NOISE REDUCTION IN ULTRASONIC GAS FLOW MEASUREMENT

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ABSTRACT

Ultrasonic meters are becoming increasingly accepted for the custody transfer measurement of natural gas. This is reflected in the most recent standards, regulations, and codes of recommended practice, such as the AGA Report Number 9, the Regulations and Guidelines of the Norwegian Petroleum Directorate, and the UK Department of Trade and Industry's Petroleum Measurement Guidelines. Although these documents encourage the use of ultrasonic meters, they do not provide rigorous installation instructions and it is possible for design engineers to place meters in locations not suitable for ultrasonic measurement. One common concern for operators is the possibility that ultrasonic noise present in the pipeline might interfere with the meter and thereby compromise its performance. Such noise is typically generated at points with significant pressure reduction, such as flow control valves.

The effects of ultrasonic noise will be shown in this paper. Additionally, we will discuss a number of actions that can be taken to mitigate noise effects on the ultrasonic meter. Most of these cost little to include at the outset of a project, but can be very expensive to incorporate once all the hardware is in place. A greater awareness of these actions should result in more successful ultrasonic flow meter applications.

THE PROBLEM

Noise Generation. It has been found that control valves with a significant pressure drop can produce noise in the same ultrasonic frequency range as that used by the ultrasonic meter. This noise can interfere with the signal detection system of the meter and may lead to transit time measurement errors if untreated. The amount and characteristics of the noise generated depends on the design of the control valve. Some valves designed for low audible emissions achieve their “quiet” nature by pushing the sound into the ultrasonic range. This is clearly not desirable for use with an ultrasonic meter. Valves use different trim and cage designs to reduce the audible noise, however experience has shown that any valve with sufficient throttling is a potential source of ultrasonic noise (Ref. 1 & 2). Experiments have shown that the noise level increases with the pressure drop ($\Delta p$) and the actual volume flow-rate ($q$) through the valve. The simplest correlation, found so far, is that noise level increases with the power dissipated by the valve ($W = q \Delta p$).

Other correlation parameters used are $\Delta p / P$ and $M = v/c$ the Mach number. They are interrelated by:

$$
\Delta p = \rho \frac{v^2}{2}
$$

$$
c^2 = \gamma \frac{P}{\rho}
$$
Where:
\[ \rho = \text{Density} \quad \text{and} \quad \gamma = \text{Isentropic Exponent} \]

Thus:
\[ \Delta p / P = \gamma \frac{v^2}{2} c^2 = \gamma M^2 / 2 \]

An example from the field illustrates the magnitude of the problem:

- Taking a 20” line flowing at 26 ft/s, giving \( q = 160,000 \text{ CFH} \), and a pressure drop \( \Delta p = 350 \text{ psi} \), the power loss \( W = 3,000,000 \text{ Watts} \) (4,000 hp). Compared to this, the electrical power to the transducers is limited to about 2 Watts by intrinsic safety considerations. It is obvious from these values that attempts to overpower the noise or even to divert the noise are of limited use and serious solutions must involve more sophisticated approaches.

**Noise Propagation.** Once generated, the noise from the valve travels both upstream and downstream. With sufficient pressure drop (\( \Delta p / P \approx 0.5 \)) the valve chokes with the velocity \( v \) reaching the local speed of sound \( c \) (or \( M = 1 \)) and the flow downstream of the valve returning to sub-sonic conditions through shock waves. This would be the worst case noise for an ultrasonic meter installed downstream of a valve (ref. 3).

Simple ideas from sonic nozzles suggest that at choked flow, pressure disturbances (sound waves) are not transmitted upstream, because they travel at \( c \) while the gas velocity \( v > c \). However, experience shows that with choked control valves the noise is still propagated upstream. The complex geometry of the valve ensures that clearances, boundary layers and separated flows do not become sonic and furthermore, the whole valve cage probably acts as a radiator. For this reason, it is not valid to assume that an ultrasonic meter placed upstream of a control valve will be immune to its noise.

This concept of the valve radiating sound opens the question of whether the noise is gas borne or pipe borne, in other words does the noise enter the meter through the gas or through the metal. Early versions of ultrasonic meters used for valve testing were fitted with isolating valves on the transducer ports to allow transducer replacement without shutting down the line. In early testing these valves were closed and the noise at the receiver disappeared. This result demonstrated the noise was gas-borne, not pipe-borne and paved the way for further improvements.

Independent, broad band measurements of the noise were not taken. Detection of the noise was monitored through the same ultrasonic transducers that detect the signals in the meter and thus the results are convoluted. However, looking at the frequency spectra of the received signals (Fig. 4 & 5) and knowing the frequency response of the transducers suggests that most of the noise is below 100 KHz.

**The Ultrasonic Meter Response to Noise.** The meter tested operates in the band 80 – 180 KHz with a center frequency of about 120 KHz. The meter has four paths and eight transducers, under noisy conditions it is normal for all 8 transducers to react differently. This makes it difficult to find a simple parameter to describe the effects of noise on the meter, but it has the advantage that some paths will cope better with the noise and hence the meter will continue to
operate while signaling the presence of noise. One very distinct effect which was observed is the noise on transducers facing the valve (i.e. the upstream transducers when the valve is installed downstream of the meter) is much larger (2 to 4 times) than the noise seen by transducers facing away from the valve (Fig. 1). In fact this asymmetry is a sure sign of external noise and can be used to signify its presence.

RELIEVING THE PROBLEM

Signal processing. (Ref. 4) A simple band pass filter is used to eliminate noise outside the transducer operating frequency range. Noise within the band is tackled with stacking (or digital averaging), the idea is that the noise has a random component while the signal is basically stationary, thus averaging will tend to cancel the noise but re-inforce the signal (Fig. 3). Stacking typically reduces the noise level by the square root of the stack size (Fig. 6) e.g. a stack of 16 reduces the noise 4 fold. Higher stacking takes a longer time with a diminishing return. The longer averaging time gives a slower response and the longer time throws doubt on the ideal ‘stationary signal’, in fact if the flow changes during the stacking process, it no longer works very well. A practical improvement was to increase the stacking speed and to change the firing sequence in order to shorten the amount of time required to perform signal averaging. Other diagnostic capabilities of the meter also help with noise:

- The approximate location of the signal from the speed of sound (c) and path length (l) is known. Thus the meter can be configured to “look” at a specific part of the received waveform.
- The Signal-to-Noise ratio (S/N) is monitored and an alarm is activated if the level falls below a predefined value.
- The signal quality is checked by the standard deviation of the transit time measurements. In normal operation a batch of 20 readings are taken to give statistical data. If the transit time data has more statistical spread than usual, it indicates a change in the metering environment.
- Signal quality is further characterized by the sharpness and frequency content of the detected signal. A steeply rising waveform with proper bandwidth makes it much easier to detect the start of the signal.

Flow Control. In normal fiscal operation, the accuracy of the measurement is of paramount importance and if this accuracy cannot be assured the meter warns the operator of an invalid reading. If the meter output is being used for a different purpose such as controlling the valve creating the noise, this might not be suitable (returning no flow value). A flow control algorithm was successfully implemented into control application software that allows the last value to be held for a set time if the meter fails and then lets this last value decay exponentially to zero.

Pipe Layout. To reduce the noise it is always better to install the valve downstream of the meter. Another advantage of having the meter upstream of the valve is that the pressure is higher, giving stronger signals, requiring less gain and hence not amplifying the noise.

Pipe length and fittings installed in between the meter and noise source help attenuate the noise (Fig. 7 & 8). Some limited experiments with straight pipe suggest that hundreds of pipe diameters are needed to achieve any significant attenuation. Fittings are more effective, and
isolated tests have shown that filters, heat exchangers and turbine meters are good at reducing noise. Bends, tees, and headers also reduce noise, mostly by reflection. A good example is a blind tee, where the flow goes past the tee, but the noise is reflected from the blind end. There is some evidence that using a smaller sized valve with an expansion to the meter tube reduces the noise level.

Sharing the pressure loss between two valves reduces noise generation, but this would normally be an expensive solution.

**Silencers.** Some progress has been made with ultrasonic silencers, such as simple reflective devices, multiple reflectors from small bodies about the same size as the wavelength, and absorptive devices using foams or visco-elastic materials. Tests of a simple silencer showed a three-fold reduction in noise. The silencer was installed immediately downstream of the meter, at the only available flange, and found not to affect the accuracy of the meter.

Silencers generally involve blockage and pressure loss, thus forfeiting some of the advantages of the ultrasonic meter. However in these cases, with a control valve dropping a large pressure to create the noise, the silencer loss is negligible. A silencer becomes appropriate when space is limited, e.g. on an offshore platform.

**FIELD RESULTS**

**Figure 1 - Typical Valve Noise**
Note that more noise is seen on the upstream transducer, facing the valve than on the downstream transducer facing away from the noise source. The noise on the upstream signal tends to blur the start of the signal.

**Figure 2 - More Severe Noise**

Note the noise completely swamps the signal and the signal is lost to the eye.

**Figure 3 -** Is for the same conditions as Figure 2, but with the addition of 32-fold stacking.
Note: Stacking is very effective at reducing the noise and finding the signal.

**Figure 4** - Shows a fast Fourier transform of the Signal of Figure 2 to show the spectral content of the signal and noise.

**Figure 5** - The spectral content of a normal ultrasonic signal (without noise)
Note that the noise appears to fill in the lower frequencies, typically below 100KHz, and not the higher frequencies. This may be in part due to the response of the transducer.

**Figure 6** - Shows a power spectral density calculation of the rms noise level with increased stacking.

![Graph showing power spectral density](image)

Note: The noise is reduced by about the square root of stack size.

**Figure 7** – Setup 1.

![Diagram of setup](image)

This has little problem with valve noise as seen in Table 1 the meter worked over the whole range of velocity and pressure drops.
This begins to experience problems at the highest velocity and pressure drops, as seen in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Valve Trim 1</th>
<th>Velocity m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test P1/P2</td>
<td>0 – 2</td>
</tr>
<tr>
<td>k</td>
<td>55/35</td>
</tr>
<tr>
<td>l</td>
<td>55/45</td>
</tr>
<tr>
<td>m</td>
<td>45/35</td>
</tr>
<tr>
<td>2 – 8</td>
<td>Work</td>
</tr>
<tr>
<td>8 – 14</td>
<td>Fail</td>
</tr>
<tr>
<td>21 +</td>
<td>Fail</td>
</tr>
</tbody>
</table>

The meter first fails at 11 m/s and 20 bar Δp, and next fails at 21 m/s and 10 bar Δp, which is at about the same power dissipation. The increased pipe length, from 27D to 71D, and the additional double-tee account for the reduction in noise in Setup 1. In fact a ‘tee’ is quite a good reflector of sound, reducing the sound transmitted upstream.

CONCLUSIONS

- Consider potential control valve noise problems at the design stage of an ultrasonic metering system. It is easier to design them out than try to cure them later.

- Always install the meter upstream of the valve.

- Separate the meter and noise source by as much pipe and as many fittings as possible.

- Use blind tees instead of bends where possible.
- In an existing installation, use the ultrasonic meter signal processing (filtering and stacking) and diagnostics to best handle the noise.

- Change the operating procedure, if possible, to use another valve or share the pressure drop between two valves.

- In a tight situation, where space is limited, consider a silencer.

**References:**