Advancement in Pulsation Control for Reciprocating Compressors

Authors:
Broerman, Eugene "Buddy"; McKee, Robert, Ph.D.; Scrivner, Christine
Southwest Research Institute®
Bourn, Gary
El Paso Western Pipelines

Presented by:
Scrivner, Christine
Fluids Engineering Department
Southwest Research Institute®
San Antonio, Texas, USA
christine.scrivner@swri.org

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Abstract:

Current acoustic manifold designs for reciprocating compressors require a balance between pulsation control, compressor performance, and mechanical vibration. The high amplitude pulsations associated with uncontrolled nozzle resonance can cause unacceptable vibration and poor compressor performance. Pressure drop elements, which are currently used to control cylinder nozzle pulsation amplitudes in combination with surge volumes, can significantly affect compressor capacity and horsepower requirements. For modern high-speed compressors units, nozzle resonance control with the use of an orifice is common but can significantly reduce unit performance and decrease capacity. As part of an ongoing, joint Gas Machinery Research Council (GMRC) and Southwest Research Institute (SwRI) research project, a pulsation control device designed to mitigate cylinder nozzle resonant pulsations without the losses typically associated with the installation of cylinder nozzle orifices was developed and field tested. This newly developed pulsation control device was named the Virtual Orifice, since this technology was essentially developed to replace the compressor nozzle orifice. The Virtual Orifice effectively reduces the nozzle pulsations without a pressure drop and a corresponding power and capacity loss. This paper presents results from the research and field trial of the virtual orifice with respect to pulsation control performance, efficiency improvements, and vibration reduction.

1 Introduction

Controlling pulsations associated with the cylinder nozzle response is a continuing challenge generally tackled through frequency avoidance or by pressure drop damping. Wide speed ranges and/or large variations in operating conditions (temperatures and pressures) often make the preferred design approach, resonance avoidance, impossible. Because it has become necessary to manage resonance rather than avoid it, orifice plates are commonly installed at or near the cylinder nozzle flange connection of most high-speed and many low-speed reciprocating compressors. A continuing need for increased operational flexibility with lower losses is driving today's pulsation control research.

Cylinder nozzle resonance is a simplified term for the quarter wave response associated with the acoustic length from the cylinder valves through the cylinder internal gas passages and compressor cylinder nozzle to the compressor cylinder bottle. When the frequency of the pulsations that are inherently generated by reciprocating compressors coincides with or is near the acoustic natural frequency of the cylinder nozzle response, the pulsations are significantly amplified.

In 2005, the Department of Energy (DOE), Gas Machinery Research Council (GMRC), and Southwest Research Institute (SwRI) formed a joint research program coined the Advanced Reciprocating Compressor Technology (ARCT) research program. This research program was continued by GMRC and SwRI in 2006. Pulsation control was one of many areas researched through the ARCT program. A primary goal of the ARCT pulsation control research program was to develop a low pressure drop method of controlling the cylinder nozzle resonance, thus eliminating the need for orifices in the nozzle region. The application of a Side Branch Absorber (SBA), or Helmholtz resonator, at or near the cylinder nozzle was conceptualized and later tested for the first time in February 2006. Because the novel application of the SBA near the cylinder nozzle was meant to replace the typical orifice plate, the device was named the Virtual Orifice (VO).

2 Development

Side Branch Absorber (SBA) technology has been used for many years to alter acoustic responses in compressor piping systems. SBAs have been industry proven to alter lateral resonances and acoustic filter responses, significantly reducing pulsations and vibrations. An example of the results that can be achieved through proper installation of an SBA are depicted in Figure 1. For the fixed speed (400 RPM) compressor piping system evaluated, the acoustic filter frequency was not adequately placed to limit pulsations in the adjacent centrifugal piping to acceptable levels. Additional pulsation control in the form of an SBA attached to the piping lateral resulted in significant reduction of the pulsations at one times the compressor running speed (1x). As an SBA applied in the compressor cylinder nozzle region, the VO has a similar impact on pulsations at the cylinder nozzle resonance frequency. For optimum reduction, the VO should be located as close as possible to the compressor cylinder valves (i.e., at the pulsation maximum of the cylinder nozzle quarter wave response).

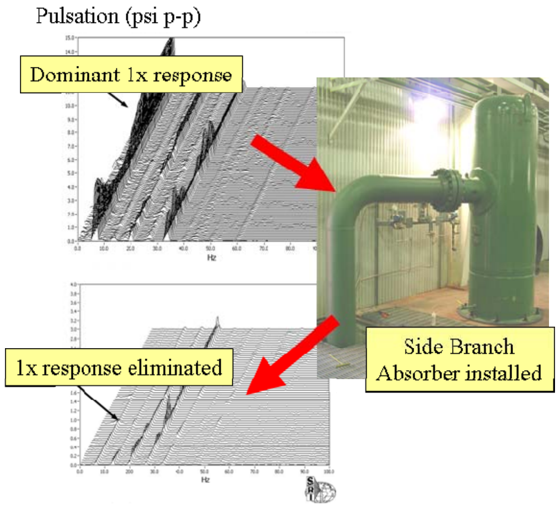

Figure 1: Effectiveness of a Side Branch Absorber

As with the SBA, the VO is comprised of a choke tube (relatively small piping) that connects a volume to the main piping. Initial sizing of the VO choke tube and volume is determined using the well-documented equation for the Helmholtz resonator. Frequency placement and effectiveness of the VO are then fine-tuned using proven acoustic simulation software to model the piping system. This sizing method has been successfully used throughout the development stages of the VO.

2.1 VO Testing at the Reciprocating Compressor Test Facility (RCTF)

Testing of the original VO design was performed at the Reciprocating Compressor Test Facility (RCTF) located at SwRI. Two VO devices were installed on an Ariel JGA/2 reciprocating compressor as indicated in Figure 2. The VO in the left circle is installed on the valve cap. The VO in the right circle is installed along the cylinder nozzle. As depicted in the figure, the choke tube of each VO included a full bore ball valve to allow quick instalation or removal from the acoustic system. Because the data could be acquired quickly with and without the VO installed, this configuration provided valuable insight. It was possible to locate the cylinder nozzle resonance peak, then almost instantaneously open the valve and watch the resonance peak drop. For this configuration, a pulsation amplitude of 9.0 psi [62 kPa] at 50 Hz was measured with the valve closed (Figure 3). With the valve open (VO installed), the pulsation amlplitude at the cylinder nozzle resonance frequency dropped to 1.5 psi [10 kPa] at 50 Hz. Testing of the original VO designs showed a pulsation amplitude reduction of 60 percent over the entire 500 to 1,000 RPM speed range.

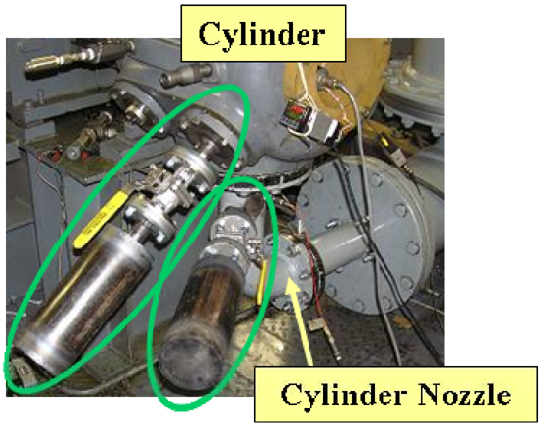

Figure 2: The Original Virtual Orifice

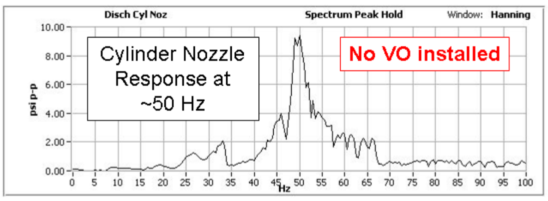

Figure 3: RCTF Cylinder Nozzle Resonance

Following successful testing of the VO in the RCTF, modifications were developed to improve the mechanical design. Some slight improvements to the acoustic design were also made. The more compact and mechanically stable VO design is depicted in Figure 4. The plot in Figure 5 presents the pulsations that were measured with the more compact and acoustically improved VO installed on one of the cylinder head-end valve caps. When compared with the plot in Figure 3 (no VO installed), an overall pulsation reduction of 67 percent is observed with the VO installed.

Figure 4: Improved Compact Mechanical Design

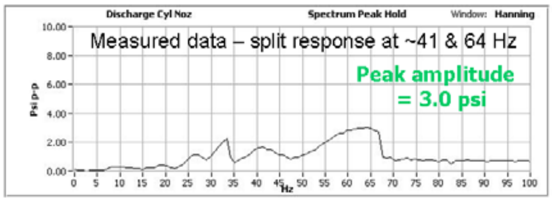

Figure 5: RCTF Test Results with Compact VO

2.2 VO Testing at the Advanced Reciprocating Compressor Technology (ARCT) Test Bed

Once initial testing of the VO on the small compressor at the RCTF was successfully completed, a similar VO design was installed and tested at the Advanced Reciprocating Compressor Technology (ARCT) Test Bed, also located at SwRI. For testing at this facility, the compact VO design was installed on an Ariel JGR/2 reciprocating compressor at a discharge valve cap. Cylinder discharge nozzle pulsation data without the VO are provided in Figure 6. Approximately 20 psi [138 kPa] was observed at 54.5 Hz. Measured pulsations with the VO mounted on the discharge valve cap are provided in Figure 7. Pulsations at the cylinder nozzle resonance frequency were reduced to less than 5 psi [34 kPa] with the VO installed. A reduction of 75 percent was achieved without the use of an orifice.

An orifice was also tested in the ARCT test bed in order to document the effects on efficiency for comparison purposes. Efficiency was measured for the relevant cylinder with the orifice installed and then with the VO installed (orifice removed). A comparison of the measured cylinder efficiencies is summarized for the entire speed range in Figure 8. At approximately 510 RPM, a 3 percent efficiency improvement was observed with the VO installed. At approximately 885 RPM, an 8 percent efficiency improvement was observed with the VO installed.

Once the VO pulsations and efficiency improvement capabilities were confirmed through lab testing at the SwRI facilities, the VO was installed at El Paso Western Pipeline's Baxter Station in a field test application.

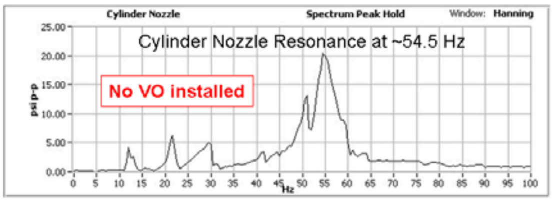

Figure 6: ARCT Test Bed Cylinder Nozzle Resonance

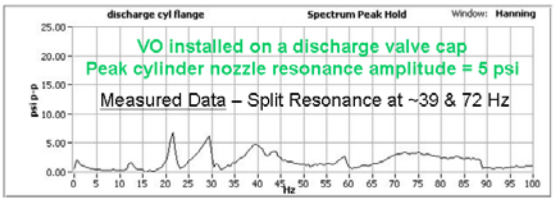

Figure 7: ARCT Test Bed Data with VO Installed

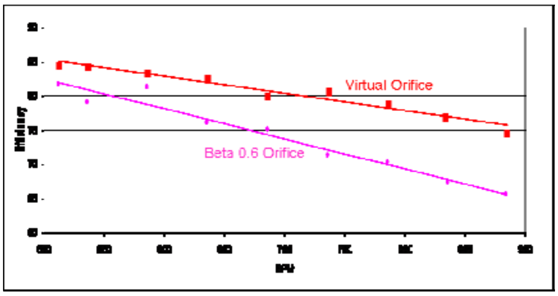

Figure 8: ARCT Test Bed Efficiency Comparison

2.3 VO Field Testing

Field testing of the VO was necessary to further validate the design. A two-throw reciprocating compressor installed at El Paso Western Pipeline's Baxter Station had experienced cylinder nozzle failures as a result of uncontrolled cylinder nozzle pulsations. As a result of the nozzle failures, fairly restrictive cylinder nozzle orifice plates were installed at the suction and discharge cylinder flange connections. Although the orifices effectively eliminated the nozzle failure issue, they also reduced unit throughput. Representatives from El Paso Western Pipelines welcomed the opportunity to install the VO with the hope that the unit efficiency would improve.

The two-throw 1,200 BHP compressor tested operates in a single stage natural gas transmission service over a speed range of 1,050 to 1,150 RPM. Each cylinder has a 7.5-inch [191 mm] bore and a 6.0-inch [152 mm] stroke. Operating pressures are 780 psi [5378 kPa] suction pressure and 1030 psia [7102 kPa] discharge pressure. Figure 9 shows the VO installed at the suction valve cap on one side of the compressor. Further improvemenst were made to the mechanical design prior to field installation. Figure 10 portrays two 3-D images of the improved VO design. In this figure, the VO volumes are transparent to show the internal details. The improved design incorporates the VO into the valve cap such that the valve cap and VO are now one assembly. Field test measurements of the compressor pulsation, vibration, and performance were acquired in July 2007 and are summarized in the following sections.

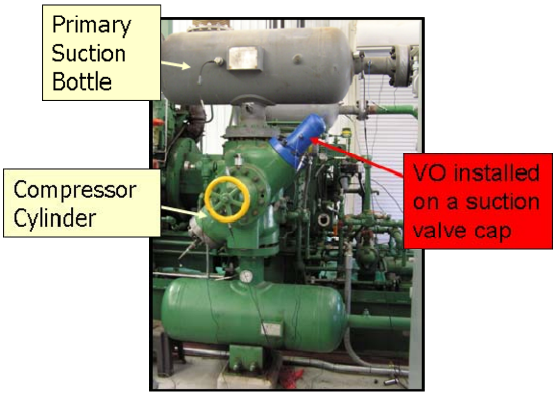

Figure 9: VO installed at GMRC Member Company Station

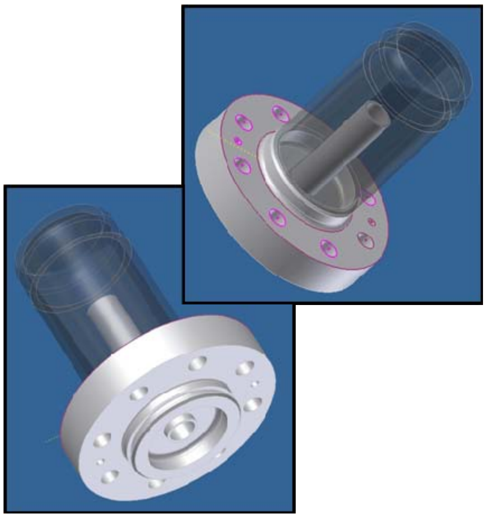

Figure 10: 3-D Model of the Field Tested VO

2.3.1 Pulsation Improvement

Pulsation measurements were obtained at a cylinder valve cap for each cylinder. Data were measured for the following configurations:

- with neither the orifice nor the VO installed,
- with only the orifice installed, and
- with only the VO installed.

Figure 11 summarizes the pulsation measurements for each of the three conditions described above, showing the benefits of installing the VO. With neither device installed, the cylinder nozzle response was just above fourth order (4x), and the maximum pulsations resulting from that response placement peaked at 52 psi [359 kPa]. Pulsation amplitudes at second order (2x) increased significantly with the orifice installed, resulting in a maximum pulsation amplitude of 30 psi [207 kPa]. The large increase in 2x pulsations is indicative of an undersized orifice. With the VO installed, maximum pulsation amplitudes were reduced to 15 psi [103 kPa]. Maximum pulsation amplitudes over the 0 to 200 Hz frequency range were reduced by 71 percent with the VO installed. Overall pulsations were approximately 50 percent lower with the VO than with the orifice. Pulsation improvements also resulted in vibration and efficiency improvements.

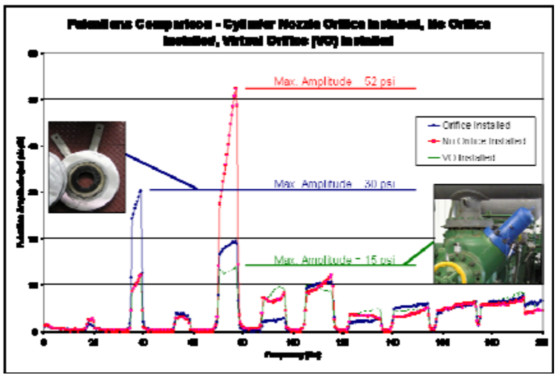

Figure 11: Field Data Show Reduced Pulsations with VO Installed

2.3.2 Vibration Improvement

Vertical cylinder vibration was measured for the three configurations described in section 2.3.1. It was clear upon review of the vibration and pulsation data that fourth order (4x) vibrations are directly related to the pulsations associated with the cylinder nozzle response. Fouth order (4x) vibrations were approximately 0.8 ips [20 mm/s] with neither device installed. With either the orifice or the VO installed, pulsations were reduced to 0.6 ips [15 mm/s] at the bottom end of 4x and 0.3 ips [8 mm/s] at the top end of 4x. The vibration data acquired at the Baxter Station are summarized in Figure 12. Maximum vibration amplitudes at the second (2x) and third (3x) orders were not affected by the system configuration changes. It was determined from the field test results that 2x and 3x vibrations were not pulsation driven and that vibration reduction at these frequencies would require modifications to the mechanical system. In this field test case, the VO did not significantly improve vibration compared to the orifice; however, because the improvements were similar to that of the orifice, these data provide further evidence that the VO could potentially replace the orifice.

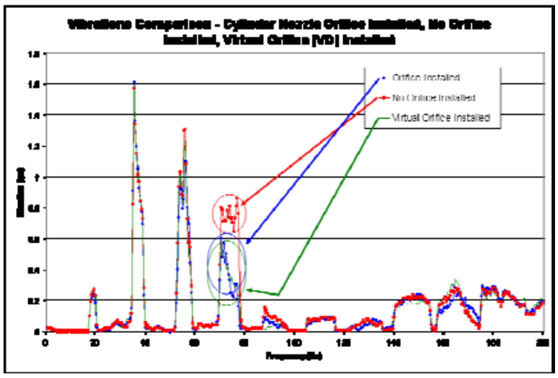

Figure 12: Field Data Show Reduced Vibrations with VO Installed

2.3.3 Efficiency Improvement

Field testing indicated that the VO more effectively reduced pulsations than the orifice and that a similar reduction in vibration amplitudes was achieved with either device installed. Further analysis was then performed to determine if the VO would have a positive impact on cylinder efficiency. Overall thermodynamic efficiency and power per unit flow were calculated based on the measured Pressure-Volume (PV) cards. Figure 13 summarizes the changes in cylinder efficiency with an orifice installed versus the changes in cylinder efficiency with a VO installed. The upper plot depicts a 2.5 to 4 percent efficiency improvement with the VO installed. The lower plot depicts a 1.7 HP/MMSCFD [1416 kW/(Nm^3/hr)] reduction in power per unit flow with the VO installed. Based on the fuel savings generated by installing the two VOs on the test compressor, a payback time of less than two years is estimated.

3 Summary

The Side Branch Absorber (SBA), an industry proven pulsation control device was adapted for a novel location of the piping system through the GMRC research program. Efforts to control cylinder nozzle pulsations with minimal losses resulted in a very useful device called the Virtual Orifice (VO). The VO can be installed on both low-speed and high-speed compressors to replace any cylinder nozzle orifices that are consuming large amounts of horsepower. Installation of the VO on a gas transmission compressor has shown significant pulsation reduction and improved efficiency. Vibration reduction achieved with a VO installed was similar to that achieved with an orifice installed. Reciprocating compressor installations require a balance between pulsation control, compressor performance, and mechanical vibration. The VO offers a solution that more effectively manages the cylinder nozzle resonance, thereby maintaining the required system balance.

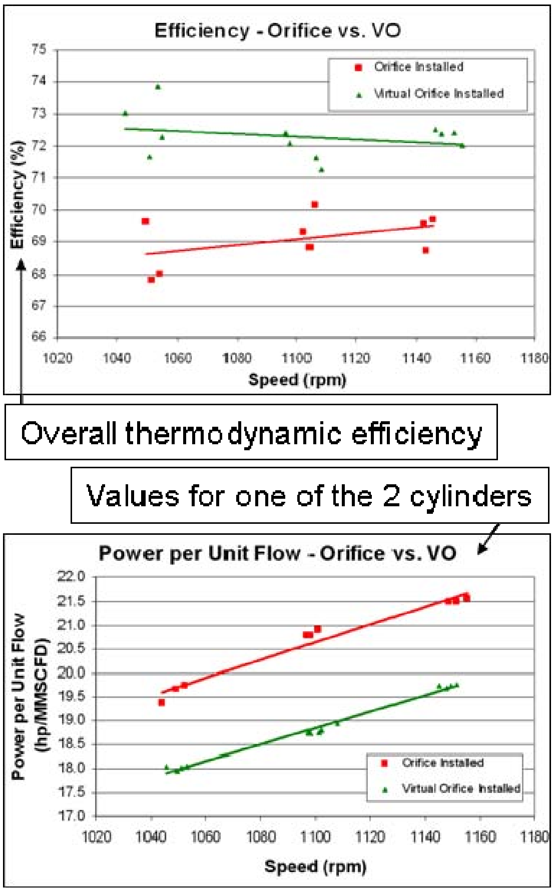

Figure 13: Field Data Show Improved Efficiency with VO Installed

4 Aknowledgements

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