

Reducing Emissions by Improving Efficiency for Reciprocating Compressors

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Oil & Gas Lecture Series: Emissions Reduction



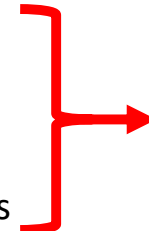
MECHANICAL ENGINEERING

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Methods for Reducing Emissions Related to Reciprocating Compressors

- When taken off-line:
 - Keep compressor pressurized
 - Connect blowdown vent lines to fuel gas system
 - Install static seals on compressor rod packing
 - Install in ejectors on compressor blowdown vent lines



Economic and Environmental Benefits								
Method for Reducing Natural Gas Losses	Volume of Natural Gas Savings (Mcf)	Value of Natural Gas Savings (\$)			Implementation Cost (\$)	Payback ¹ (months)		
		\$3 per Mcf	\$5 per Mcf	\$7 per Mcf		\$3 per Mcf	\$5 per Mcf	\$7 per Mcf
Option 1. Keep compressor at pipeline pressure ²	3,800	\$11,400	\$19,000	\$26,600	\$0	Immediate	Immediate	Immediate
Option 2. Keep compressor pressurized and route gas to fuel system ²	5,100	\$15,300	\$25,500	\$35,700	\$2,040	2	1	1
Option 3. Keep compressor pressurized and install static seal ²	5,000	\$15,000	\$25,000	\$35,000	\$4,900	4	3	2
Option 4. Install Ejector. ³	780	\$2,340	\$3,900	\$5,460	\$11,644	60	36	26

¹ 10 percent discount rate. ² Incremental savings for peak load compressors. ³ Assumes 15 Mcf per blowdown and 52 blowdowns per year; does not include capturing leakage from unit or blowdown valves.

https://www.epa.gov/sites/default/files/2016-06/documents/II_compressoroffline.pdf

- While in operation:
 - Replace rings & rods in compressor rod packing
 - Improve/replace oil wiper &/or valve unloader packing
 - Improve/replace valve cover gaskets



Economic and Environmental Benefits								
Method for Reducing Natural Gas Losses	Volume of Natural Gas Savings (Mcf/year)	Value of Natural Gas Savings (\$/year)			Implementation Cost (\$)	Payback (Months)		
		\$3 per Mcf	\$5 per Mcf	\$7 per Mcf		\$3 per Mcf	\$5 per Mcf	\$7 per Mcf
Economic replacement of rings and rods in compressor rod packing	865 ^a	\$2,595	\$4,325	\$6,055	\$540 ^b	3	2	1

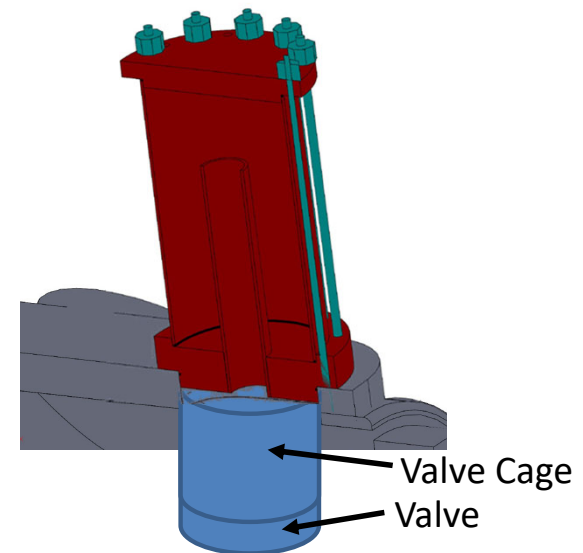
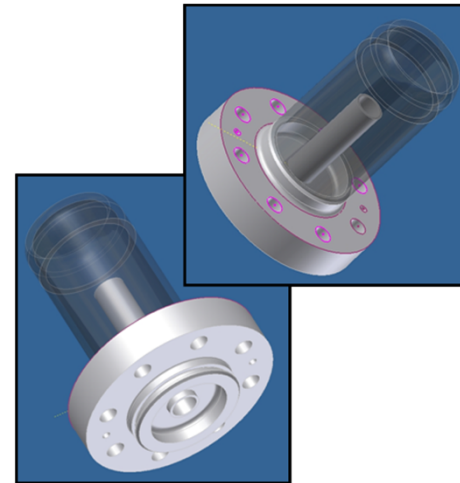
General Assumptions:
^a Pipeline Research Committee International (1999).
^b \$1,620 cost of ring replacement every three years rather than four years (industry average).

https://www.epa.gov/sites/default/files/2016-06/documents/II_rodpack.pdf

- ...what about reducing the required power consumption?

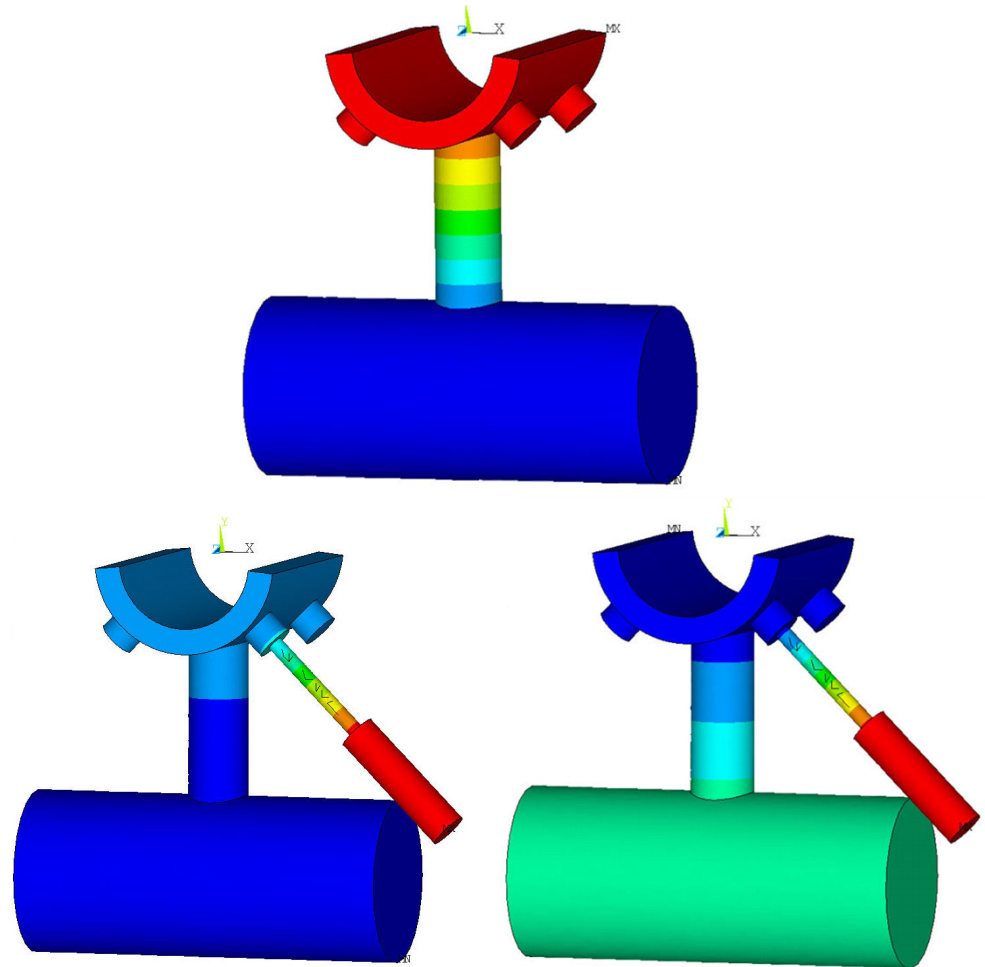
Agenda

- Background
- Case Studies x 3
- Redesigning the VO
- Pulsation, Pressure Drop, & Performance Predictions
- Summary and Concluding Remarks



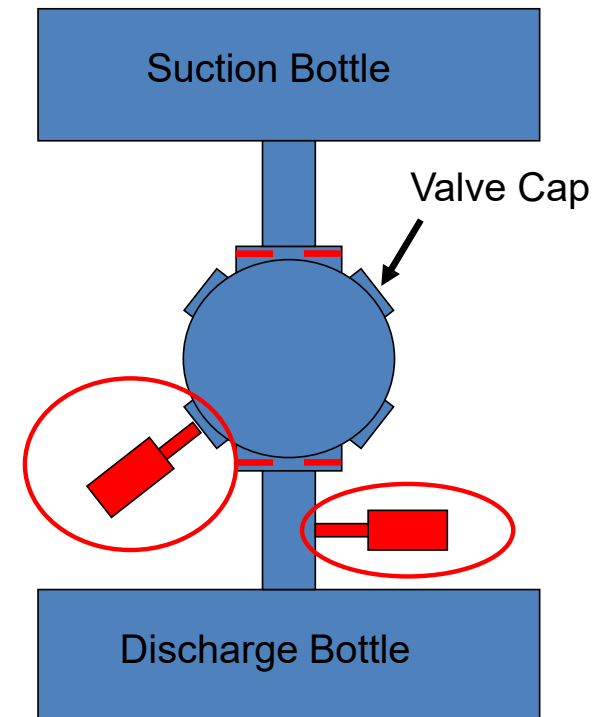
The Virtual Orifice (VO) – background theory

- Cylinder nozzle resonance is a common concern for recip
- Cylinder nozzle resonance typically damped with orifice
- VO is an acoustic resonator or Helmholtz resonator or side branch absorber/resonator (SBA) applied at valve cap
- VO detunes/alters cylinder nozzle resonance



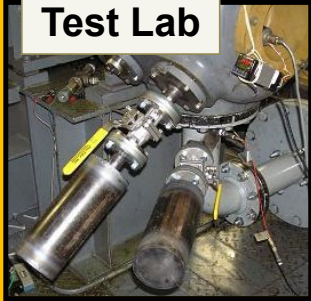
The Virtual Orifice (VO) – background info.

- The VO is an orifice replacement that results in pulsation amplitude reductions of 64-86% relative to no orifice; Relative to typical cylinder nozzle orifice, sometimes as much as 50% better
- The VO can be installed on any cylinder that already has a cylinder nozzle orifice installed or has high enough cylinder nozzle pulsation amplitudes that need to be reduced.
- The VO can be installed on the suction and/or the discharge side of each cylinder depending on the application/need
- Each suction or discharge side of a reciprocating compressor cylinder typically has 2 or 4 (or more) valve caps – The VO is installed on 1 valve cap per suction and/or discharge side of a cylinder
- Measured vibration improvements – 16-85%
- Measured efficiency improvements –
 - Relative to an orifice – 7-8% improvement
 - Relative to no orifice – 0-3% improvement

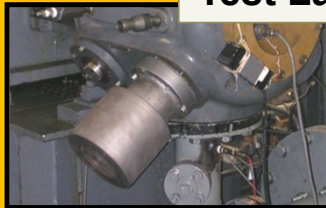


Virtual Orifice – Lab & Field Site Test History

**A. Air
Test Lab**



**B. Air
Test Lab**



**C. MRF
Laboratory
Test on
Natural Gas**

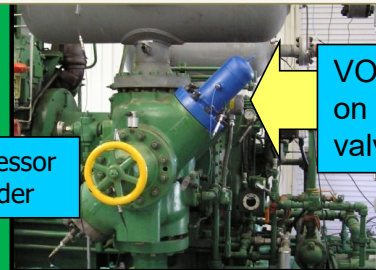


Lab Testing

Field Testing

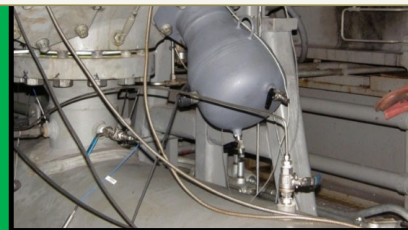
**1. Two VO's on suction side
of a 2-cyl Cameron Cooper
(El Paso in 2007)**

Compressor
Cylinder



VO installed
on a suction
valve cap

**2. Three Discharge VO's on
2-cyl & 4-cyl Ariel (Kinder
Morgan; 2008)**



**3. Eight VO's (suc+dis) on 4-
cyl Ariel unit
(Boardwalk Pipeline in 2009)**



**4. Discharge VO on 4-cyl
Ariel (Kinder Morgan; 2009)**

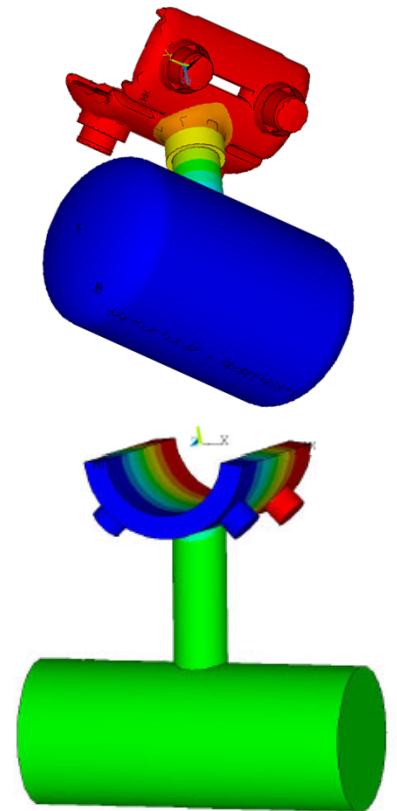
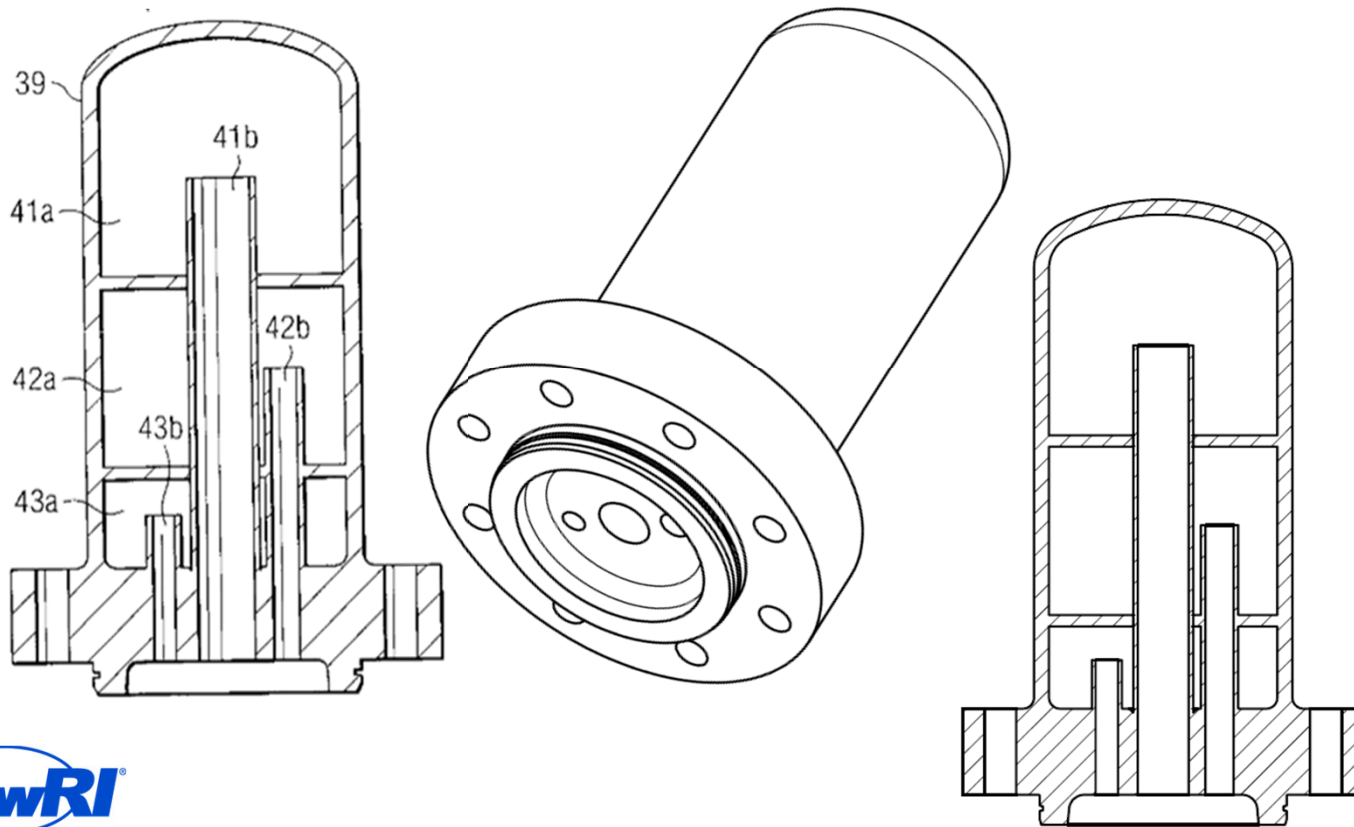


Similar Patent by SwRI

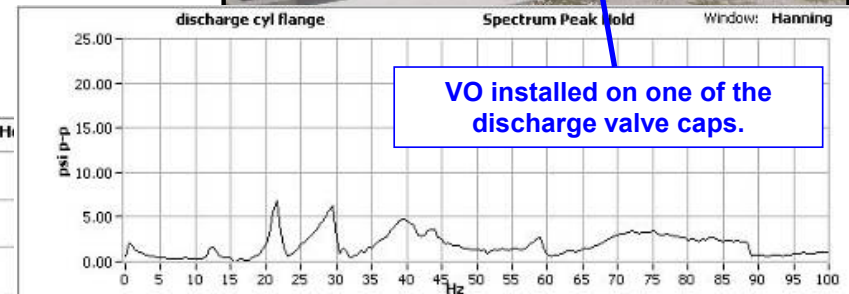
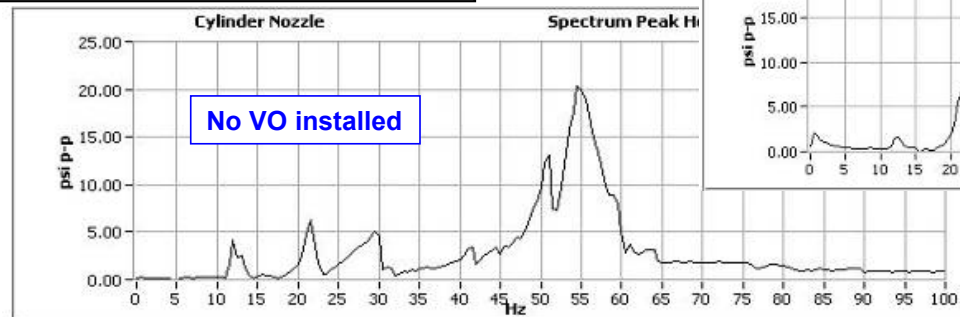
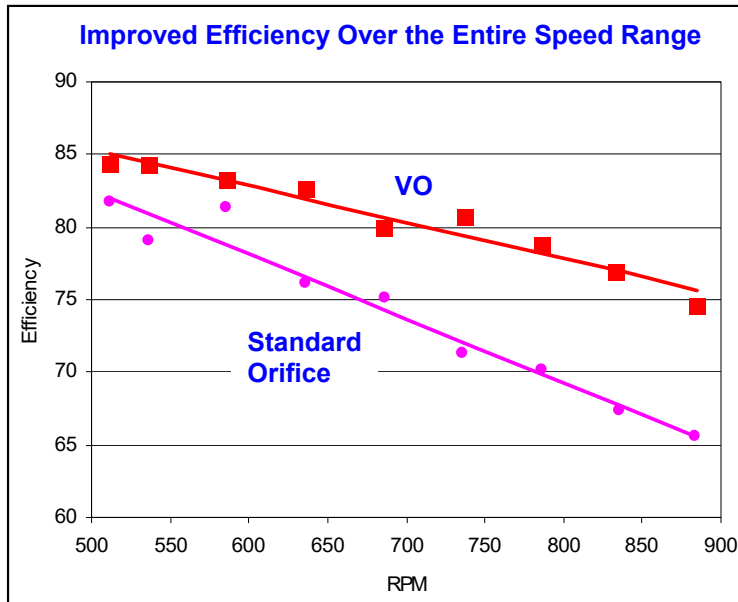
US20100329899A1

Patent title: "Multi-frequency pulsation absorber at cylinder valve cap"

Marketing title: M-FOR
"Multi-Frequency Orifice Replacement"

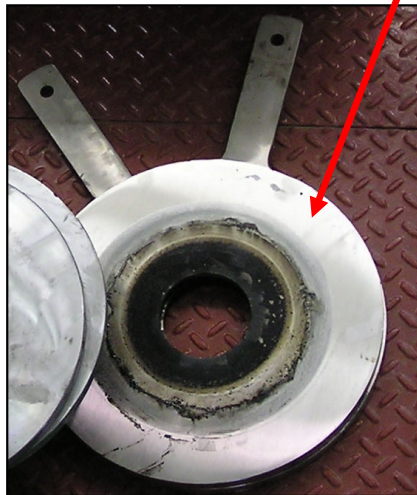


Case Study 1: Orifice vs VO at SwRI MRF

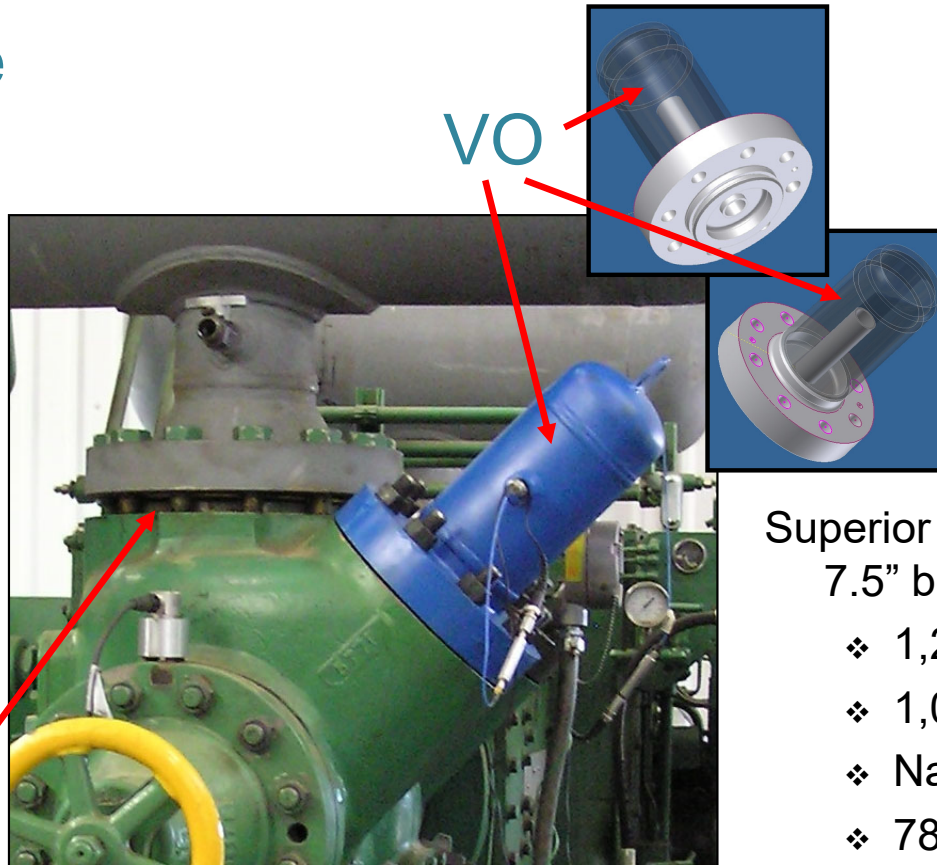


Case Study 2: VO – 1st Field Application

Standard Orifice



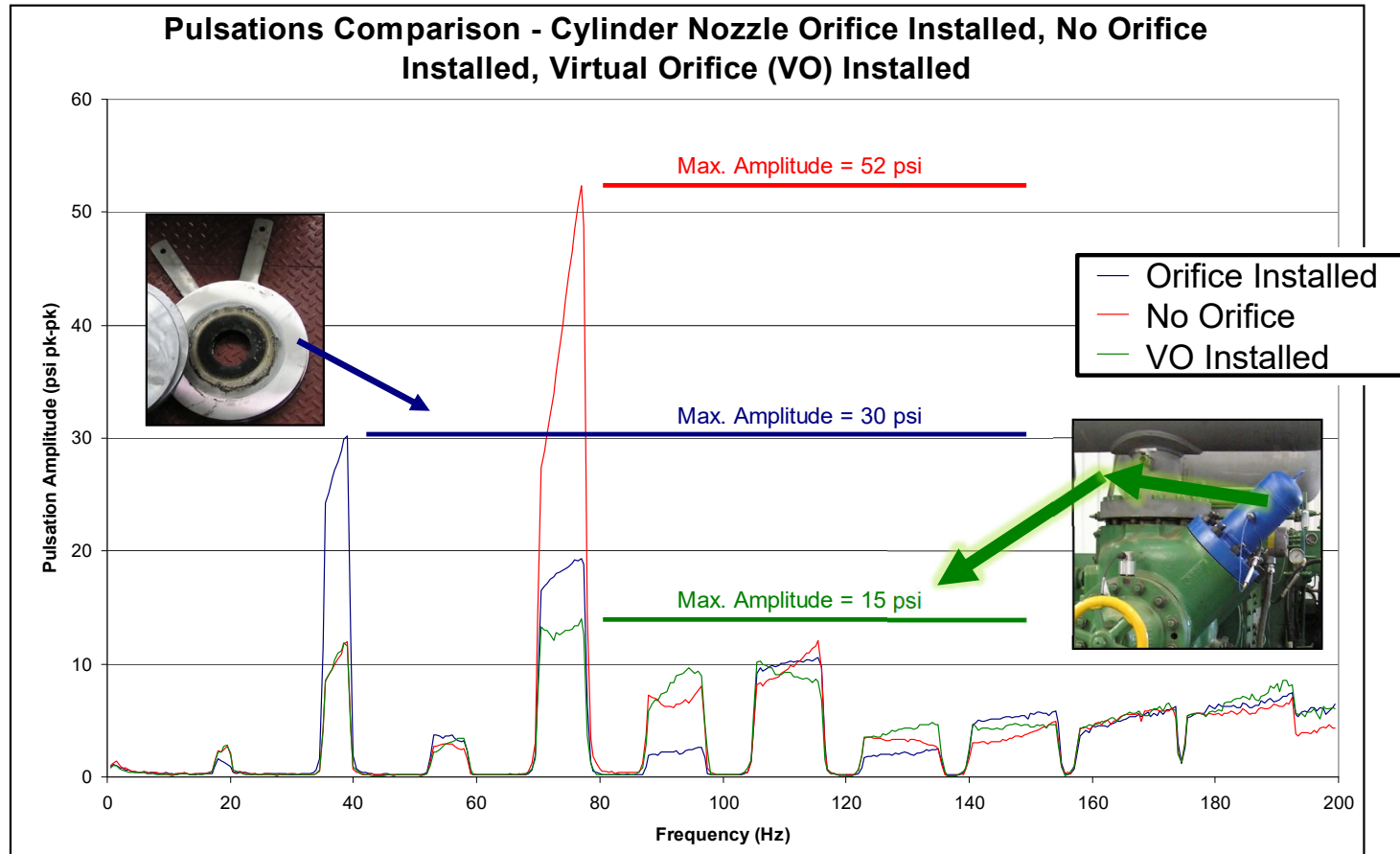
The standard orifice would typically be installed here



Superior MH 62 (2 cyl,
7.5" bore, 6.0" stroke)

- ❖ 1,200 BHP
- ❖ 1,050-1,150 rpm
- ❖ Nat. Gas Trans.
- ❖ 780 – 1030 psia

Case Study 2: Field Measured Pulsation Data



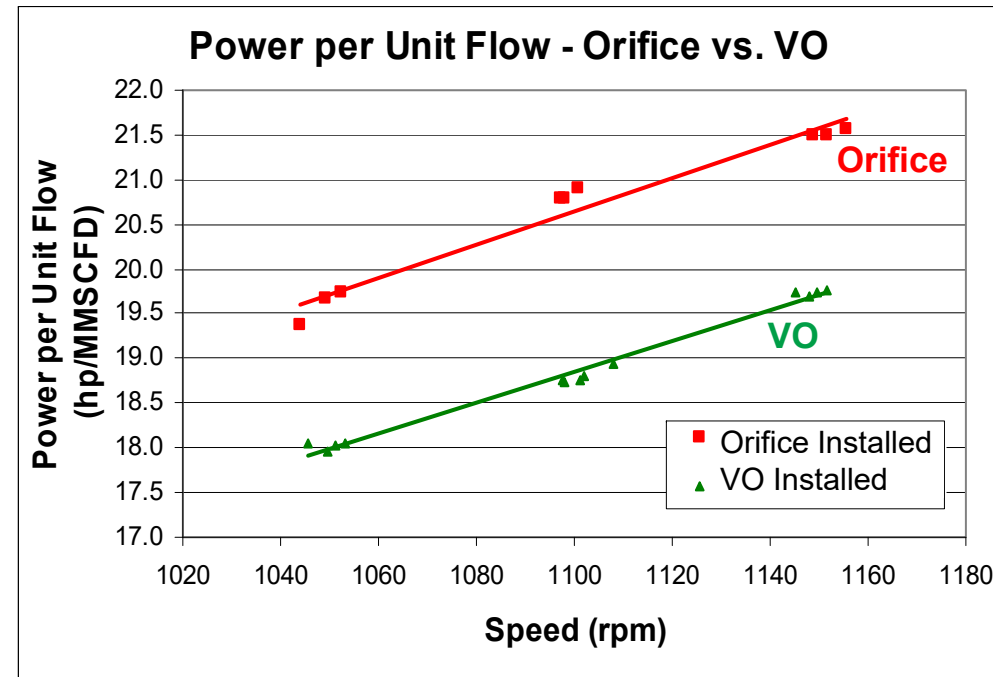
Case Study 2: Field Measured Efficiency

The VO technology is a replacement for a standard orifice with the following advantages:

- ❖ Nearly eliminates the cylinder nozzle response instead of just dampening the response.
- ❖ Nearly eliminates the dynamic pressure drop and significantly improves the cylinder efficiency.

Resulting financial benefits:

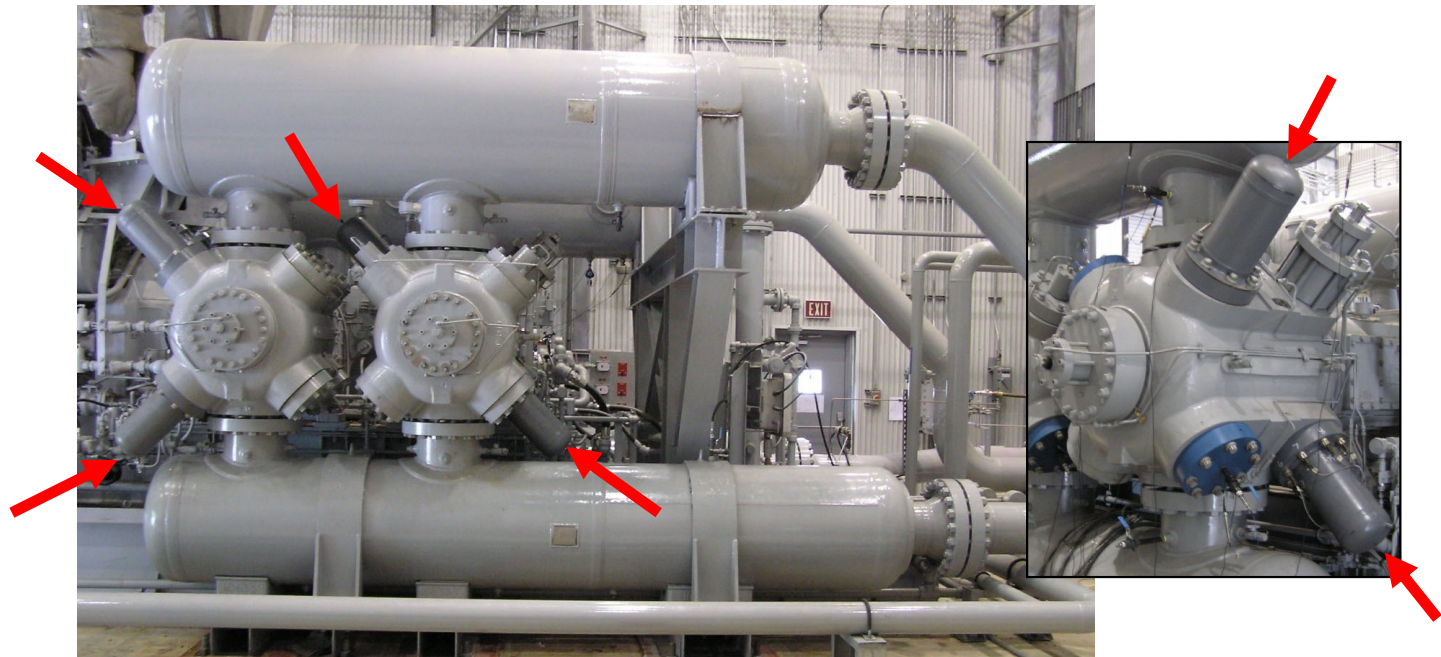
- ❖ Reduced fuel usage for the same capacity, or
- ❖ Increased capacity with same fuel use and permit, i.e. “horsepower recovery”.



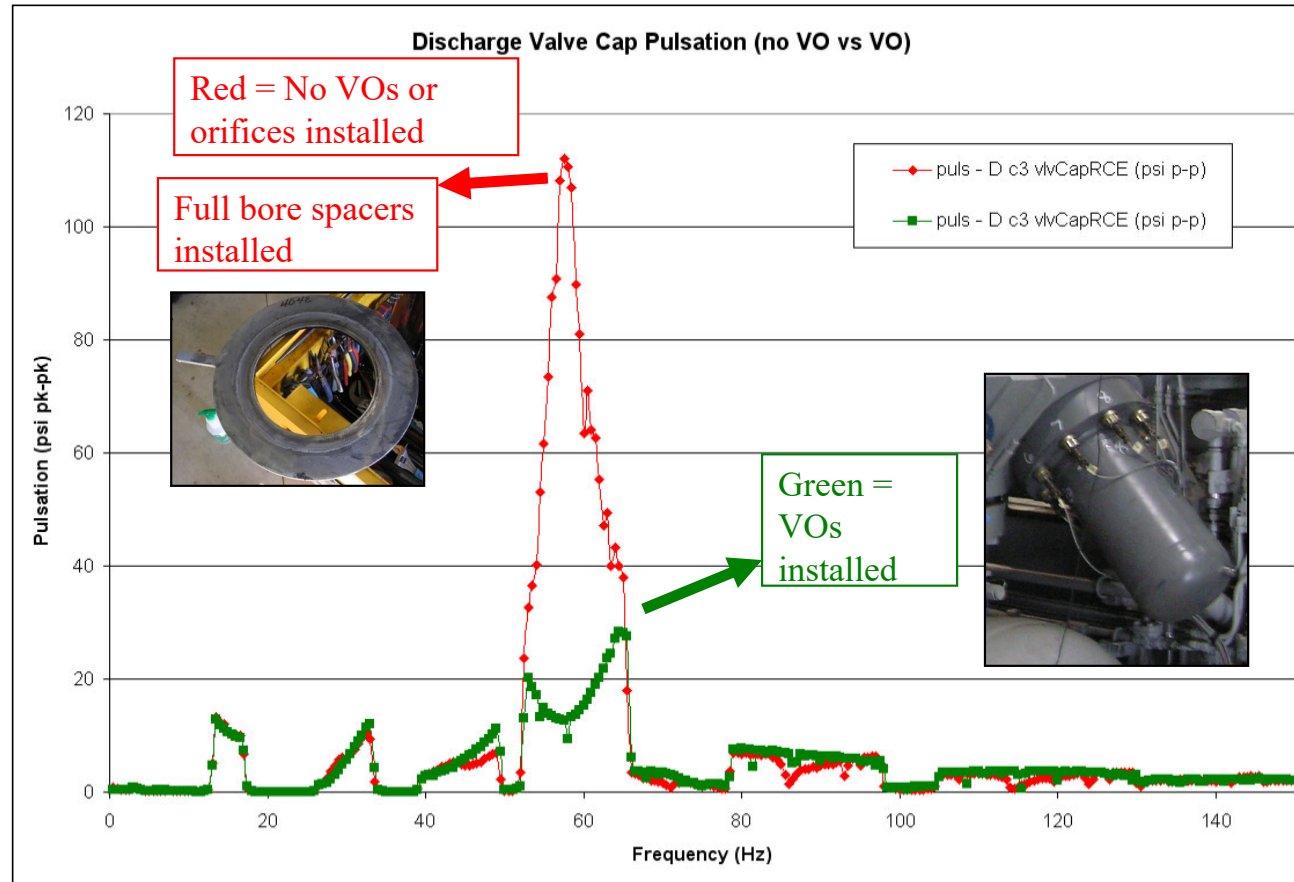
Successful operation since October 2007 to 2014
(removed in 2014 due to system changes, not
due to any issues with the VOs)

Case Study 3: Boardwalk Pipeline – Destin Field Testing

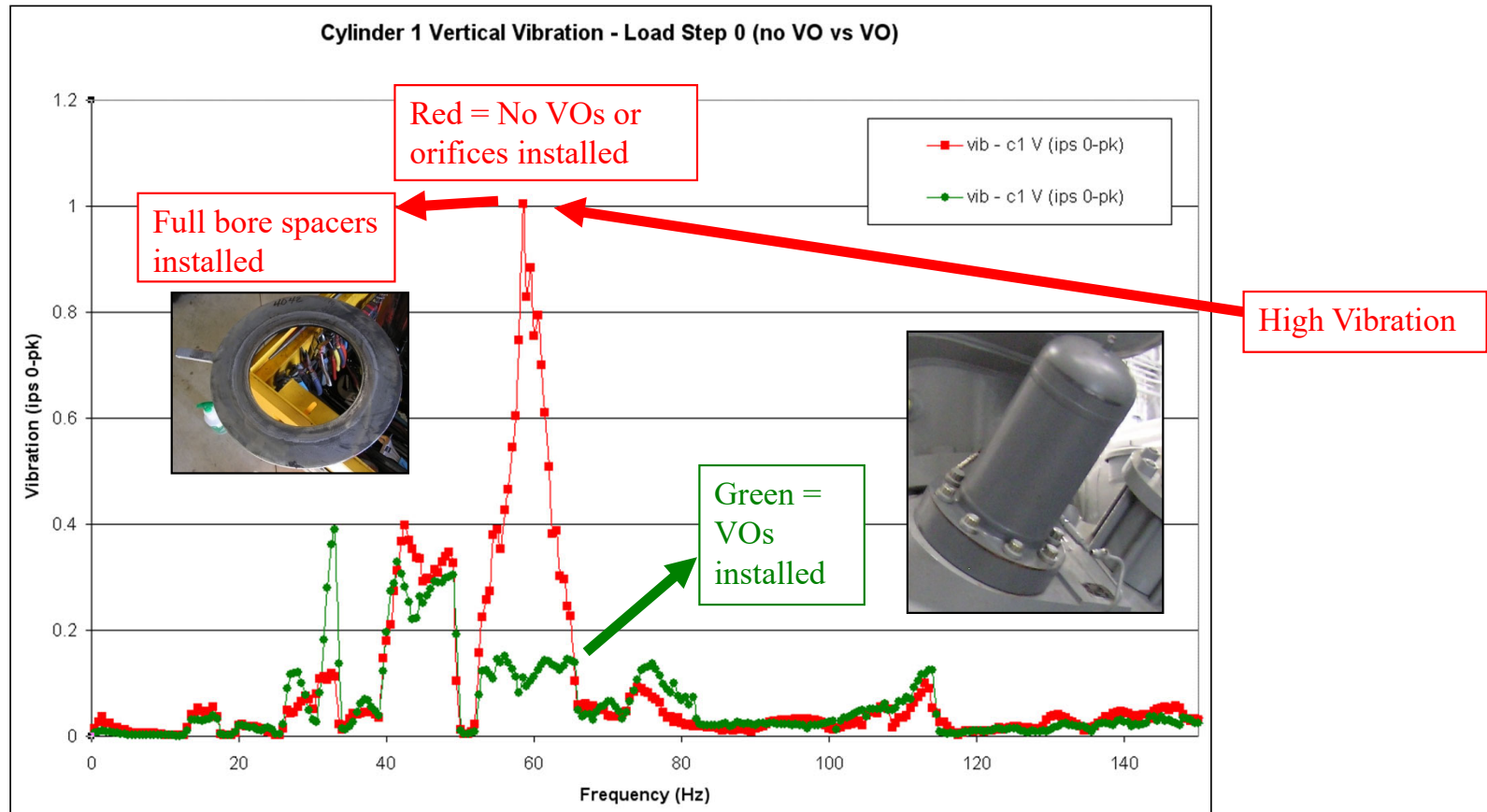
- **Objective:** To further develop and verify performance of the VO through field testing. Testing to evaluate reliability, mechanical responses, material considerations, and performance.
- Compressor Specifications: Ariel JGC/4, 790-1000 rpm, ~950 to 1080 psig suction pressure, ~1090-1210 psig discharge pressure, all cylinders can SA



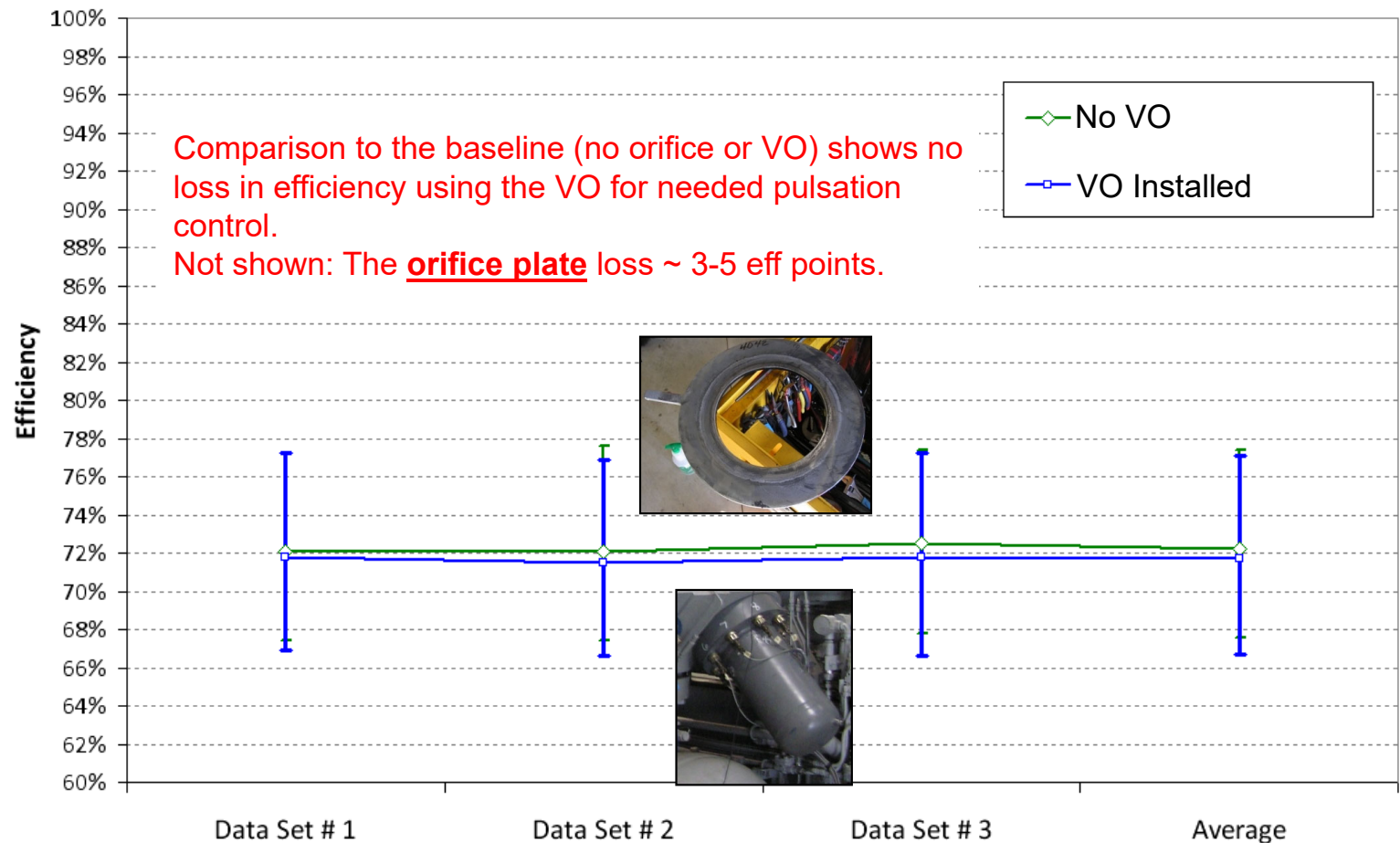
Case Study 3: Destin Field Testing – Measured Pulsation Data (Discharge)



Case Study 3: Destin Field Testing – Measured Vibration Data (Suction)

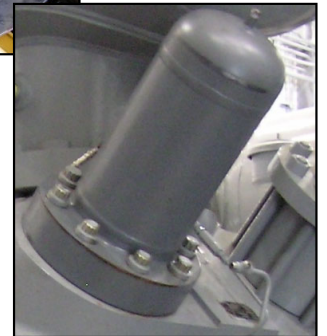


Case Study 3: Measured Enthalpy Rise Performance Data



Case Study 3: Destin Field Testing – Summary

- Cylinder Valve Cap Pulsation Improvement:
 - Suction: 64% (83% at the initial resonance)
 - Discharge: 73% (86% at the initial resonance)
 - Cylinder Vibration Improvement:
 - Vertical: 60% (85% at the initial resonance)
 - Horizontal: 16% (77% at the initial resonance)
 - Performance Changes – When the VOs were installed (compared with no control),:
 - PV Card Measurements indicated comparable performance.
 - Enthalpy Rise measurements indicated only a 0.5% efficiency reduction. *
 - hp/MMSCFD comparisons indicated a 3% improvement
- * The measured values were statistically equal when considering the uncertainties associated with the measurements.



Verified System Changes That Resulted From the Installation of VOs

Standardizing the Virtual Orifice (VO) Ongoing GMRC Research

- Matrix included 32 different size, bore, stroke, and/or model cylinders from Ariel, Cooper, and Dresser-Rand – Cylinder details and specific or approximated piping operating conditions used for sizing VOs based on ratios relative to previously sized VOs
- Contacted end users regarding their experiences with the field-installed VOs:



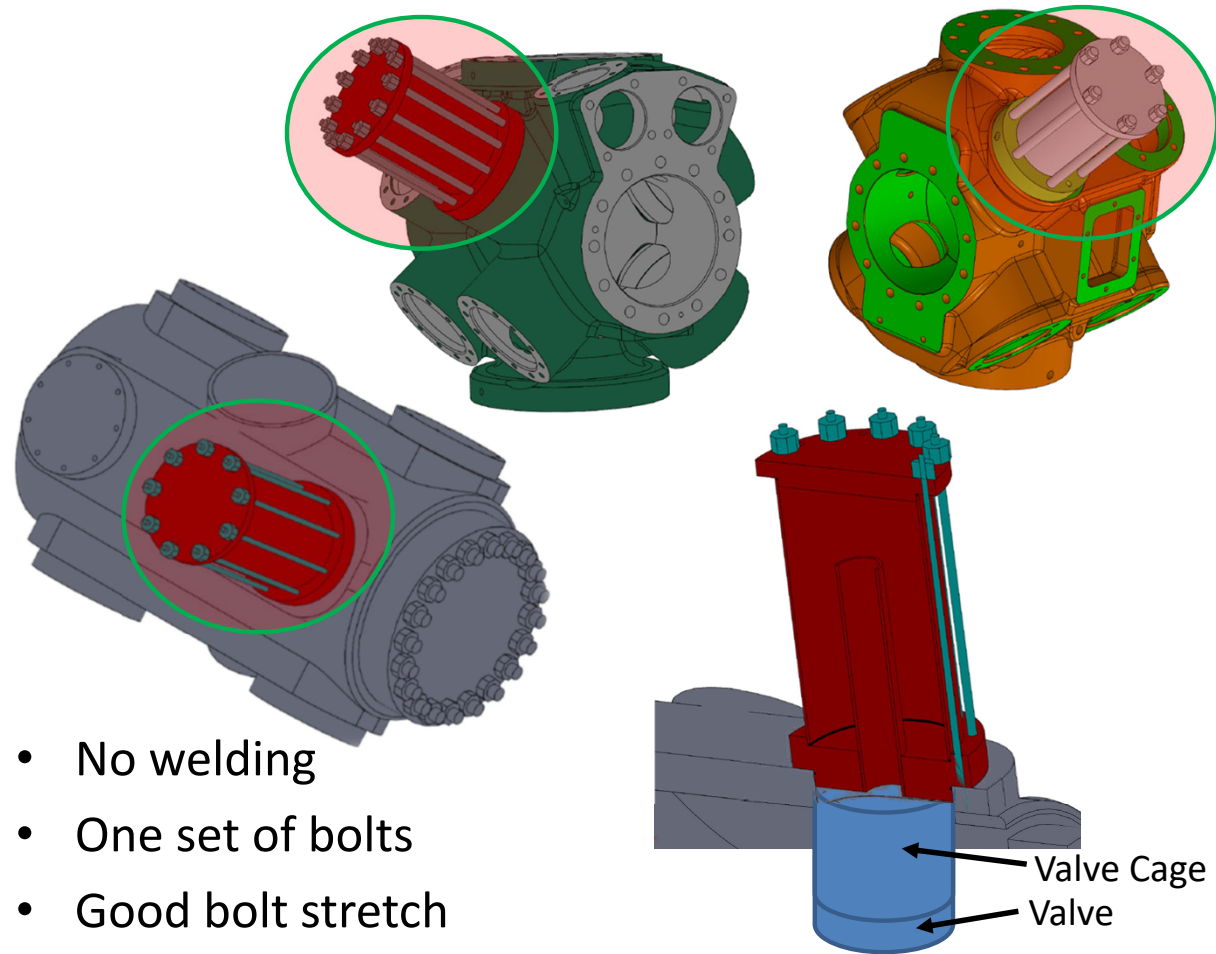
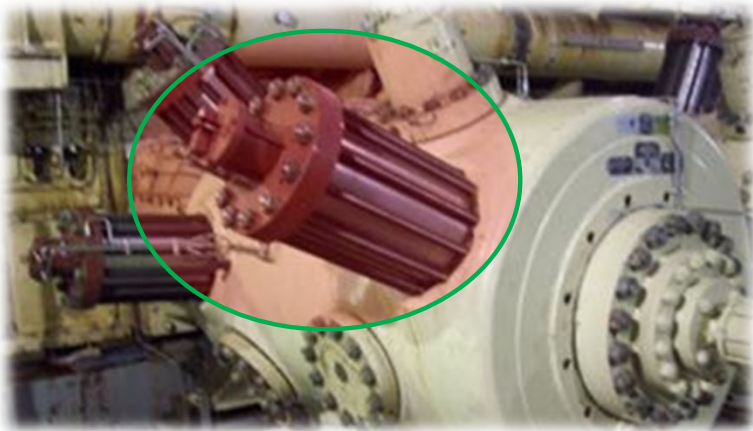
- Kinder Morgan, Baxter Compressor Station – VOs that were installed on the suction system operated without concern or issues from 2007-2014. In 2014 the VOs were removed due to system changes, not due to any issues with the VOs.



- Boardwalk, Destin CS – VOs are still installed (since May 2010), unit hasn't operated much in the past few years; best estimate is VOs have about 11,600 hours on them; only concerns were that the VO's were hot to the touch when the unit was running and had to remove two head end deactivators to install the VO's, but removing those 2 deactivators did not affect the operation

Modular VO Concept – already field proven

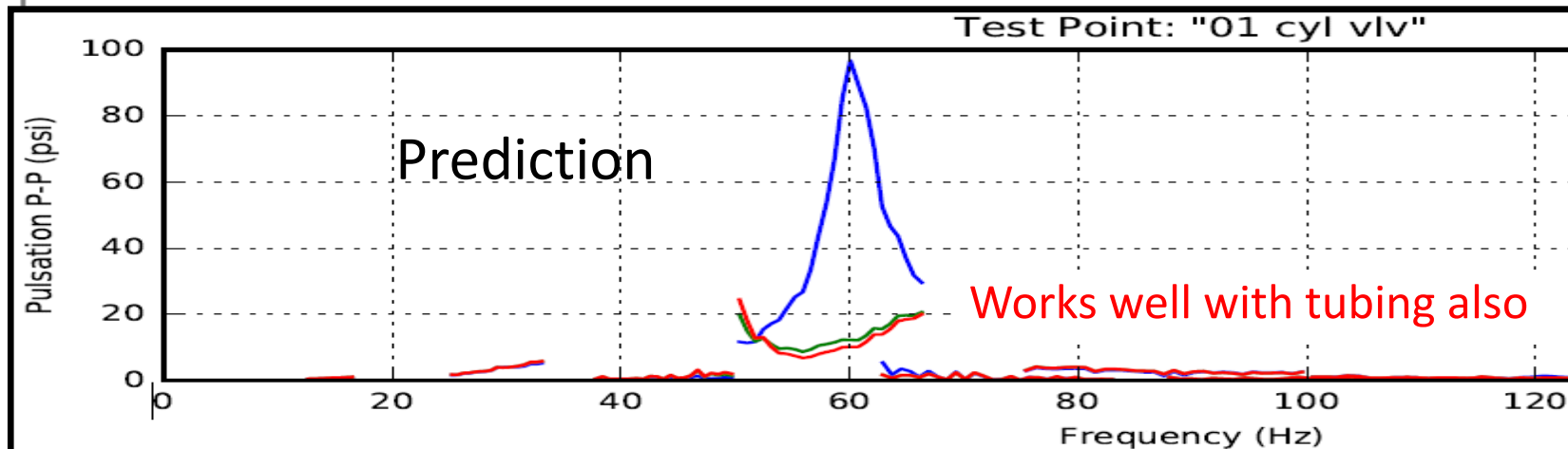
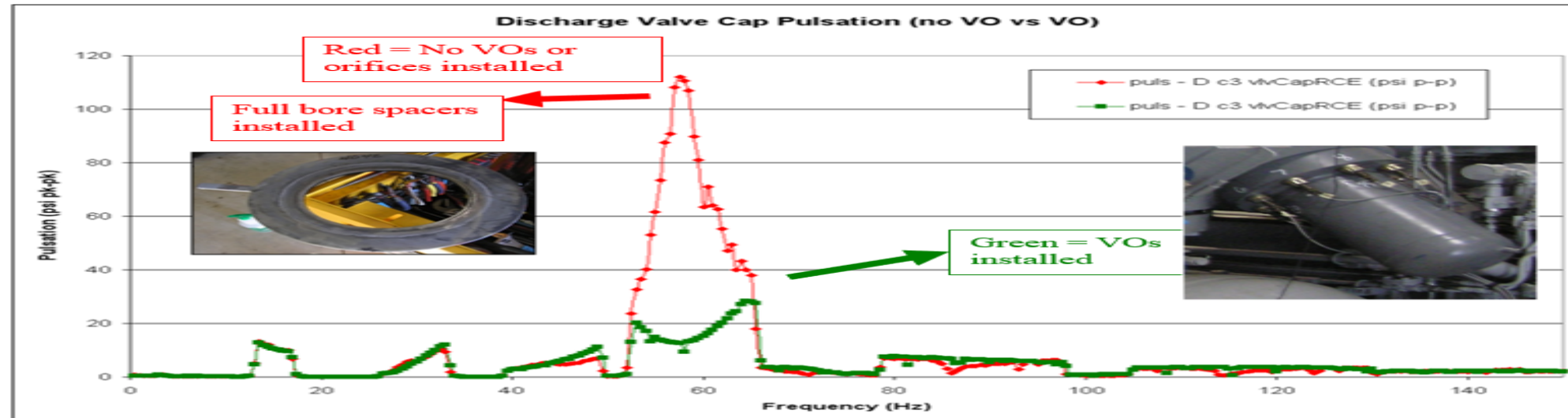
- Photo of existing unloader on low speed compressor
- Field proven design for low speed and high speed units



- No welding
- One set of bolts
- Good bolt stretch
- Designed for cylinder MAWP

Pulsation Predictions – Largest Pipeline Cylinder

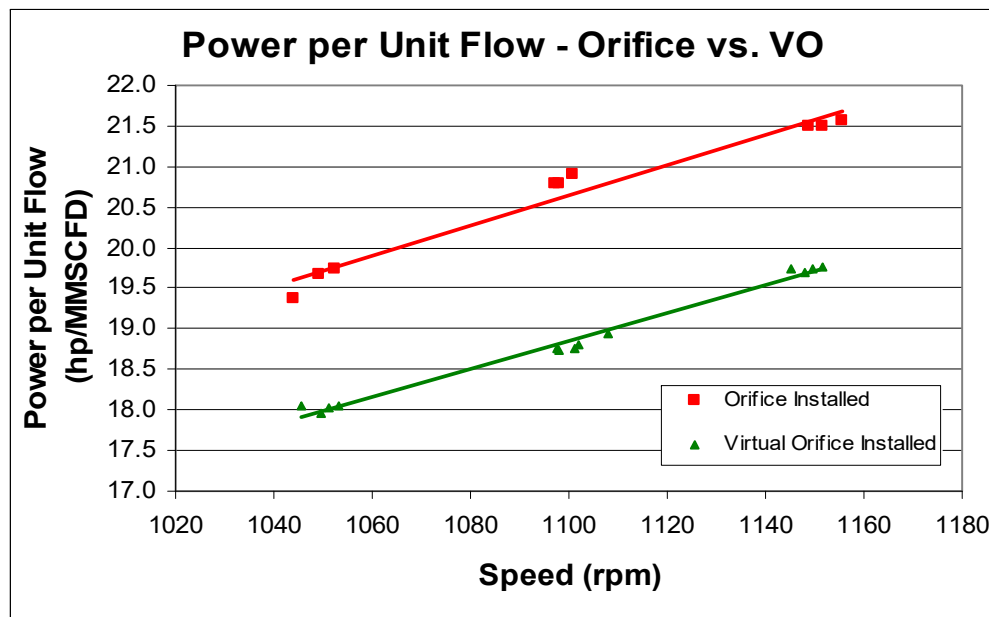
Data pulled from 2011 VO Summary



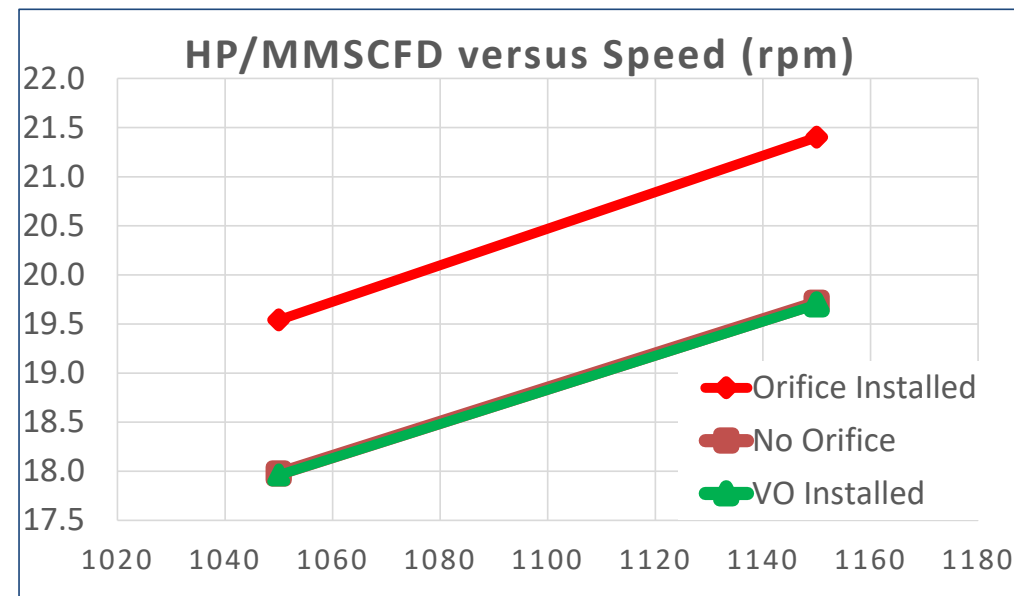
Initial Step –
Correlation
with field
data / model
validation

Correlation with Field Data

Field Testing – Baxter Station



Prediction Data – Baxter Station

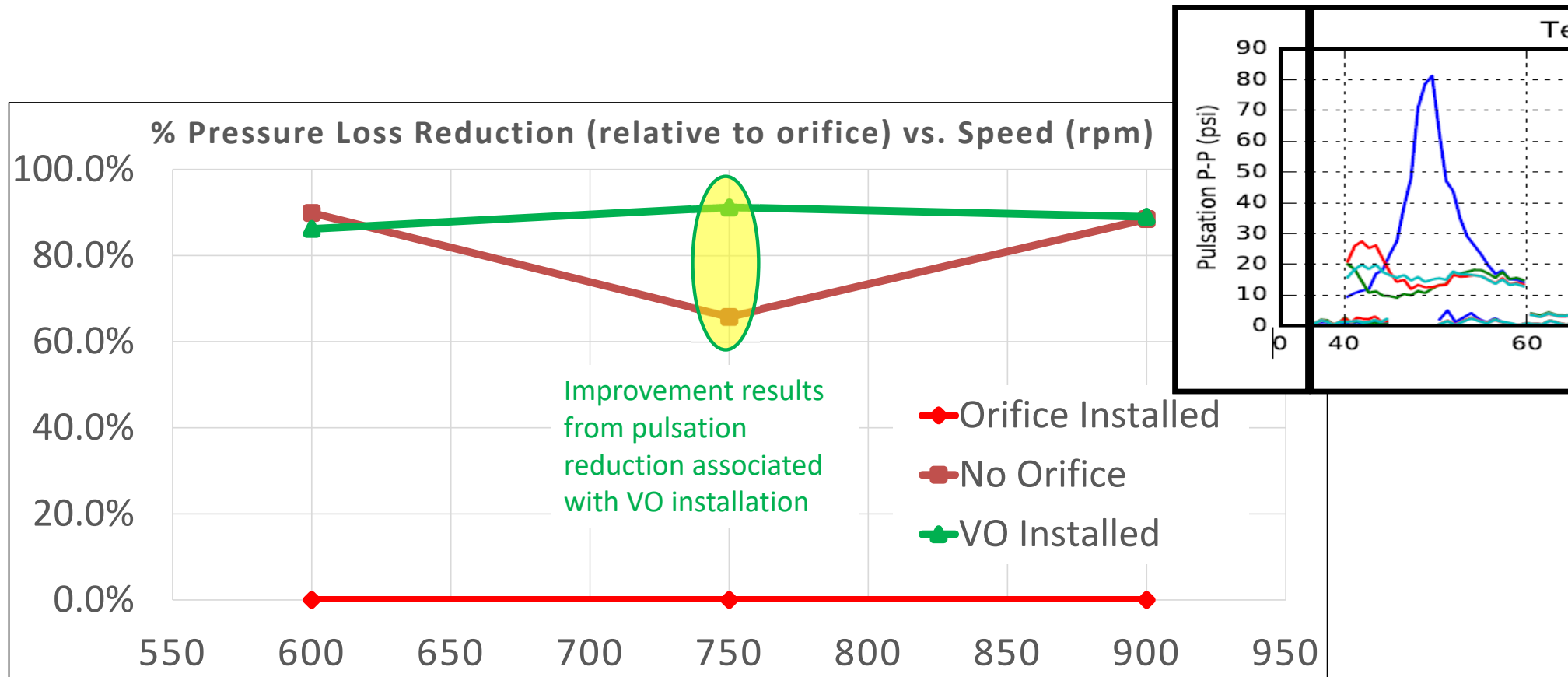


Successful operation October 2007 to 2014

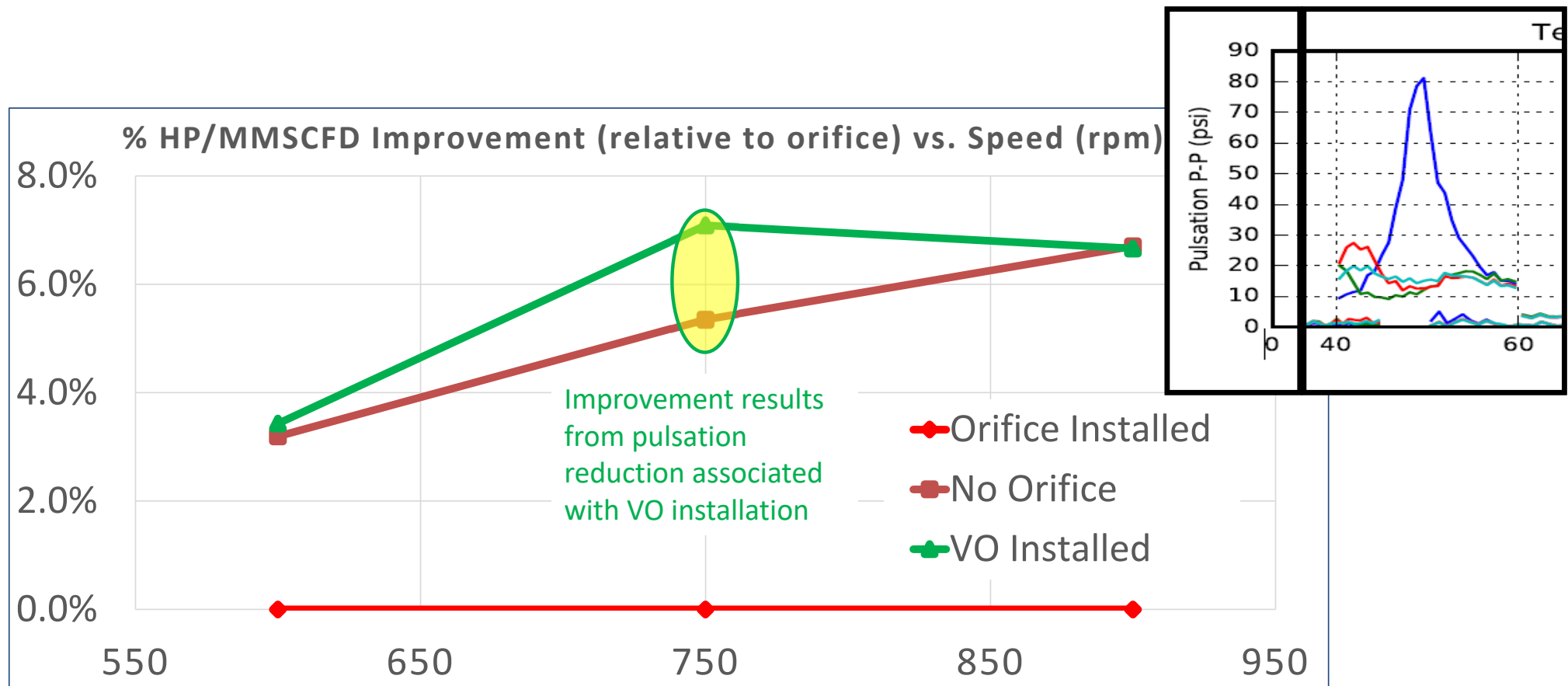
VOs removed due to system changes, not due to any issues associated with the VOs



Pressure Drop Predictions for Largest Analyzed Pipeline Cylinder



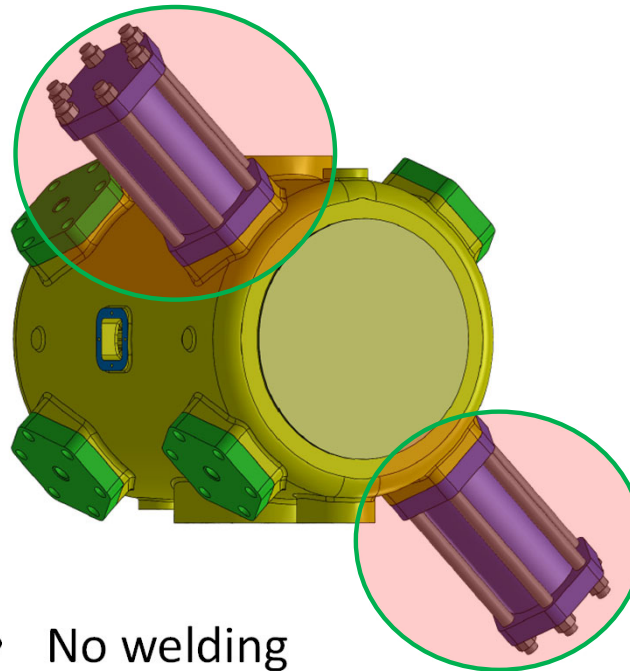
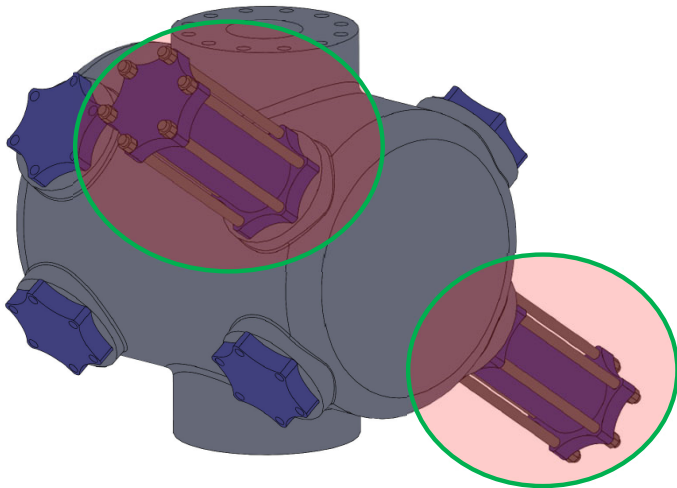
Performance Predictions for Largest Analyzed Pipeline Cylinder



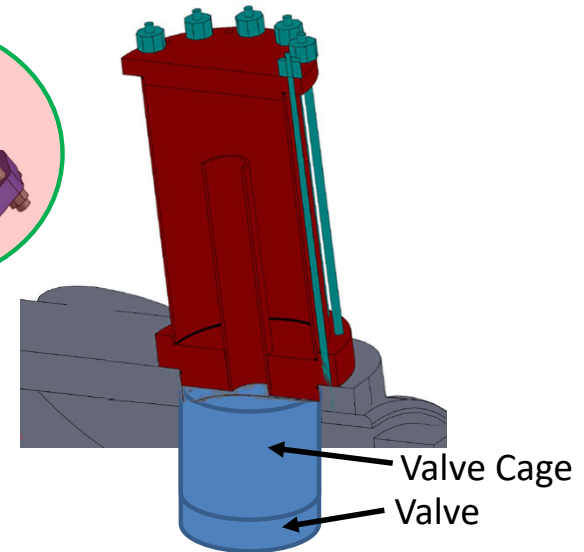
VO better than orifice over entire speed range

VOs for Low Speed Recips

- Similar predictions
- Slightly longer VOs than high speed VOs



- No welding
- One set of bolts
- Good bolt stretch
- Designed for cylinder MAWP



The Virtual Orifice (VO) – Emissions Reduction Tech.

- Field Measurements to-date are excellent:
 - ~50-90% pulsation reductions
 - ~15-85% vibration reductions
 - ~3% efficiency boost = emissions reduction
- Correlated pulsation and efficiency prediction data with field data
- Predicted performance and pressure loss improvements for 3 high-speed cylinder and improvements (or zero change) for 2 low-speed cylinders (suction and discharge)
- Field test new VO design is being scheduled

