PULSATION REDUCTION BY ACOUSTIC FILTERS FOR METERING APPLICATIONS

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INTRODUCTION

Because of the adverse effects of pulsations on orifice and other types of flow meters there is for many installations, a need to eliminate or decrease the amplitude of pulsations in the piping. This task has been the primary domain of acoustical piping designers who have had both theoretical and practical field experience in such areas. The most common and effective treatment for pulsation control is the design and installation of acoustic filters. However, most filters designed by novices are not effective and are costly to operate because of pressure drop losses. This paper discusses the basic principles and considerations in acoustic filter design.

There are many small compressors such as well-head gathering compressors that cannot justify the cost of a thorough acoustic analysis in order to protect the nearby orifice meter from excessive pulsations and accompanying square root error. This paper will make an effort to demonstrate design procedures related to a specific type of acoustic filter to be used to reduce pulsations in most simple metering applications. The specific filter is a symmetrical in-line low pass filter. The important elements of this filter can be summarized in the following points:

1. The inlet line is located at the acoustic center of the first chamber of the filter.
2. The first chamber of the filter, the choke tube, and the last chamber are all the same acoustical length.
3. The choke tube connects the acoustical centers of each filter chamber.
4. The outlet line is located at the acoustical quarter point of the final chamber.

It is fully realized that this is a specialized filter design and other types of designs could be recommended but this particular filter design was chosen because of its conservative and foolproof aspects. Drawings of the physical aspects of the acoustic filter piping are shown in the Appendix.

WHERE DO PULSATIONS COME FROM?

Pulsations in metering applications can be generated by reciprocating compressors, centrifugal compressors, flow induced phenomena, or turbulent sources. The primary focus of this paper is directed toward filtering the most persistent pulsations that are produced by reciprocating machinery.

A reciprocating compressor produces pulsation at compressor crankshaft RPM and its multiples. Pulsation frequencies are generally expressed in cycles per second (Hertz). A 300 RPM compressor produces pulsation at 5 hertz, 10 hertz, 15 hertz, and higher multiples. Most compressors (for natural gas services) are double-acting and compress gas on the head and crank end of the cylinder. Double-acting cylinders tend to produce more pulsation at the even multiples of RPM and less at the odd multiples. Therefore, a 300 RPM double-acting cylinder will produce its strongest pulsation at 10 hertz. When compressors have more than one cylinder, the crankshaft phasing of the cylinders will also cause certain multiples to be higher than others. For example, if two double-acting cylinders are phased 90′ apart they will produce a significantly higher pulsation level at four times RPM. In the case of a 300 RPM machine and two double-acting cylinders phased 90 degrees apart there will be a high fourth harmonic or 20 hertz. Generally, the higher multiples (sometimes called compressor harmonics or compressor orders) will contain less energy than the lower orders.

WHAT ARE THE IMPORTANT CHARACTERISTICS OF LOW PASS FILTERS?

The single most important factor of a low pass acoustic filter is its natural frequency. The volume-choke-volume configuration exhibits a relatively low natural frequency in comparison with the acoustic halfwave natural frequencies of the chamber and choke tube lengths. At frequencies below the filter natural frequency, there will be no attenuation of pulsations passing through the filter. There will be a sharp attenuation starting at about 20 percent above the natural and extending out to several hundred hertz. It is very important to understand that pulsations at the natural frequency of the filter will actually be magnified by as much a 10 to 40 times. Therefore, it is very important that the natural frequency of the filter system not be frequency-coincident with pulsations. This can be accomplished in two ways. The filter natural frequency can be placed 20 percent below the RPM of the compressor or it can be placed halfway between the first order of the maximum RPM and second order of the minimum RPM.

HOW TO CALCULATE THE BEST FREQUENCY FOR THE FILTER NATURAL FREQUENCY

This procedure will assist in a correct design for placing the filters natural frequency below the fundamental RPM or between the first and second RPM orders of the compressor. The following two cases illustrate the calculations and limitations:

Case 1: Placing the filter natural frequency F_0 below the fundamental order.

$$F_0 = \frac{RPM_{min}}{(60)(1.2)}$$

Where:

F_0 = filter natural frequency of filter system

RPM_{min} = the minimum actual operating RPM of the compressor

Case 2: Placing the filter natural frequency between the first and second orders.

$$F_0 = \frac{RPM_{min} * 2 + RPM_{max}}{(60)\ (2)}$$

This frequency F_0 must be at least 20 percent separated from $\frac{RPM_{max}}{60}$ and $\frac{RPM_{min} * 2}{60}$. This 20 percent detuning will ensure that the filter natural frequency is not excited by the compressor.

CALCULATING THE INSIDE DIAMETER OF THE CHOKE TUBE

The inside diameter (ID) of the choke tube should be as small as pressure drop limits will allow because larger choke tubes require large volumes to create effective filters. A standard procedure is to limit the gas flow velocity to 100 feet per second as implemented in the following equations.

$$q = 0.327 \frac{MMSCFD(T+460)Z}{P} \left(\frac{ft^3}{sec}\right)$$

$$ID_C = \frac{1.354 \sqrt{q(in.)}}{P}$$

Where:

MMSCFD = million standard $feet^3$ per day flow

T = gas temperature (°F)

P = gas pressure (psia)

Z = real gas correction factor

q = flow rate ($feet^3$ per second)

ID_C = inside diameter of choke tube (inch)

CALCULATING THE FILTER CHAMBER INSIDE DIAMETER

To ensure sufficient attenuation of pulsation above the filter natural frequency, the bottle or filter chamber ID_B should be at least 2.5 times the choke tube diameter ID_C.

$$ID_B = 2.5 * ID_C$$

CALCULATING THE FILTER ELEMENT ACOUSTIC LENGTH

To complete the acoustic filter design, the acoustic length of each bottle and the acoustic length of the choke tube are all equal. This length is calculated based on the following equation.

$$L_f = \frac{c}{\sqrt{2}\ F_0} \frac{ID_C}{ID_B} = 0.225 \frac{c}{F_0} \frac{ID_C}{ID_B} \quad (ft)$$

Where:

c = gas velocity of sound (feet per second)

An equation and method for calculating gas velocity of sound is shown in the Appendix.

Because of acoustic end effects, the physical length choke of the tube should be slightly shorter than the calculated acoustic length. The acoustic length must be reduced a total of 1.2 times the ID of the choke so that the physical length has the proper acoustic effect.

EXAMPLE CALCULATIONS (CASE 1)

General Information

A set of reciprocating compressors operating over an RPM range of 300 to 400 RPM is causing pulsation at a metering site approximately 500 feet from the compressors. The compressors single-act on occasion. The maximum flow rate through the meter site is approximately 31.5 MMSCFD. The discharge temperature is 84°F and the pressure is 925 psia. The ratio of specific heats is 1.32. The gas specific gravity is 0.62 and the compressibility is estimated to be 0.947. The velocity of sound is calculated to be 1371.9 feet per second.

Solution

The natural frequency of the filter system should be placed below the fundamental compressor frequency, since single-acting is possible. The highest possible placement of the filter natural frequency is 4.17 Hertz.

The choke tube volume flow rate is 5.735 feet^3 per second. The choke inside diameter of 3.548 inches is elected. The bottle inside diameter is calculated to be at least 8.87 inches but this would produce a very long cumbersome installation; therefore, a 22.626-inch inside diameter is selected instead. This will produce a bottle chamber acoustic length of 11.62 feet (single chamber). To account for the acoustic end effects, 1.2 times the choke diameter is subtracted from the characteristic filter length to give a choke tube length of 11.26 feet.

EXAMPLE CALCULATION (CASE 2)

General Information

A reciprocating compressor operating over an RPM range of 300 to 360 RPM is causing pulsation at a metering site approximately 200 feet from the compressor. The compressor has no mechanism to single-act. The maximum flow rate through the meter site is approximately 10.5 MMSCFD. The discharge temperature is 120°F and the pressure is 925 psia. The gas specific gravity is 0.62 and the compressibility is estimated to be 0.947. The ratio of specific heats is 1.32. The velocity of sound is calculated to be 1416.5 feet per second.

Solution

The natural frequency of the filter system can be placed between the fundamental and second compressor frequency since single-acting is not possible. The best placement of the filter natural frequency is 8.0 Hertz. This is 25 percent below the minimum second order and 33 percent above the fundamental compressor order. The choke tube flow rate is 2.038 feet^3 per second and the choke tube is calculated to be 1.933-inch inside diameter so a 1.939-inch pipe is selected. The calculated bottle diameter is 4.848, which would again produce an awkward layout, so a 13.124-inch ID is selected. The filter characteristic length of 5.888 feet is calculated and the physical length of the choke tube is calculated to be 5.694 feet.

MECHANICAL CONSIDERATIONS

If a single-bottle design is selected the internal choke tube should be restrained at both ends to ensure that the cantilever lengths on each side of the baffle are not resonant mechanically. The baffle should be dished head with thickness approximately the same thickness as the bottle wall. If a two bottle design is selected, the branch connections should be saddles or pads. Weld-o-lets should be avoided because of the high stress riser they inflect on the bottle wall. Elbows in the choke tube are acoustically irrelevant as long as the center line length is used for the length. Elbows do serve as acoustical to mechanical coupling points and should be avoided if possible. The filter bottle should be securely restrained to ensure mechanical stability and an external choke should be restrained to ensure that the mechanical natural frequency is not coincident with the half wave resonant frequency of the acoustic length.

OTHER PULSATION REDUCTION APPROACHES

In some cases, careful design of meter installations can be effective in reducing or eliminating the chances of pulsations. Meter installations should be designed so that the piping is not resonant and so that the orifices or other meter is located at a velocity minimum. This involves the meter tube length being unrelated to acoustic wave length and being symmetrically about the orifice or other meter.

Restrictions or additional orifice plates installed at various locations in a pipe can dissipate some of the energy in pulsating waves. To be effective these pulsation restrictions are sized to create pressure drops and thereby require an increase in compression horsepower. Pulsation plate performance is dependent on adjacent pipe configuration and frequency content of the pulsations. In some cases, pulsation plates cause higher frequency resonances and increased amplitudes of pulsations.

Surge volumes or single-bottle filters such as scrubbers or separators generally do reduce pulsation levels, however, they are not always effective and their specific frequency responses vary with the installation.

CONCLUSIONS

It is theoretically possible to reduce pulsations at metering sites with acoustic filters so that little or no pulsation will influence flow measurement. The two examples illustrate that the bottle-to-choke diameter ratio of 2.5 is usually increased to ensure practical physical construction on the system. Reduction of choke tuber pressure drop could be reduced even further by the use of a bell mouth entrance fitting. Bell mouths are common when a single-bottle design is selected. It is advantageous to have an experienced acoustical engineer evaluate your filter design practically if the installation or the metering accuracy is critical. If the filter natural frequency is placed below the compressor fundamental, it is possible to be conservative on the low side. However, if the natural frequency is to be placed between the first and second, it is important to be accurate in both calculations and physical construction. Other methods for reducing pulsation are not as effective and foolproof as acoustic filters.

APPENDIX

Speed of Sound Calculation

The velocity of sound can be approximated by the following expression:

$$c = 1.354 \sqrt{\frac{kTZ}{G}}$$

where:

c = velocity of sound (feet per second)
k = ratio of specific heats
T = gas temperature (degree R)
G = gas specific gravity
Z = real gas correction factor at flowing conditions

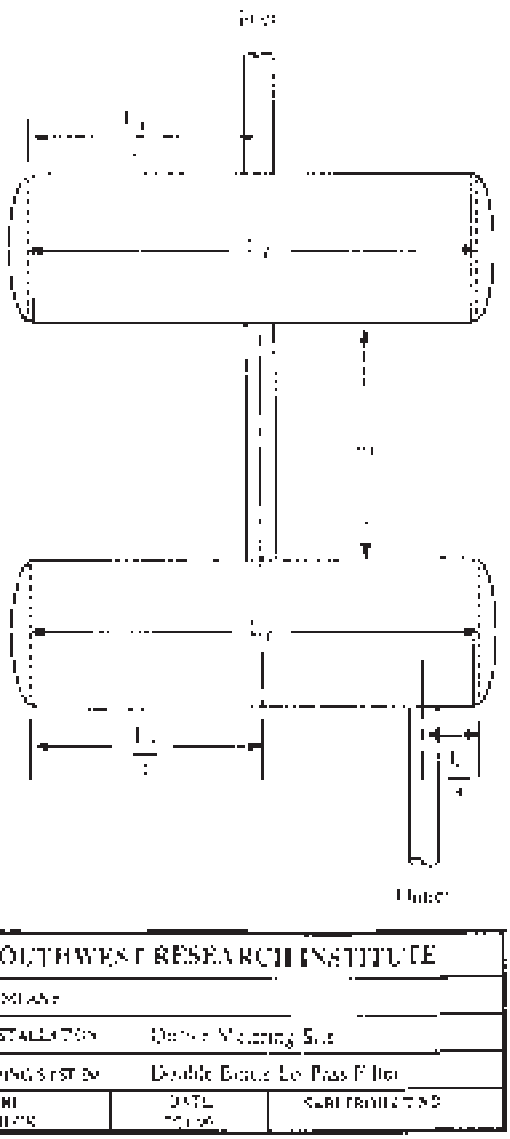


FIGURE 1.

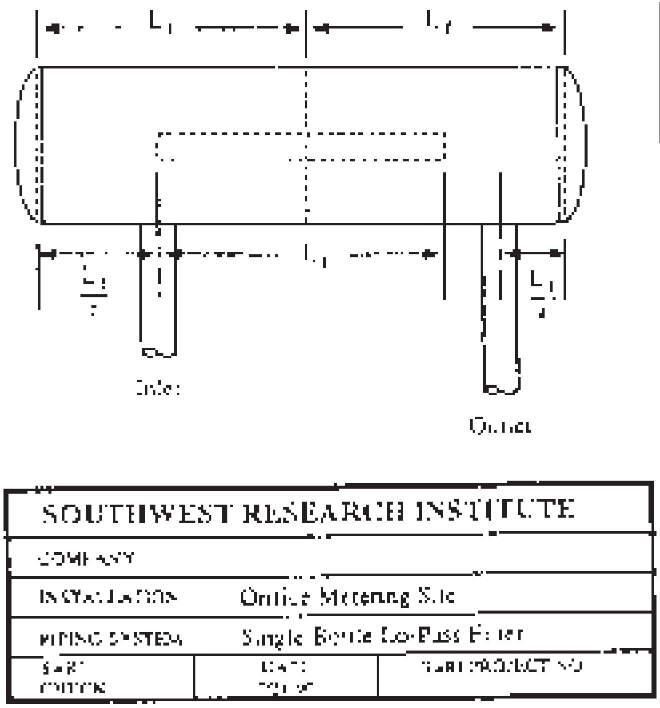
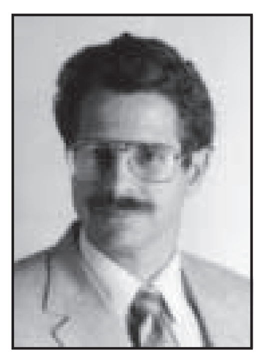


FIGURE 2.



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