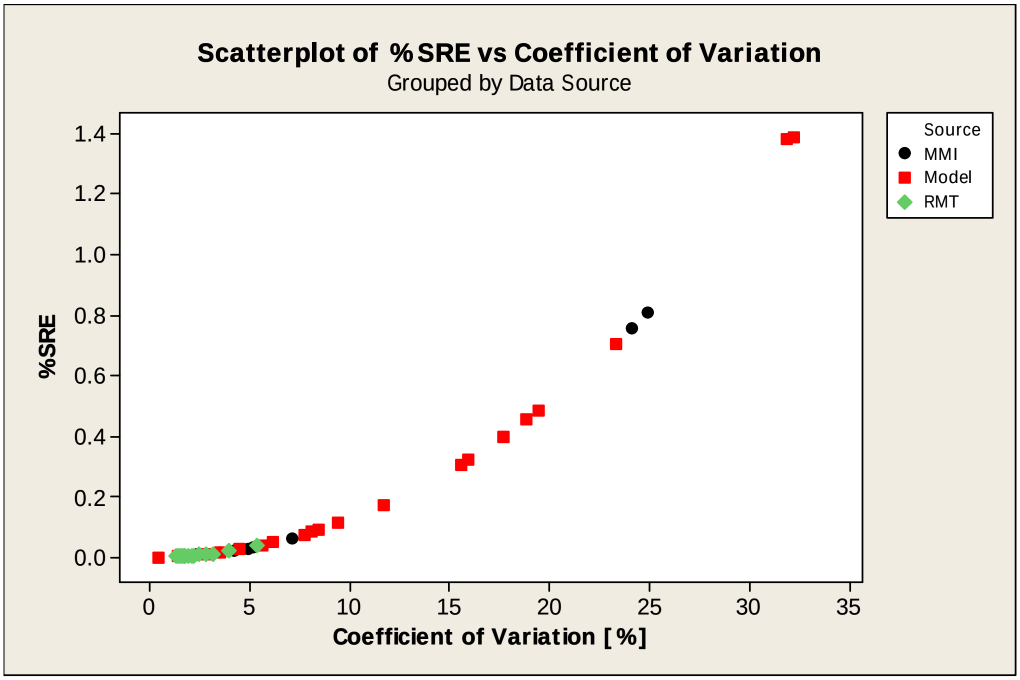

Figure 1: %SRE Correlation with the Coefficient of Variation

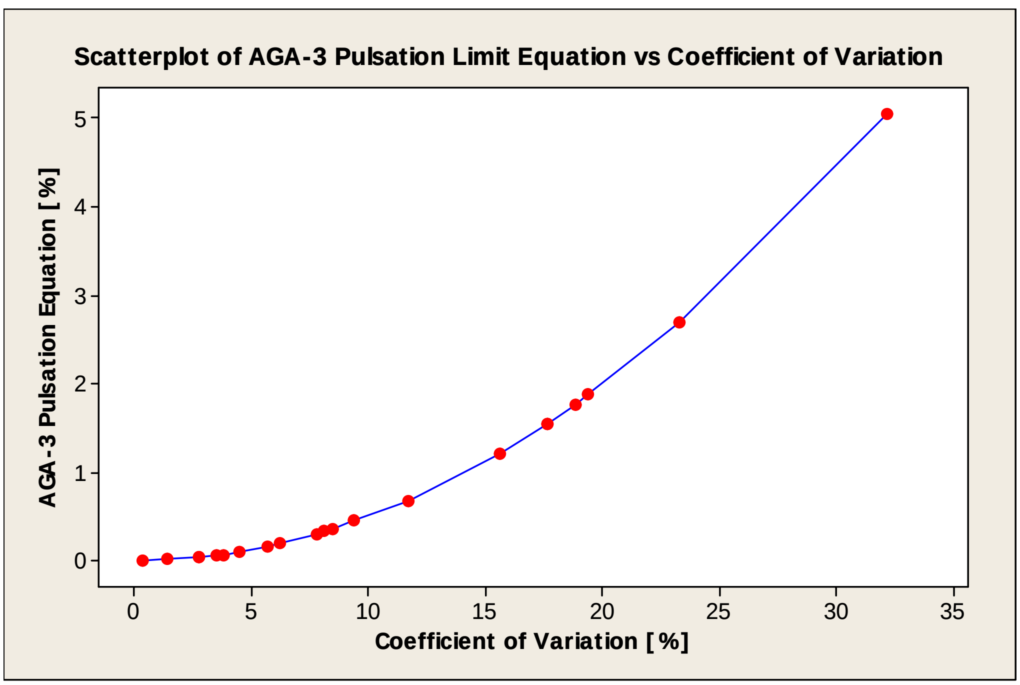

Figure 2: AGA-3 Pulsation Equation Correlation with the Coefficient of Variation