PULSATION EFFECTS ON GAS MEASUREMENT

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The existence of pulsation has long been recognized as a source of measurement error; however, the mechanics and degree of error are not well understood. Errors resulting from pulsation have been witnessed in a variety of instances both in the laboratory and in the field. These occurances have ranged from inferred flow through capped lines, to large differences in measured thruput between series meters, to common moderate examples exposed as square root error.

Pulsation effects in orifice meters are not simply the result of the readout system (lead lines, mercury meters, etc.). Though the components of the readout system can contribute error components, the basic error is directly across the orifice plate and is independent of the readout system.

The basic error arises primarily from two sources. The orifice coefficient can be drastically altered by pulsations which distort the flow profile (jet or vena contracta) downstream of the orifice plate. Even when pulsation is not sufficiently severe to alter the orifice coefficient, the average differential pressure existing across the orifice under unsteady flow conditions is not equivalent to the differential pressure that would exist if the flow were steady because of the basic non-linear character of the orifice. This phenomenon is usually referred to as "Square Root Error". Since an orifice is a square law device, ($\Delta P \propto Q^2$), the error results from taking the square root of the average differential pressure rather than the average of the instantaneous square root of the differential pressure. Unfortunately, this produces an inordinately high differential which does not correspond to average flow even if the orifice coefficient has not changed in response to pulsations.

The most troublesome problems result from attempting to infer true average flow from measured differential under pulsative (unsteady) flow conditions while utilizing orifice flow coefficients based on steady state flow. Normal steady flow coefficients are not applicable under unsteady flow conditions.

Pulsation can be generated by numerous devices and apertenances in the piping system from reciprocating compressors to unstable regulators and even the piping itself. It is quite common in many systems to observe pulsation frequencies overlaying one another without any particular one being dominent. There are often several non-synchronous waves acting to attenuate or strengthen the pulsation effect and subsequent error. Instrusive piping apertenances can and do create pulsative waves under flow through the creation of vortices.

The result of these combined flow disturbances is simply that under such conditions no unique relationship exists between differential pressure and orifice flow. It follows that no certification can be made of meter error as a function of measured pulsation, nor can the error magnitude be adequately defined by measurement at the orifice.

It can be demonstrated that square root error is predictable and always positive. This, of course, implies a flow that is greater than actual. Instability errors (those pulsations which alter the orifice coefficient) can be of any magnitude and of either positive or negative influence. Under severe pulsation, changes in frequency of only a few Hertz can result in error of several percent and frequently a change in sign.

The elimination of pulsation through the use of pulsation control devices seems to be the only solution to pulsation introduced meter errors. The design of pulsation control equipment has become a fairly exact science by use of computer analogs. Assessment of square root error remains the best rule of thumb in determining when pulsation control equipment is required to improve absolute accuracy.

Square Root Error

Any fluid dynamicist will tell you that under turbulent flow conditions the frictional pressure drop across any piping component is proportional to the square of the flow velocity. However, whenever the flow is modulated rather than steady, the average pressure differential changes. Even though the flow has not changed, the average pressure drop in the pulsative state is not the same as the pressure drop in the steady state condition. The phenomenon we refer to as "Square Root Error" simply results from the process by which ΔP data is reduced to flow.

$$\sqrt{\overline{\Delta P(T)}} \neq \overline{\sqrt{\Delta P(T)}}$$

Where $\sqrt{\overline{\Delta P(T)}}$ = Square Root of Average Differential Pressure

$\overline{\sqrt{\Delta P(T)}}$ = Average of the Instaneous Square Root of Differential Pressure

Figure I

The square root error component can be defined by pulsation measurement at the orifice through measurement of both DC (steady) and AC (pulsative) components of differential pressure. This will provide the best available guideline to measurement uncertainty. Experience in the lab and in the field tells us that if square root error is approximately 1% or less, then in all likelihood meter inaccuracies are not the result of pulsative flow instabilities which generally result in substantial erratic meter errors. In addition, what can be said after measuring both the AC and DC differential components is that meter error is <u>at least</u> as large as the square root error.

Our concern here is not with an analytical review of square root error. It is our purpose to adequately describe this phenomena to the extent that field personnel may utilize current analytical theory in a positive way to detect pulsation induced errors. The following equations expressed in Figures II and III are the simplest approaches to defining differential pressure errors and a corresponding error in flow. These equatins involve a measurement of differential pressure modulation ratios and defining square root error from this ratio. It should be pointed out that current theory is inadequate to describe complex pulsation induced errors. Figures II and III assume a single predominate pulsation frequency. The error in differential pressure due to square root affect is

$$E_p \simeq 1/8 \left(\frac{\delta P_1}{\overline{\Delta P(T)}}\right)^2 \times 100\ \%$$

Figure II

and the corresponding error in flow is

$$E_F \simeq 1/16 \left(\frac{\delta P_1}{\overline{\Delta P(T)}}\right)^2 \times 100\ \%$$

Where $\overline{\Delta P(T)}$ = The Average Steady Value (DC)

δP_1 = The Pulsation Value of ΔP, Measured Zero to Peak

Figure III

This type of field analysis can be successfully accomplished provided that the ΔP transducer is of sufficient frequency response to faithfully measure the ΔP and assuming that the ΔP transducer and its associated lead line are sufficiently short so as to avoid resonance amplification or attenuation of the pulsative element of ΔP. Obviously, this type of field analysis is a very simple approach and the least accurate. However, it will provide, in a fair majority of case, a sufficient approximation of the pulsative effects on meter accuracy.

The process by which these measurements are taken are as simple as connecting a differential pressure transducer across the orifice and in comparing the square root of average differential pressure to the average square root of instantaneous differential pressure. From this square root error of flow can be calculated as shown in Figure IV.

$$SRE_F = \frac{\sqrt{\overline{\Delta P}} - \overline{\sqrt{\Delta P}}}{\overline{\sqrt{\Delta P}}} \times 100\%$$

Figure IV

Even this sort of analysis should not be construed as indicating total meter error. At best, it gives indication as to whether or not measures should be taken to install acoustic filters or other pulsation control devices.

Studies have shown that as a result of significant changes in orifice coefficients as a result of vena contracta or jet instabilities which occur as a result of pulsations, no unique relationship between flow and differential pressure across the orifice is apparent when flow is pulsative. Under severe pulsation conditions, most systems defy an analytical approach to coping with the problem through the sheer number of variables which will affect meter accuracies.

<u>Control of Pulsation Induced Meter Error</u>

In very simple piping systems, analytical techniques can be applied to the design of an effective pulsation control filter. However, this approach would normally neglect the basic meter piping layout. The use of analog design techniques have successfully shown that the basic layout of the meter piping can serve to minimize pulsation induced meter error by the prevention of resonate build-up and by placing the orifices at less responsive points in a piping system. Analog simulations of meter installation which deal with the entire configuration are an extremely valuable tool in the elimination of pulsation and most particulary in those instances where headers and multiple meter runs are present.

The orifice meter is a particularly accurate device. It shows excellent repeatability under steady flow conditions. The degree of accuracy attainable for the orifice meter is reflected in the vast number of these devices which are in use in custody transfer installations. The elimination of meter error and subsequent improvement in cash flow for those companies involved in custody transfer is largely dependent upon the reduction or elimination of pulsation induced meter error.