# Reciprocating Compressor Pulsation Control Using PAN™ Filters

***Pulsation control achieved without pressure drop.***

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## THE PROBLEM

Pulsation is most often created by reciprocating compressors and resonance in system/yard piping. Traditional pulsation control systems employ combinations of primary and/or secondary volume bottles, often with complex internal choke tubes, baffles, and chambers, as well as external choke tubes and various orifice plates installed at specific locations in the system piping. These devices accomplish pulsation control by adding resistance, or damping, to the system; and they can cause significant system pressure losses upstream and downstream of the compressor cylinders. Although these systems may be well designed, the resulting pressure losses reduce overall system efficiency.

The reduction in pulsation vs. the increase in pressure loss trade-off is tolerable for many high pressure ratio compressor applications. However, for common pipeline transmission applications having low pressure ratios (in the range of about 1.1 to 1.6), system pressure losses can severely degrade the compressor operating efficiency, especially when higher speed (>600 rpm) compressors are used[5,6]. For example, a 20% loss of efficiency on an 8,000 HP compressor wastes 1,600 HP.

This loss of efficiency has become more significant in recent years as the U.S. pipeline industry has expanded its use of larger high-speed reciprocating compressors. With the world's increased awareness of the need for higher energy efficiency and a reduced carbon footprint, new more efficient pulsation attenuation systems are required now.

## THE SOLUTION

A relatively new, field proven technology, PAN™ Filters, can be used to solve pulsation problems without causing pressure drop or compromising the system efficiency[3]. PAN Filters can be used to attenuate pulsation in virtually any piping system, including reciprocating compressor suction and discharge headers, upstream of flow metering stations, and upstream or downstream of centrifugal compressors. They can be designed to replace most pipeline pulsation control bottles in service today, and they are worthy of consideration as an alternative to bottles for new compressor applications.

The application of PAN Filters to reciprocating compressor suction and discharge headers is the focus of this particular paper. PAN Filters can be applied to reduce harmful pulsations and associated shaking forces and pipe stresses in reciprocating compressor suction and discharge headers, without causing any significant pressure losses.

In a PAN Filter, the flow stream, as well as the pulsation energy, is carefully and equally split into two paths. As explained in detail in a previous paper[3], a carefully engineered TST-collector directs half of the pulsating flow through a loop of pipe and the other half of the pulsating flow passes straight through the TST-collector. The PAN Filter's primary cancellation frequency is the frequency that has a wavelength of twice the difference in the two flow path lengths, i.e., the path that includes the loop of pipe and the path straight through the TST-collector. When the two waves of equal amplitude, at this primary frequency, travel through the two flow paths and then carefully rejoined 180˚out of phase by the TST-collector, one wave completely cancels the other, eliminating the pulsation at that frequency in the downstream flow.

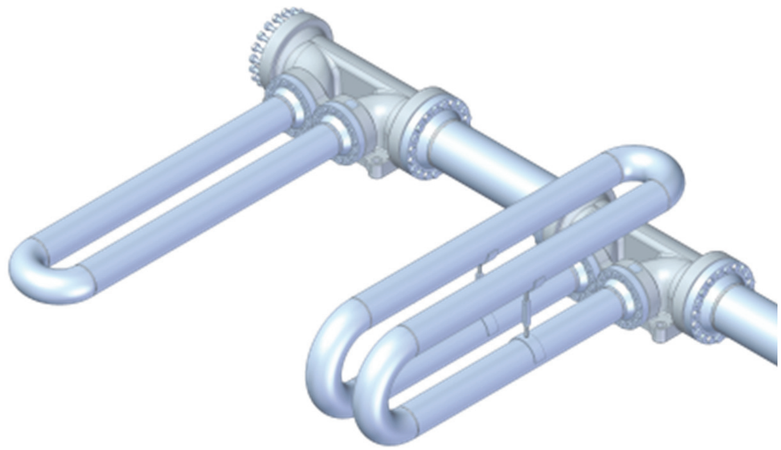

Figure 1: 2-Loop PAN Filter – Loops in series

In addition to the primary frequency, all odd harmonics of that frequency are also completely cancelled. Additional loops can be added in series to produce broad bands of pulsation attenuation that fill in the cancellation gaps between the odd and even orders of the primary frequency. Two or more loops may be necessary for applications with variable speed compressors, varying gas compositions and temperatures, varying flow velocities and flow streams with complex pulsation signatures. A 2-loop PAN Filter is shown in Figure 1. Note that, when necessary, the footprint can be reduced by folding loop pipes over themselves.

Figure 2 shows the extensive band of pulsation frequency cancellation that can be achieved with a 4-Loop PAN Filter. These particular loops are designed to cancel primary frequencies of 4, 8, 16, and 32 Hz. Note that 4 Hz and all 14 harmonics of 4 Hz up to 60 Hz are completely canceled. In addition, note that <u>all</u> frequencies from 11 Hz to 53 Hz are attenuated by more than 90%.

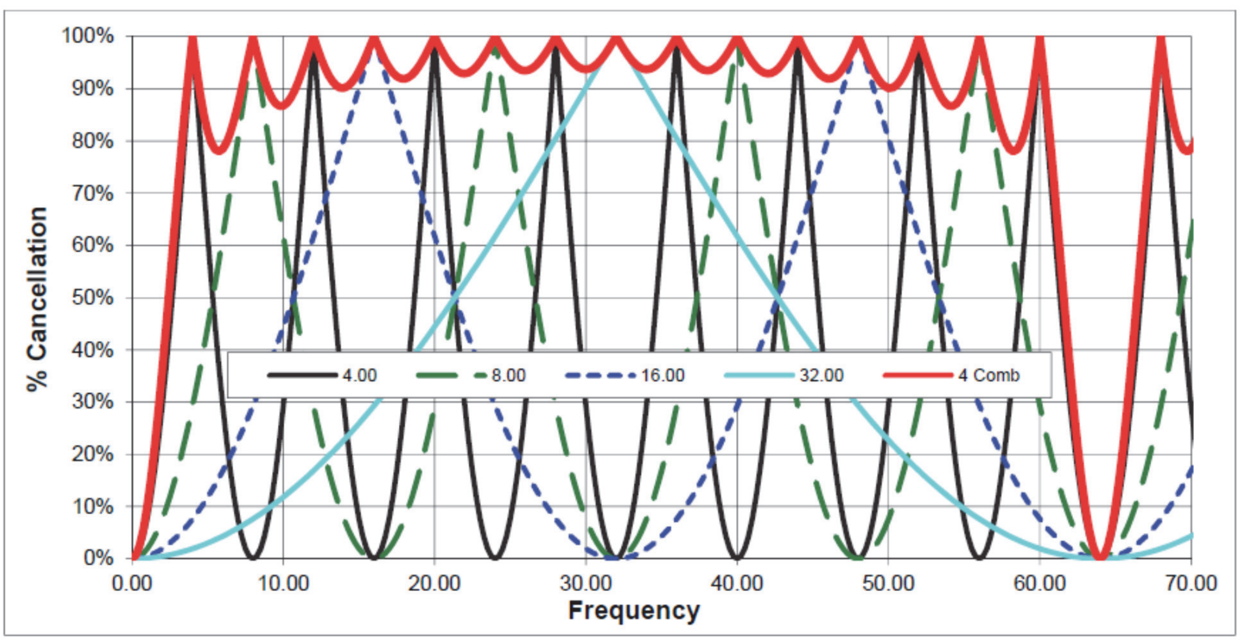


Figure 2: Example of 4-Loop PAN Filter pulsation cancellation

While the pressure losses of conventional bottles and pulsation damping orifice plates are significant, as much as ¼ of line pressure in extreme cases that have been documented[6], pressure losses in PAN Filters and PAN Hi-Performance Compressor Manifolds are nearly zero[4], even in the highest transmission line flow cases. As a result, PAN Filters will increase operating efficiency, so that more flow can be produced for a given horsepower input, or less horsepower is required for a given flow rate. Either way, the use of a PAN Filter reduces operating cost and greenhouse gas (GHG) emissions.

## EXAMPLES OF PAN FILTER APPLICATIONS FOR RECIPROCATING COMPRESSORS

Three examples are presented to show how PAN Filters can be retrofitted to existing reciprocating compressors to solve pressure drop, pulsation and pulsation-related vibration problems. As suggested by the several examples, PAN Filters can be used with compressors in any operating speed range. Longer pipe loop lengths are typically needed for PAN Filters applied to slower speed compressors, and loop lengths are typically shorter for higher speed compressors. PAN Filters can also be designed into new compressor packages to reduce the losses associated with traditional means of pulsation control.

### Example 1

In 2009, collaboration with a major gas transmission company led to the installation of a proof-of-concept PAN system on a compressor at a gas storage site in Northern-Central Pennsylvania[4]. A combination PAN Manifold and PAN Filter was designed and retrofitted to the discharge of one side of a 4-throw, single-stage Superior MH64 compressor having 9.5 in. cylinders. The 6 in. stroke compressor operated from 750 to 1000 rpm and the existing system employed a volume-choke-volume pulsation control system that also included multiple orifice plates. At low pressure ratios, pressure drop in the existing system was excessive, and at high pressure ratios, the pulsation control was not sufficiently effective over at least some of the operating range.

The primary objective of the PAN system was to eliminate the excessive pressure drop associated with effective pulsation control. The resulting PAN system for this application combined a simple PAN Manifold with a two-into-one wye TST-collector, and a two-loop PAN Filter operating in series as shown in Figure 3. The end user's requirement to minimize changes to the package skid and to make the PAN removable in case it did not meet expectations, led to mounting the PAN Filter in a stacked arrangement in a pre-fabricated steel frame that was lagged-bolted to a 4 in. thick concrete floor, i.e., no foundation under it, as shown in Figure 3. Results from the field test[2] of this arrangement showed that there was negligible pressure drop across the two-loop PAN Filter.

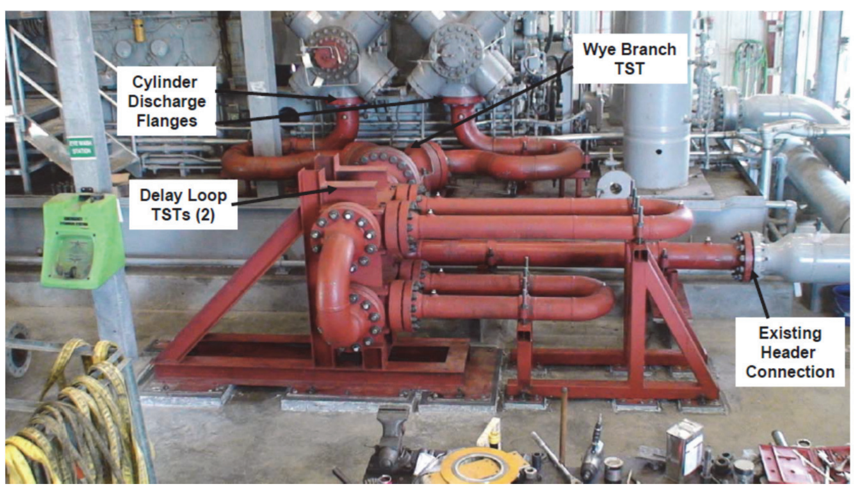


Figure 3: Proof-of-concept PAN system, including a two-loop PAN Filter, installed on the discharge of one two-throw side of a field compressor in 2009.

And, as shown in Figure 4, the PAN Filter, not including the additional benefit of the upstream PAN Manifold, reduced the pulsation by 51% to 87% over the tested speed range of 860 to 1000 rpm.

| Speed (rpm) | Pulsation Before PAN Filter (P/P psi) | Pulsation After PAN Filter (P/P psi) | Pulsation Reduction (%) | Final Pulsation % of Line Pressure |
|---|---|---|---|---|
| 860 | 9.8 | 4.8 | 51 | 0.5 |
| 900 | 27.0 | 3.6 | 87 | 0.4 |
| 950 | 14.8 | 4.0 | 73 | 0.4 |
| 980 | 20.6 | 4.8 | 77 | 0.5 |
| 1000 | 20.8 | 5.3 | 75 | 0.6 |

Figure 4: Proof-of-concept discharge PAN pulsation measurements at 886 psig average discharge pressure and 1.35 pressure ratio.

**Example 2**

In late 2015, an existing compressor station encountered high vibration and related failures in system piping – loose pipe clamps, broken anchor bolts, etc. – around a 3000 HP, 300 rpm Clark TLAD integral engine compressor. As often happens, operating conditions had changed over time as new shale gas supplies increased the demands on the compressor.

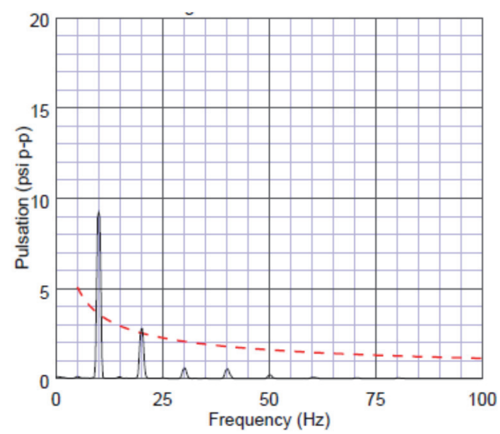

Figure 5: 1st stage suction line pulsation – Load step 12

The 19 in. stroke two-stage compressor had two 18.5 in. first-stage cylinders with two head end and two crank end fixed volume clearance pockets, along with two 12.0 in. second-stage cylinders with two head end and one crank end fixed volume clearance pocket. This provided 17 load steps for operating the compressor with suction pressures ranging from 100 to 260 psig and final discharge pressures of 900 to 1180 psig.

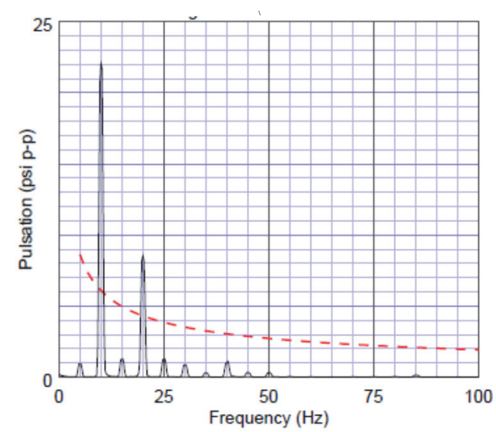

Figure 6: 2nd stage suction line pulsation - Load step 12

A detailed field analysis found that vibration and pulsations at various locations in the compressor piping were in excess of acceptable limits at discrete frequencies of 10 Hz and 20 Hz, which are 2x and 4x multiples of the compressor rated running speed. Figure 5 shows that typical 10 Hz (2x) pulsation level is 4 to 5% of average pressure in the 1st stage suction line. Figure 6 shows that the 10 Hz (2x) pulsation is nearly 5% and 20 Hz (4x) pulsation is about 2% of average pressure in the 2nd stage suction line. Pulsations measured in the 1st stage discharge were generally acceptable, with the highest amplitude occurring at 20 Hz (4x). Figure 7 shows that the 10 Hz (2x) pulsation level is more than 3% of average pressure in the 2nd stage discharge line.

Installing orifice plates to control pulsations met with very little success, and it was determined that new pulsation bottles would be required in order to reduce the pulsation levels to safe levels. In lieu of this expensive option, the possibility of applying PAN Filters was investigated. Close examination of the field test data showed that pulsation was only higher than generally acceptable limits at a discrete frequency of 10 Hz on the 1st stage suction line and on the discharge lines of both stages. The pulsation in the 2nd stage suction line, however, was above acceptable levels at both 10 Hz and 20 Hz frequencies as shown in Figure 6.

PAN Filters, designed with one-loop to cancel pulsation completely at a frequency of 10 HZ, were proposed for the 1st stage suction and 2nd stage discharge lines. As shown in Figure 8, this PAN Filter cancels 100% of the pulsation at 10 Hz and all its odd harmonic frequencies (10 Hz, 30 Hz, 50 Hz, etc.). There is no cancellation at even harmonics of 10 Hz (20 Hz, 40 Hz, 60 Hz, etc.). There is partial cancellation at frequencies in between as shown in Figure 8.

For the 2nd stage suction line, a two-loop PAN was proposed to completely cancel pulsation at both 10 Hz and 20 Hz. As shown in Figure 9, this PAN Filter cancels 100% of pulsation at 10 Hz and all its odd harmonic frequencies (10 Hz, 30 Hz, 50 Hz, etc.). It also cancels 100% of pulsation at 20 Hz and all its odd harmonic frequencies (20 Hz, 60 Hz, 100 Hz, etc.). It cancels 72% to 100% of pulsation over the entire range of frequencies from 10 to 30 Hz, 50 to 70 Hz, 90 to 110 Hz, etc. as shown by the pattern in Figure 9.

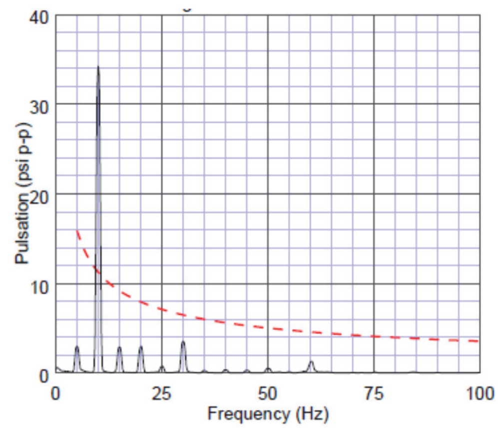


Figure 7: 2nd stage discharge line pulsation - Load step 10

A PAN Filter with one-loop, designed to cancel pulsation completely at a frequency of 20 HZ, was proposed for the 1st stage discharge line. This PAN Filter cancels 100% of pulsation at 20 Hz and all its odd harmonic frequencies (20 Hz, 60 Hz, 100 Hz, etc.). There is no cancellation at even harmonics of 20 Hz (40 Hz, 80 Hz, etc.). There is partial cancellation at all frequencies in between.

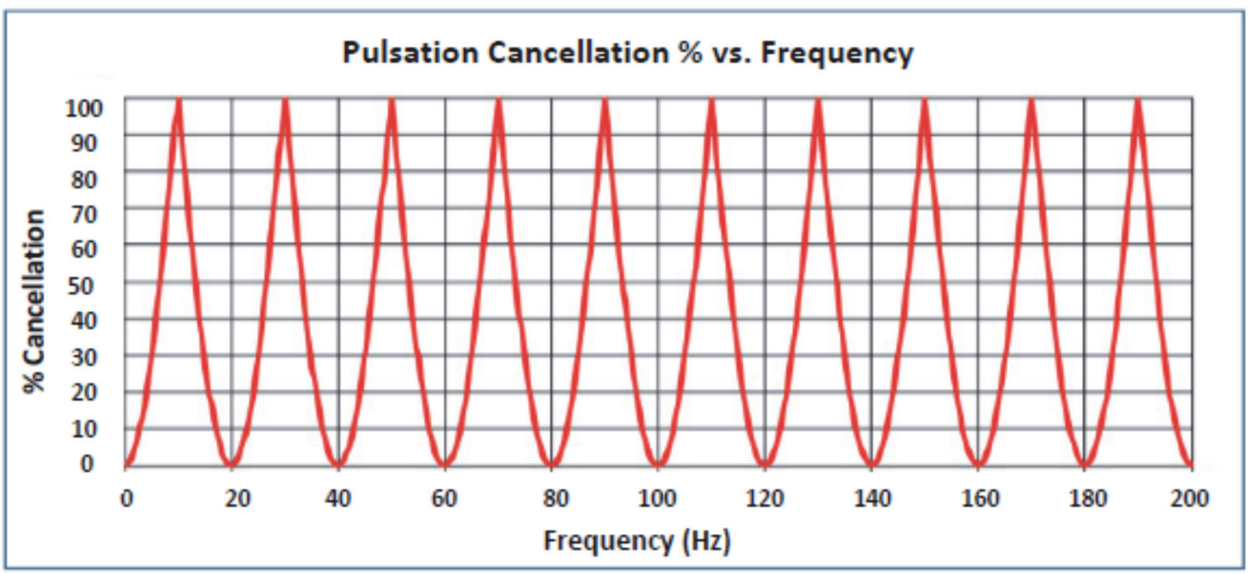


Figure 8: Pulsation cancellation of single-Loop PAN Filter designed for 10 Hz primary frequency attenuation.

The PAN Filter loops are constructed of standard pipe, flanges and U-bends welded into a configuration that bolts onto mating ANSI flanges designed into the proprietary TST-collectors (tuning section transitions).

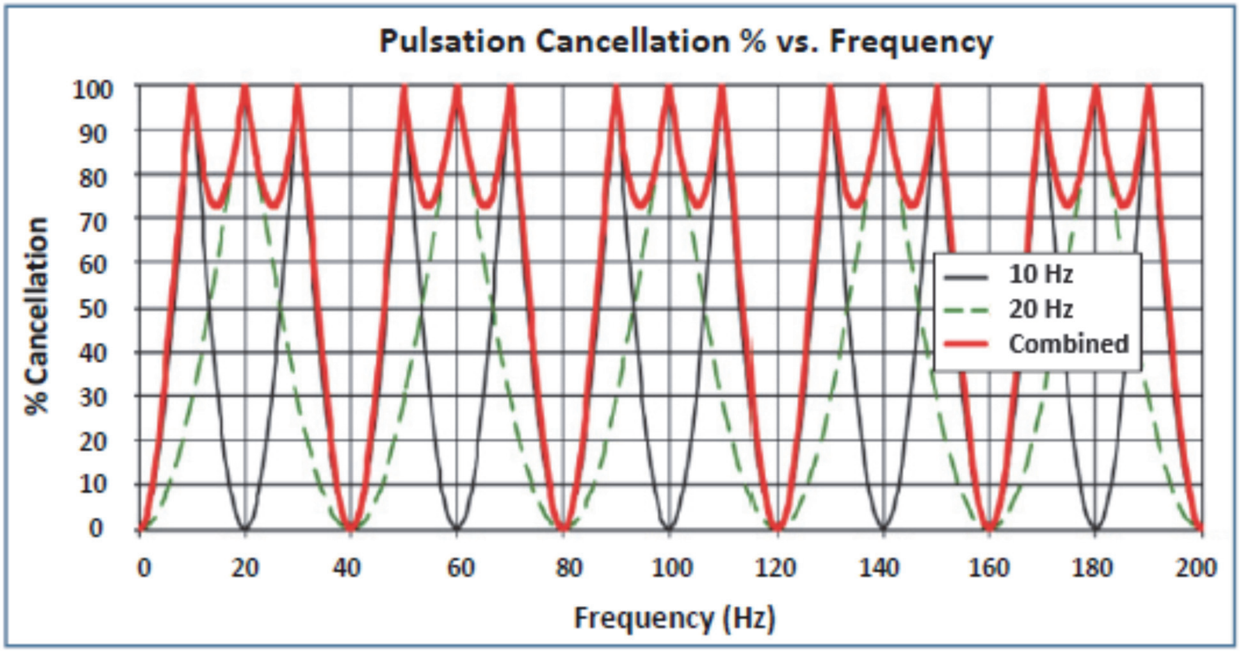


Figure 9: Pulsation cancellation of two-Loop PAN Filter designed for 10 Hz and 20 Hz primary frequency attenuation.

As shown in Figure 10, the TST-collectors are carefully designed with internal aerodynamic flow passages that avoid sudden changes in area that would cause unintentional wave reflection or pressure drop. These essential elements split the entering flow into two equal halves. Half of the flow passes straight through the TST-collector. The other half of the flow is diverted through the delay loop and then rejoined by the TST-collector in such a way that the pressure waves interleave out-of-phase, cancelling each other. This process eliminates the pulsation at the primary frequency, and as well as at all its odd harmonics, without any significant pressure loss.

Figure 11 is a sketch of the proposed PAN Filter installation, showing single loop filters on the 1st stage suction and both discharge lines, along with a two-loop filter (two loops in series) for the 2nd stage suction line. For Loop 1 in the 1st stage suction, the TST-collector fits into an existing 16 in. line and provides connections for 10 in. loop piping. The loop (for 10 Hz cancellation) has a flow length of approximately 70 ft. The overall length is approximately 35 ft. due to the "U" shape.

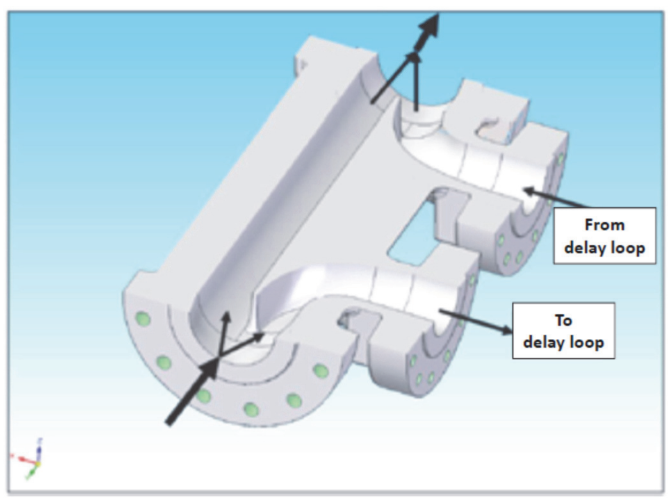


Figure 10: TST-collector cross-section

For Loop 2 in the 1st stage discharge, the TST-collector fits into an existing 12 in. line and provides connections for 8 in. loop piping. The loop (for 20 Hz cancellation) has a flow length of approximately 35 ft. and an overall length of approximately 17 ft.

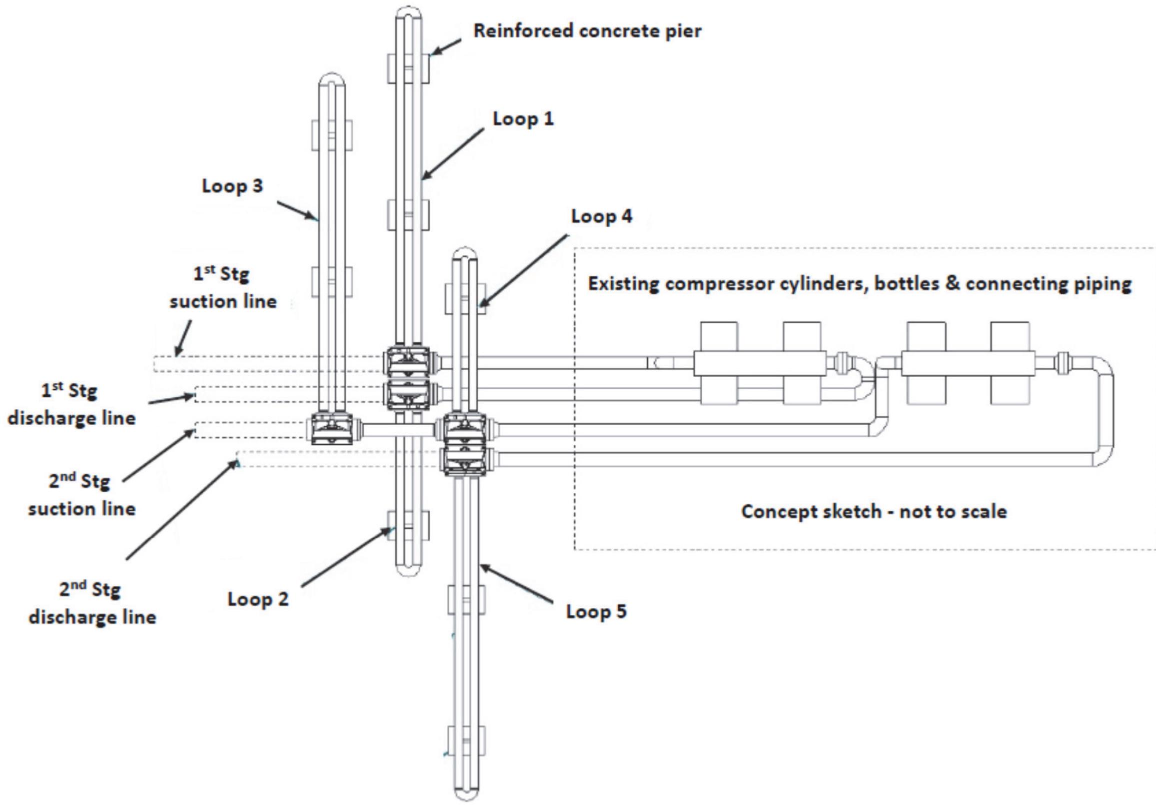


Figure 11: Sketch of proposed PAN Filters for an existing 2-stage compressor system

The 2nd stage suction has two of the 12 in. x 8 in. TST-collectors in series. Loop 3 has a loop length of 70 ft. and Loop 4 has a loop length of 35 ft. for 10 Hz and 20 Hz cancellation, respectively. For Loop 5 in the 2nd stage discharge, the TST-collector fits into an existing 8 in. line and provides connections for 6 in. loop piping. The loop length (for 10 Hz cancellation) is approximately 70 ft.

The loops are supported by concrete piers, spaced to avoid mechanical natural frequencies that might be excited by the resident pulsations in the system. Although the loops in the sketch in Figure 10 are shown laid out flat, they can be doubled back over themselves as shown in Figure 11, oriented vertically (with appropriate supports), or even buried, if necessary to fit into tight space constraints. The installed cost of the five PAN Filters was estimated to be about 20 to 25% less than the cost of installing new pulsation bottles, and the reduced pressure drop was a further benefit. The proposed arrangement is currently under consideration pending approval of capital funds.

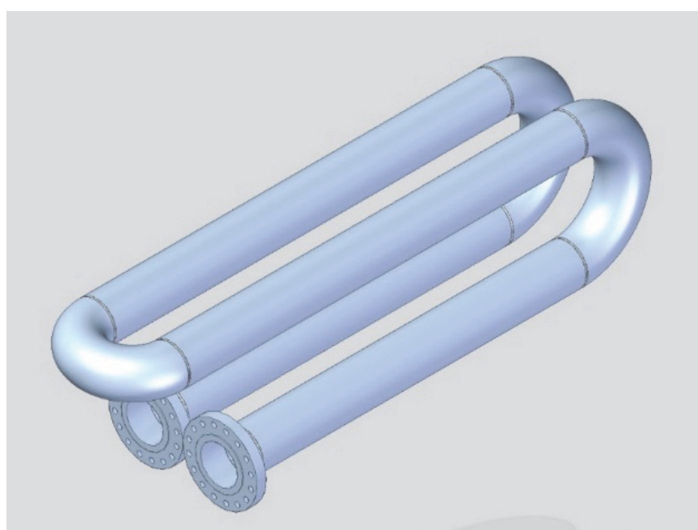

Figure 11: Example of Loop Configuration with Reduced Footprint.

**Example 3**

An existing compressor currently requires new pulsation bottles to safely accommodate expected changes in operating conditions. The 2050 HP, 300 rpm Clark HBA-8T integral engine compressor is equipped with three 17 in. diameter x 15.5 in. stroke EnBloc cylinders operating in parallel as a single-stage. Although the new pulsation bottles were predicted to control pulsations to safe levels, fitting the large bottles into the available space in the basement adjacent to the large foundation block under the integral engine compressor was a challenging problem.

Using the results of a previous pulsation study to determine the pulsation frequencies requiring control, a quick look showed that single-loop PAN Filters could be designed to provide effective pulsation control in both the suction and discharge headers. Preliminary calculations indicate that the line size could be reduced from 20 in. to 12 in. before connecting to the entrance of each TST-collector and then expanded from 12 in. back up to 20 in. after each TST-collector, with less than about 1 psi of pressure drop. This enables the use of 12 in. TST-collectors in the header lines and 8 in. loop piping, making the system more compact and less cost. The TST-collectors with the reducers and increasers can be installed in the existing suction and discharge piping along the ceiling in the basement. The 75 ft. long, 8 in. PAN loops can be fabricated and oriented to loop back and forth along the vertical sides of the compressor foundation block as shown the concept sketch in Figure 12. A suitable mounting frame, secured to the basement floor and the sides of the concrete foundation block, would support the loop pipes to ensure that there is no pulsation induced vibration or mechanical resonances. This proposed arrangement will fit the available space and still enable maintenance access in the basement, as it occupies only 12 to 18 in. of width along the wall that runs parallel to the integral engine compressor crankshaft.

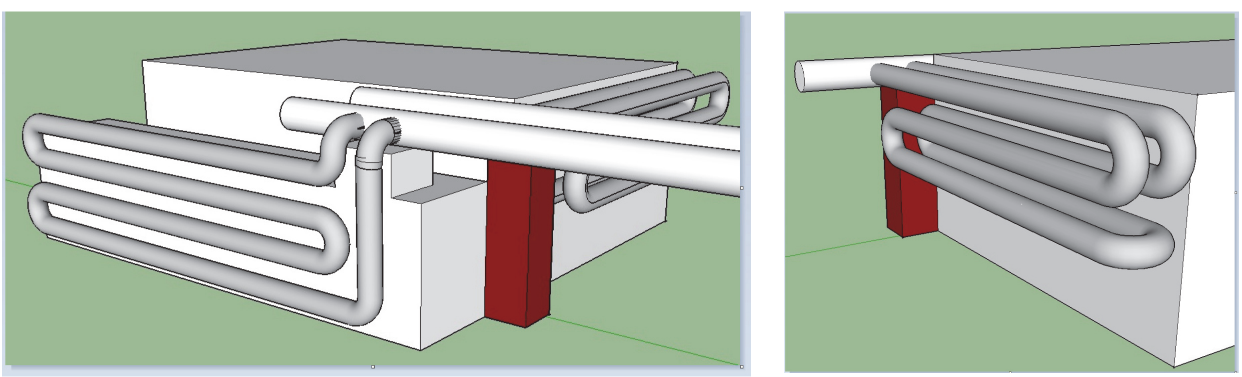

Figure 12: PAN Filter loops in compressor discharge [left] and suction [right] arranged along the side of the foundation block in basement under a large integral engine compressor.

**SUMMARY**

Lab testing and field installations have successfully demonstrated that PAN Filters effectively control pulsations without the pressure drop penalty associated with traditional pulsation control approaches. Using OPTIMUM Pumping Technology's advanced Virtual Pumping Station (VPS™) simulation software, optimal PAN systems can be designed and the performance reliably predicted for the wide range of operating conditions that are typical of most reciprocating compressor applications.

PAN Filters have been applied successfully on reciprocating compressors[2,3,4] and upstream of flow metering stations[1]. They also hold promise for application on lines upstream, or downstream, of centrifugal compressors to eliminate pulsations that might otherwise lead to premature surge and a reduction in the compressor's useful operating map. Given the typical high flow rates of centrifugal compressors, PAN Filters provide solutions with significantly less line pressure loss and typically lower cost than other pulsation control alternatives.

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