How to Boost the Energy Efficiency of Rotary Screw Air Compressors

Andrew Smith, P.E.
SMARTCAir
Keynote Speaker

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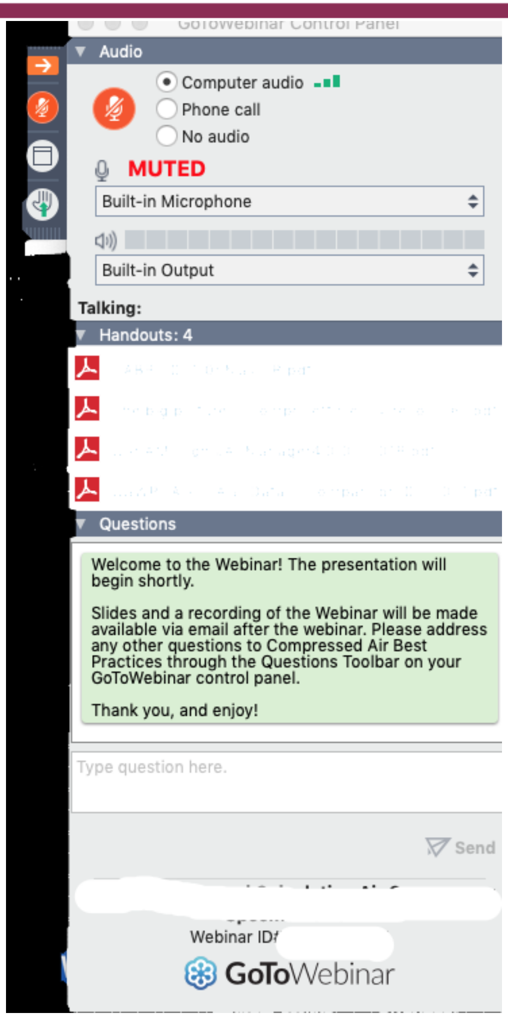

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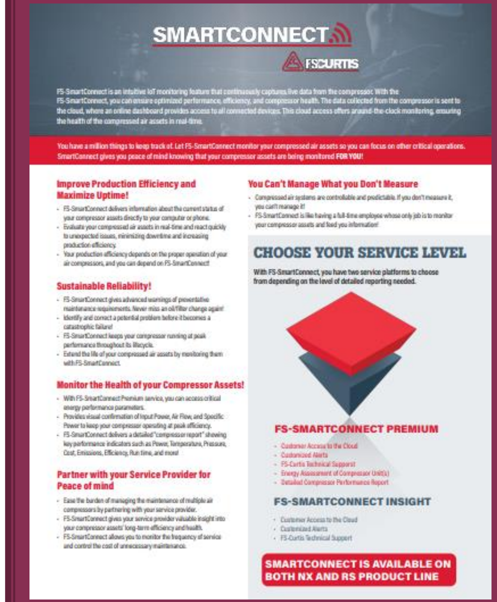
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How to Boost the Energy Efficiency of Rotary Screw Air Compressors

Introduction by

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About the Speaker

Andrew Smith, P.E.
SMARTCAir

- Co-Founder, SMARTCAir
- 20 years of experience in industrial energy efficiency projects for pumps, fans, chillers, and compressed air
- Spent 10 years with DuPont Canada
- Mechanical Engineer with master's degree in heat transfer

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Objectives

Often optimizing compressed air systems is approached from an ad-hoc ‘rule of thumb’ / ‘black box’ point of view

Our objectives today are:

a) Highlight that everything we do in compressed air has a straight-forward linkage back to the first principles driving system energy **cost**.

b) Illustrate this approach with a particular focus on the impact system volume can have in optimizing compressed air systems.

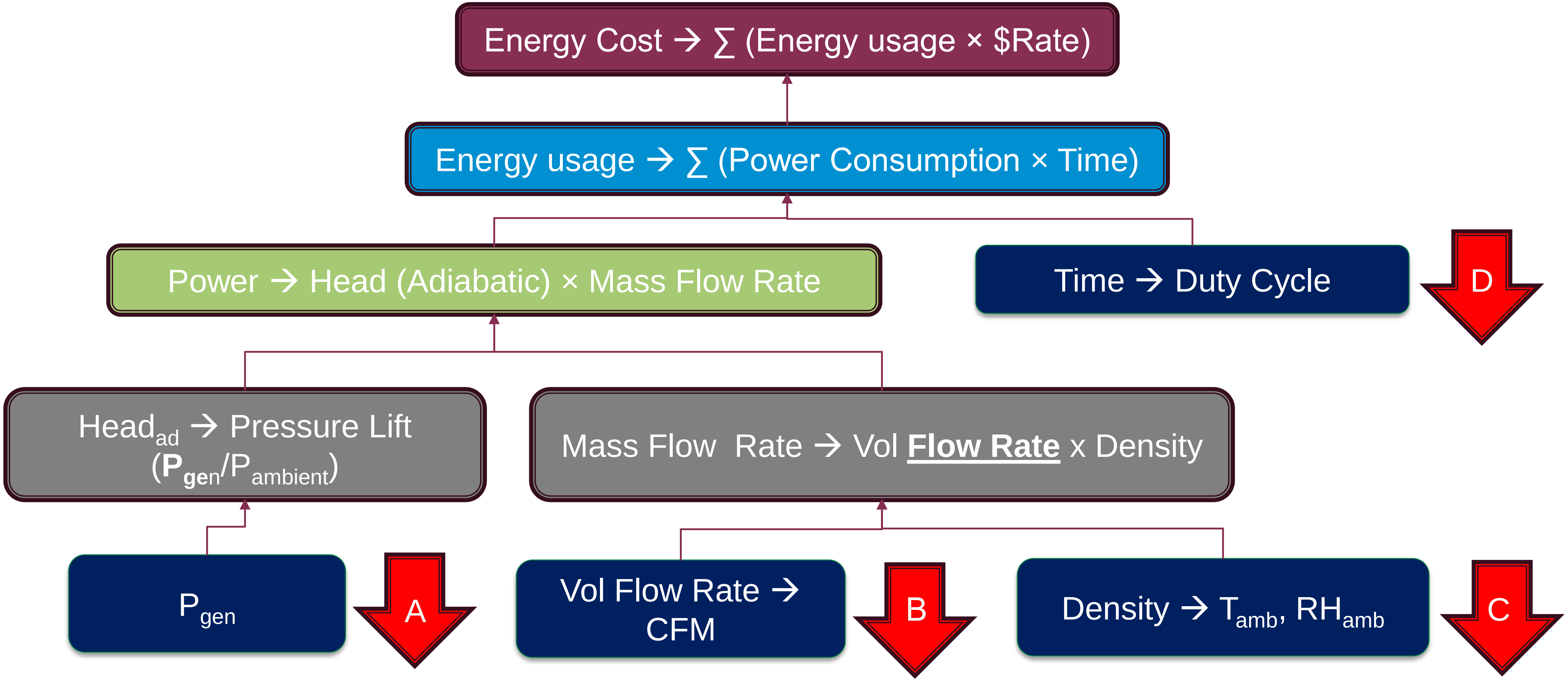
Making the Connection to First Principles

- Regardless of a demand or supply side focus… ultimately, compressed air practitioners are interested in saving the client $$$:

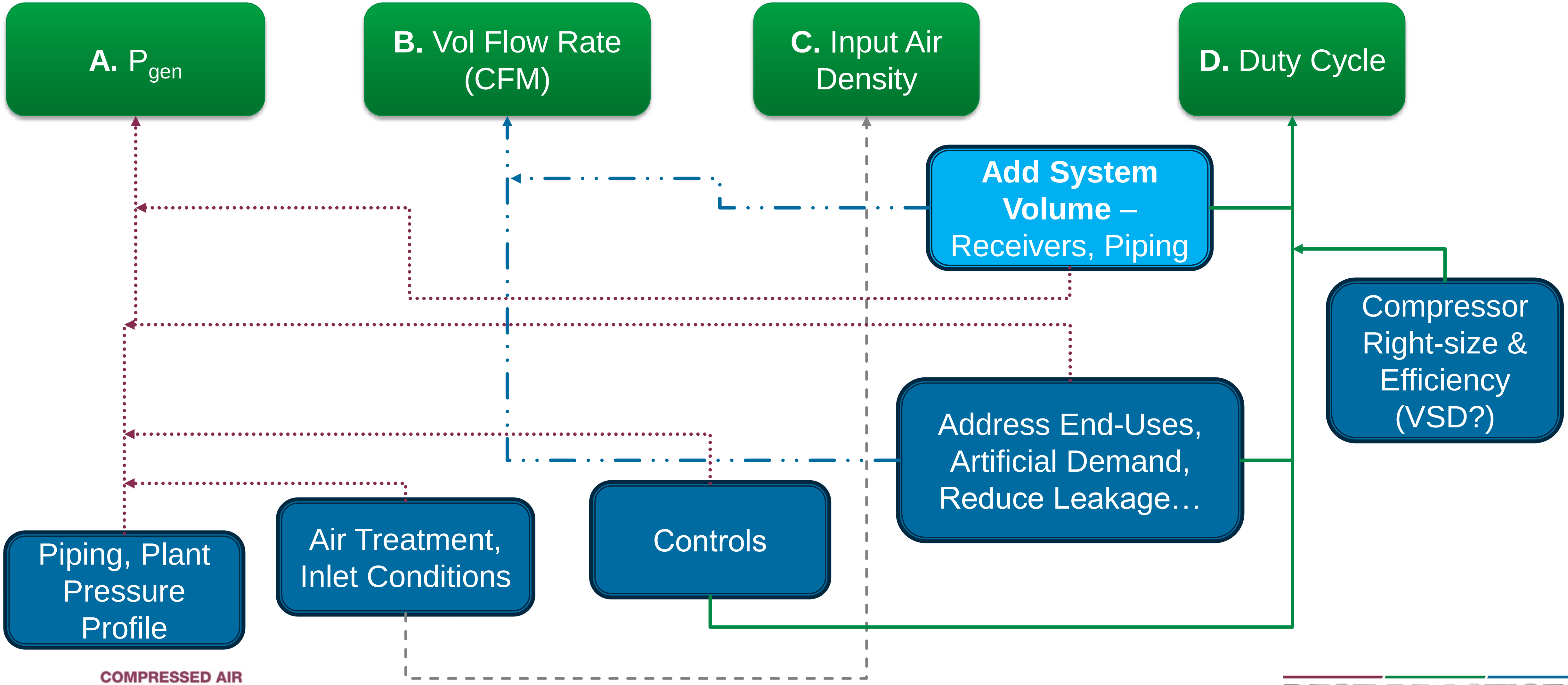
  - Primarily through lower energy usage leading to lower energy costs, but also….
    - Reduced wear and tear on equipment
    - Eliminate process issues (e.g., low pressure, air quality, capacity)

- Generally, there will be a strong connection between these objectives:
  - Run compressors less, run the system more efficiently, run at lower pressure, reduce air flow demand…

First Principles – Identify the Key Parameters



Solutions for Key Parameters



Usefulness of Boyle's Law & System Volume

Supply > Consumption → ↑ P_{sys}

Supply < Consumption → ↓ P_{sys}

Supply = Consumption → No change P_{sys}

ΔV_{actual} = (Supply – Consumption) x Δt

$\frac{\Delta \boldsymbol{V}_{\boldsymbol{actual}}}{\Delta \boldsymbol{t}}$ **= Supply – Consumption**

- The system pressure is driven by how much mass (volume x density) is present in the system.
- The actual volume of air in the system changes at any given time based on the difference between the Supply and Consumption flow rates.

Usefulness of Boyle's Law & System Volume

$$P_1V_1 = P_2V_2$$

$$P_{sys}V_{sys} = P_{amb}V_{actual}$$

$$P_{sys} = \frac{V_{actual}}{V_{sys}} \times P_{amb}$$

$$\frac{\Delta P_{sys}}{\Delta t} = \frac{\frac{\Delta V_{actual}}{\Delta t}}{V_{sys}} \times P_{amb}$$

$$\frac{\Delta P_{sys}}{\Delta t} = \frac{Supply\ - Consumption}{V_{sys**} \times 60(\frac{s}{min})} \times P_{amb}$$

$$\frac{\Delta V_{actual}}{\Delta t} = \text{Supply CFM – Consumption CFM}$$

The **actual volume** of air in the system changes at any given time based on the **difference between the Supply and Consumption** flow rates

** **Note:** V_{sys} in Cubic Feet (1 Cubic foot = 7.481 USG)

System Volume Discussion

$$\frac{\Delta P_{sys}}{\Delta t} = \frac{Supply \ - Consumption}{V_{sys} \times \ 60(\frac{s}{min})} \times \ P_{amb}$$

Often see this formula used to size receiver tanks to meet a desired pressure decay ***or*** estimate leakage rates based on an estimated system volume

a) Solve for receiver Volume size (Cubic Feet) required to limit the drop in pressure over a given time period based on a given rate of drainage (Consumption) flow rate (Supply = 0).

b) Use the given drop in pressure over time and estimated system volume to calculate the system leakage rate (Consumption) with no Supply.

System Volume Discussion

$$\frac{\Delta P_{sys}}{\Delta t} = \frac{Supply\ - Consumption}{V_{sys} \times\ 60(\frac{s}{min})} \times\ P_{amb}$$

⬆ V_{sys} → *reduces* $\frac{\Delta P_{sys}}{\Delta t}$ (pressure changes **slower** with time) which 'flattens' the pressure gradients in the system

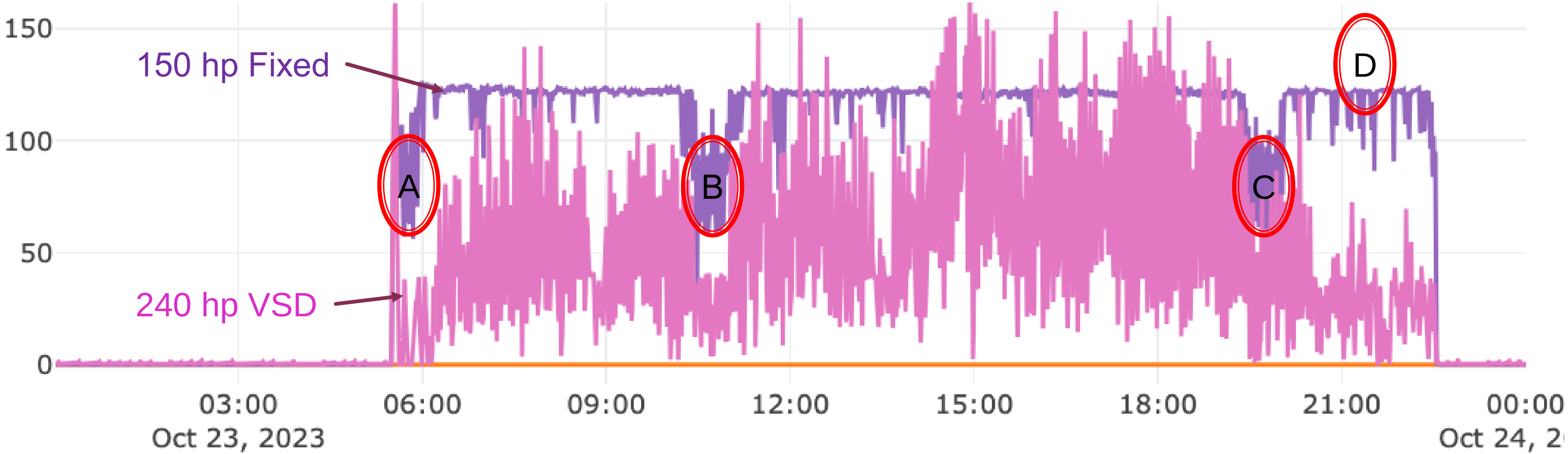
- generally what we would like to see – slower changes in pressure
- System pressure will drop slower when consumption increases suddenly
- May allow the system to manage short term flow fluctuations without adding capacity

⬇ V_{sys}→ *increases* $\frac{\Delta P_{sys}}{\Delta t}$ (pressure changes **faster** with time) which 'steepens' the pressure gradients in the system

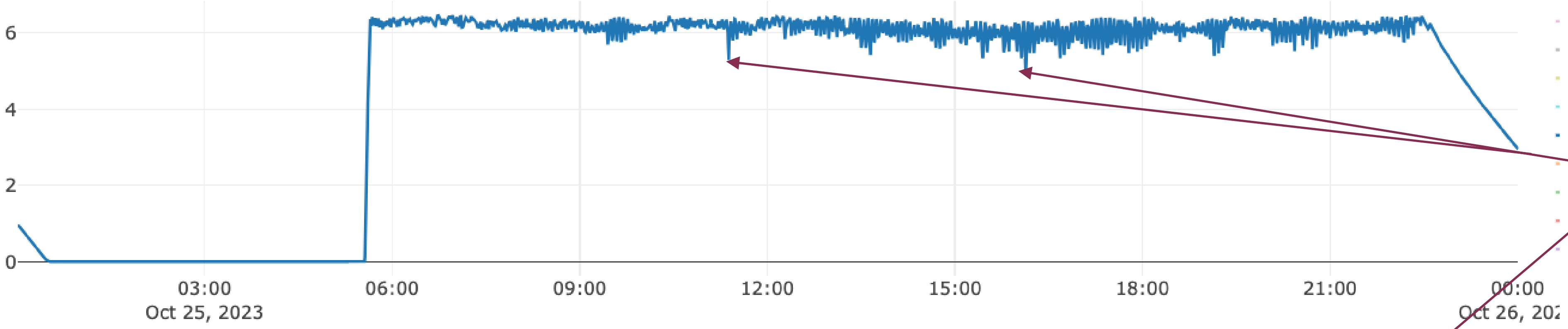
- generally not what we would like to see – faster changes in pressure
- System pressure will drop faster when consumption increases suddenly
- May trigger additional capacity response sooner

Case Study 1 – Base Case Power Demand (kW)

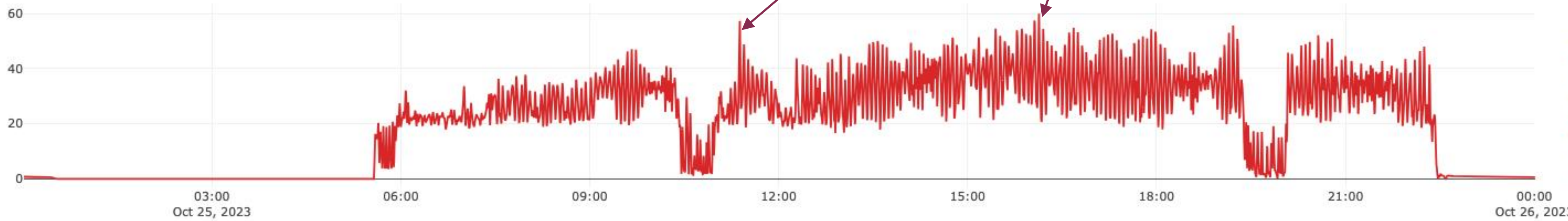
- 1 x 240 hp VSD, 1 x 150 Fixed Speed, 20 m^3 storage – 17 h/d operation
- 150 hp fixed speed runs almost fully loaded most of the time
- 150 hp and 240 VSD often both trying to 'lead' (150 drops off, 240 ramps up)



Case Study 1 – Base Case Generation Pressure in Bar(g)

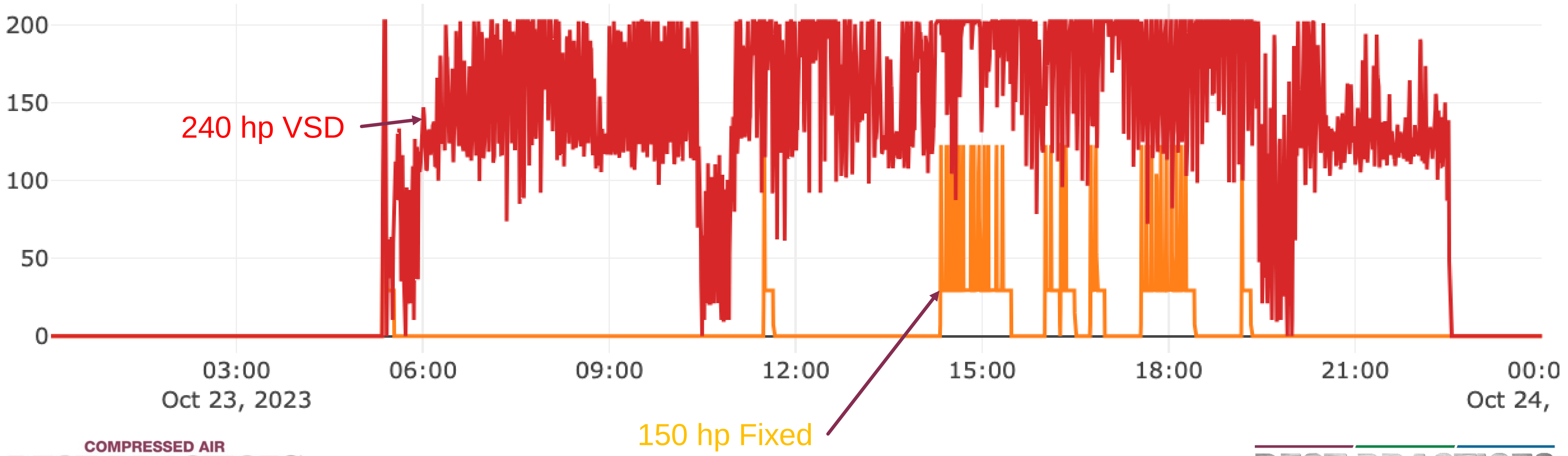


Low-pressure events < 5 Bar(g) related to short term peak flow events



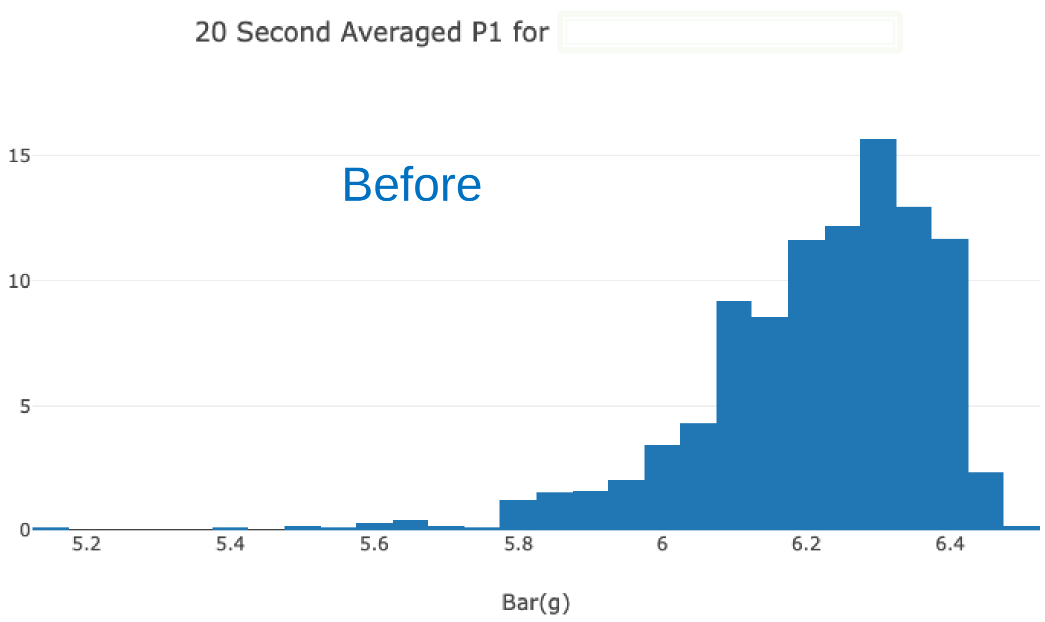
Case Study 1 – Modeled Power Demand (kW)

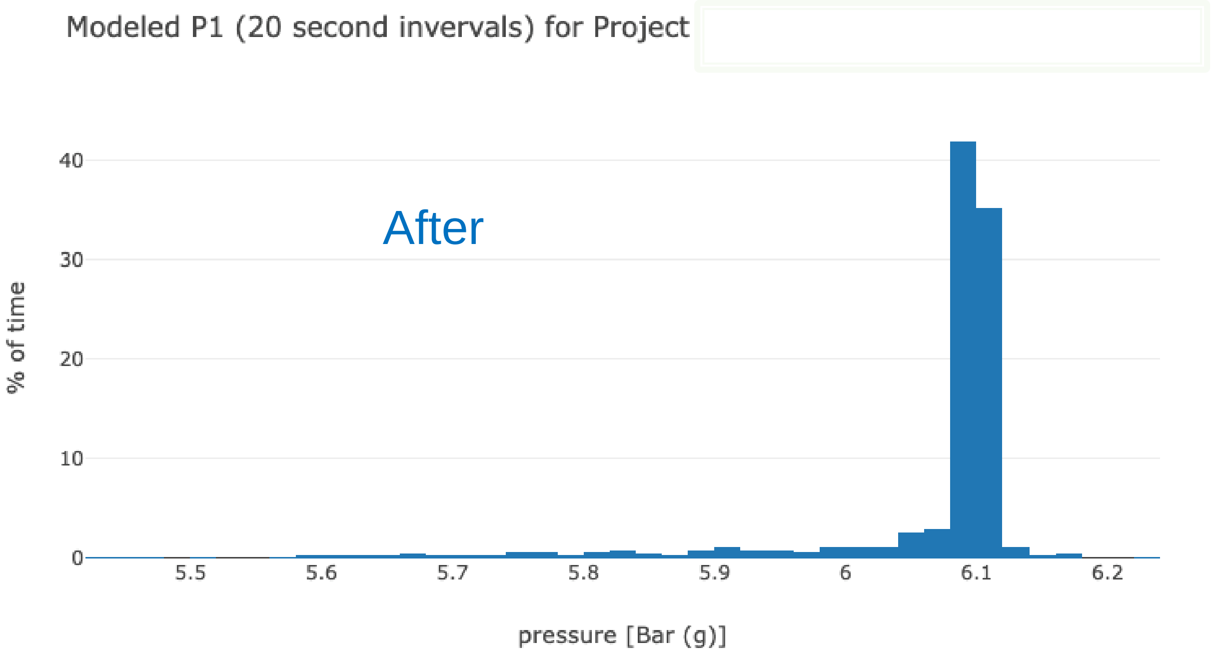
- Modeled adding 3 m^3 additional volume
- 240 hp VSD is now able to run the system alone 95% of time including during startup, break periods and end of shift lower demand



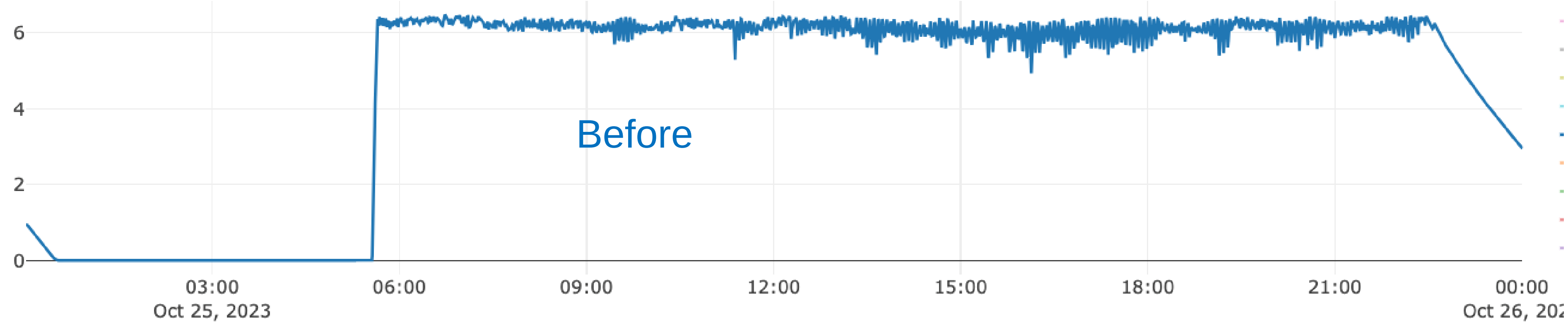
Case Study 1 – Modeled Pressure Profile (Bar(g))

- Improved pressure control.

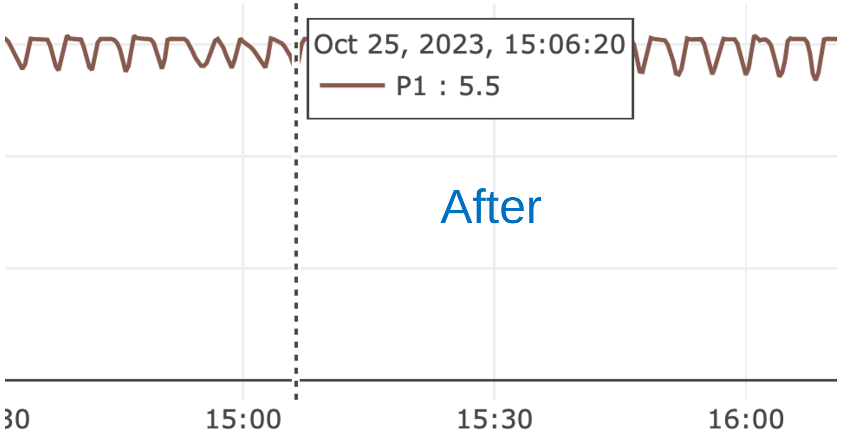




Base Case Versus Modeled Pressure Profile



- Pressure now remains above 5.5 Bar(g) – same flow, no 'low' pressure points (below 5 Bar [g])



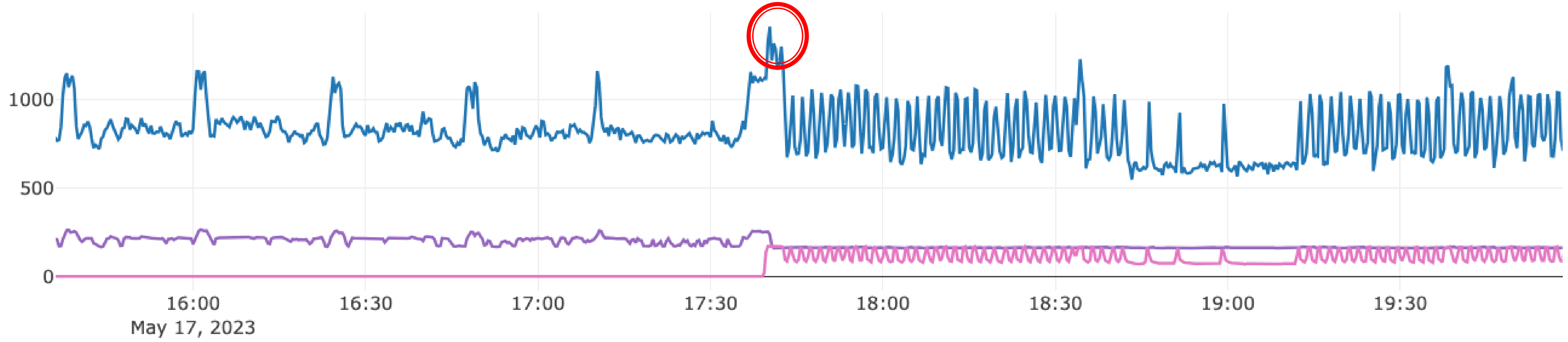
Case Study 1 – Summary Results

- 5.3% reduction in energy usage, 5.6% reduction in demand, 6.5% improvement in specific power with the same air compressors and increased system volume.
- Better pressure control leads to a small reduction in average generation pressure (probably could go lower) and eliminates process issues related to low pressure/high flow events.
- Reduced wear and tear → 95% reduction in operating hours (lower duty cycle) for 150 hp fixed speed.

	Annualized kWh	Average kW	Annualized Cost	P1	Average Daily FAD	Average Poduction FAD	Annualized GHG	Specific Power
Units:	[kWh]	[kW]	EUR	[Bar]	[m3/min]	[m3/min]	[tCO2e]	[kW/ (m3/min)]
Base Case Calc	706,464.7	81.8	162,486.9	6.2	13.3	26.2	7.1	6.2
model_a	668,925.6	77.2	153,852.9	6.1	13.3	26.0	6.7	5.8
Reduction	37,539.1	4.6	8,634.0	0.1	0.0	0.2	0.4	0.4
% Reduction	5.3	5.6	5.3	1.6	0.0	0.8	5.6	6.5

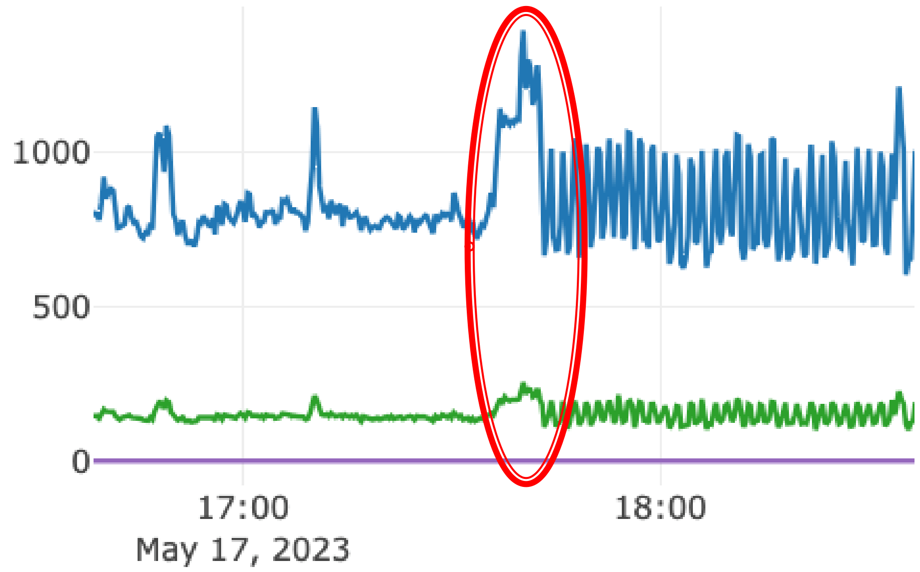
Case Study 2 – Base Case Flow (ACFM) and Power Demand (kW)

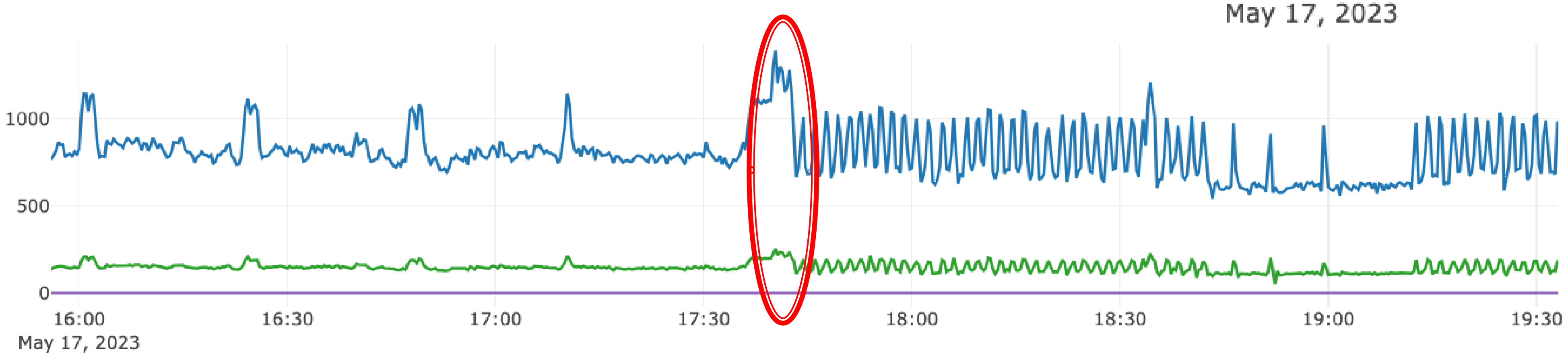
- 1 x 300 hp & 1 x 200 hp Turn Valve machines, 24 h/day operation
  - ~ 900 USG system volume (600 Gallon receiver + estimated piping)
- First peak flow event during the audit period ~ 1,300 CFM causes the 200 hp to cycle on and both machines start modulating (300 hp should have managed on its own)
  - Remains this way for rest of 14-day assessment period



Case Study 2 – Modeled Power Demand (kW) and Flow (ACFM)

- Modelled increasing system volume to 3,000 USG (from 900 USG).
- 300 hp now manages the system alone without any support from the 200 hp for the same peak air flow event.





Case Study 2 – Summary Results

- **<u>46.3%</u>** reduction ($160k/yr!!) in energy usage with the same air compressors, 48.0% reduction in demand, 45.8% improvement in specific power.
- Wear and tear reduced dramatically.
- 6.1% pressure reduction.

	Annualized kWh	Average kW	Annualized Cost	P1	Average Daily FAD	Average Poduction FAD	Annualized GHG	Specific Power
Units:	[kWh]	[kW]	CAD	[psi]	[ACFM]	[ACFM]	[tCO2e]	[kW/ 100 CFM]
Base Case	2,468,750.2	285.7	345,625.0	115.0	856.4	818.4	24.4	33.4
model_a	1,326,739.4	148.5	185,743.5	108.0	818.7	818.4	13.1	18.1
Reduction	1,142,010.8	137.2	159,881.5	7.0	37.7	0.0	11.3	15.3
% Reduction	46.3	48.0	46.3	6.1	4.4	0.0	46.3	45.8

Discussion & Conclusions

- Focus effort on the key system parameters that impact the energy consumption leading to improved system performance:

A. P_{gen}

B. Vol Flow Rate (CFM)

C. Input Air Density

D. Duty Cycle

- Two case studies show that addressing system volume can deliver dramatic improvements in wear and tear, process stability, and input electricity costs without any upgrades or modifications to existing machinery.
  - Should always include system volume in modelling considerations.

About the Speaker

Matt Smith
FS-Curtis/FS-Elliott

- Vice President, FS-Curtis
- Serves on the Board of Directors of the Compressed Air & Gas Institute (CAGI)
- Started career in marketing and product management at Ingersoll Rand

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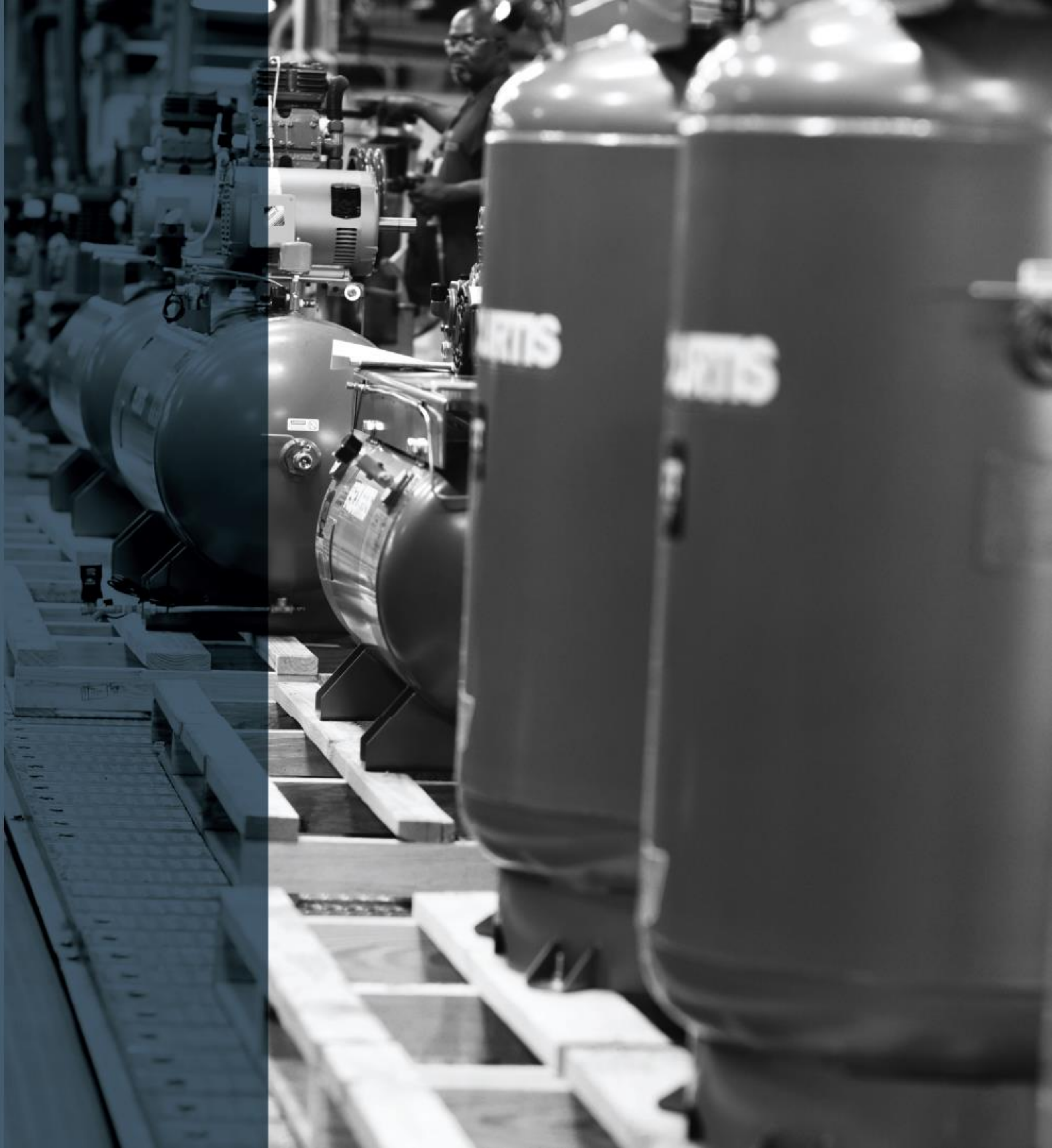
Optimizing Efficiency & Reliability

Key Considerations in Compressor Control Systems

Matthew Smith

Importance of Compressor Controls

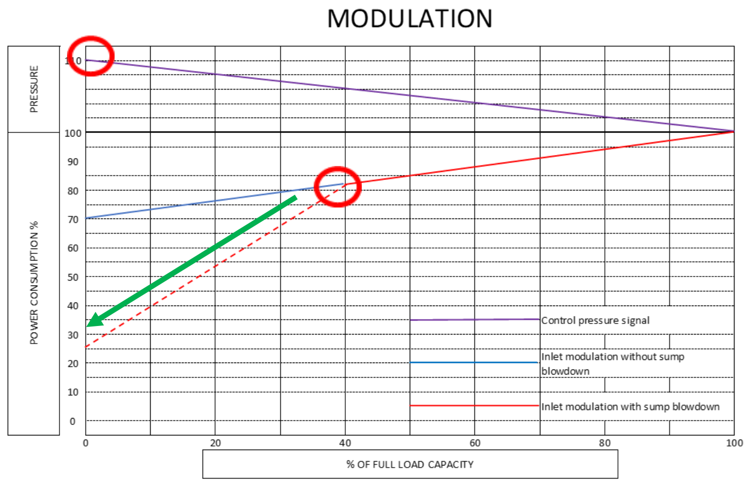
- Compressors play a critical role in industrial processes.
- In many cases, equipment is specified based on peak demand or worst-case scenario. Even most of the day requires lower CFM requirements. **Compressor controls are the solution to this.**
- Efficient control systems systems are essential for optimizing compressor performance.
  - Reduces energy consumption, saving your facility money and reducing environmental impact.

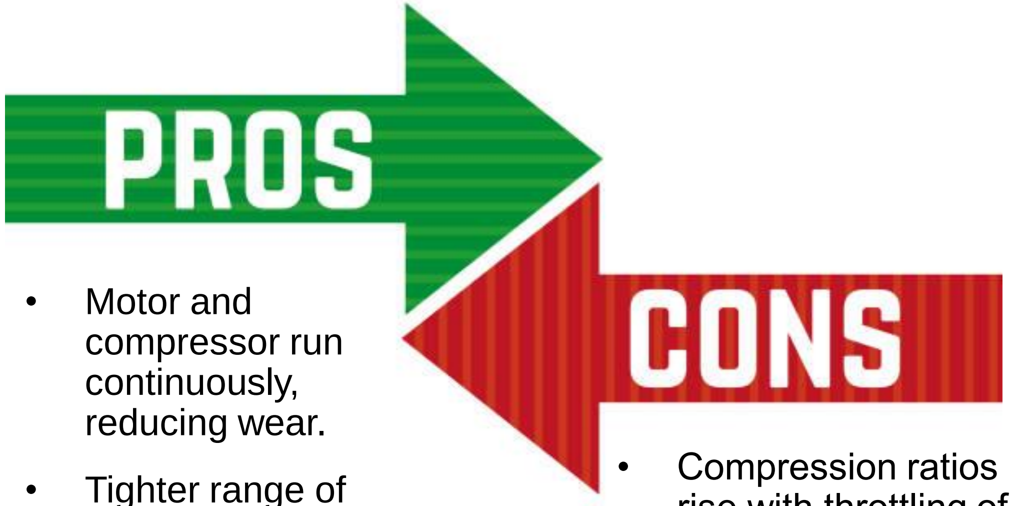


Understanding Control Modes

Modulation

Restricts the inlet air by “throttling” the inlet valve closed to progressively reduce the compressor output in response to pressure changes.





Pros

- Motor and compressor run continuously, reducing wear.
- Tighter range of pressure control, approximately 1-3 psig.
- Capacity control to match demand.

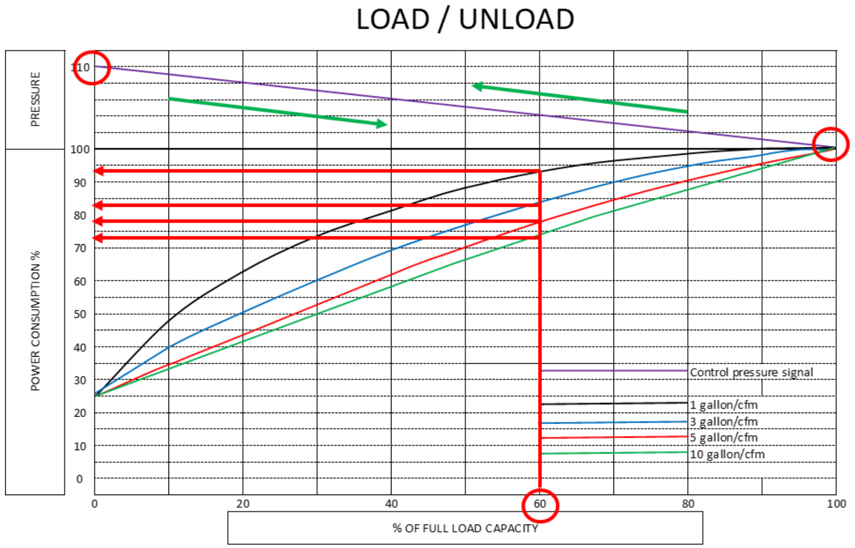
Cons

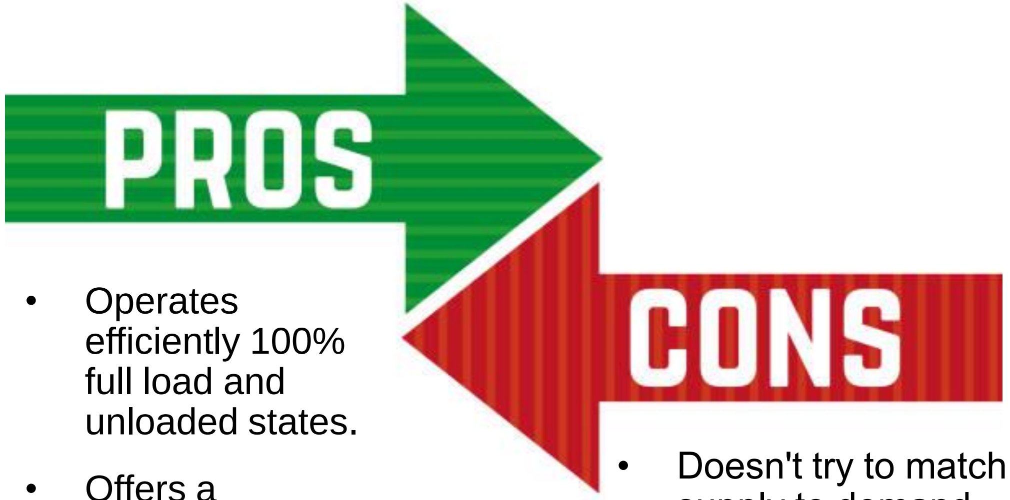
- Compression ratios rise with throttling of inlet pressure valve.
- Inefficient at lower loads.
- Limited modulating range; rotary screw compressors typically modulate back to around 40-60% of full load capacity before unloading, similar to a load/unload compressor.

Understanding Control Modes

Load/Unload

The compressor operates at 100% full load or unloaded based on changes in pressure.





Pros

- Operates efficiently 100% full load and unloaded states.
- Offers a reasonable range of pressure control, approximately 10 psig.
- When equipped with sufficient storage (tank), provides energy-efficient control for rotary screw and reciprocating compressors.

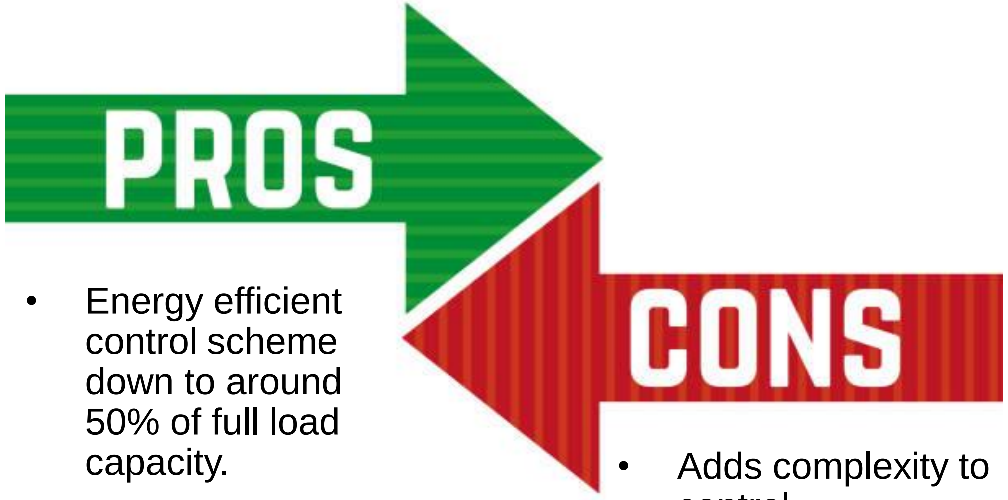
Cons

- Doesn't try to match supply to demand.
- Improper "short cycles" lead to premature wear, minimal power savings for rotary screw compressors.
- Adequate blow-down time and storage are crucial for energy savings, preventing lubricant foaming in rotary screw compressors.

Understanding Control Modes

Variable Displacement

Mechanically changes the displacement of the air end by opening/closing ports in response to pressure changes.



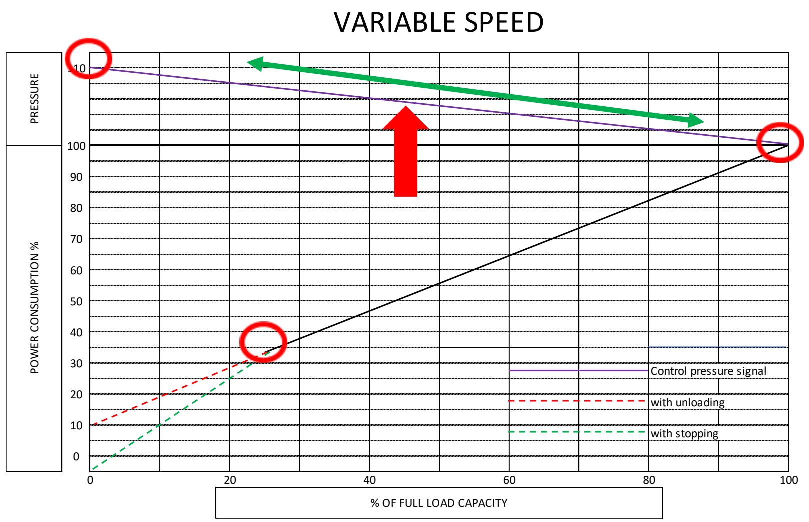
- Energy efficient control scheme down to around 50% of full load capacity.
- Matches displacement of the air end to demand without reducing inlet pressure, increasing compression ratios (like modulation).

- Adds complexity to control.
- Relatively high initial cost.
- Generally available only for 50 hp (37 kW) and larger.

Understanding Control Modes

Variable Speed

Adjusts the compressor’s capacity by varying the speed of the drive motor in response to pressure changes.



PROS

- Attempt to match supply with demand!
- Energy efficient and precise control at part load.
- Varies the rotating speed of the main motor, thus changing the displacement and power consumption.

CONS

- Adds control complexity.
- Higher initial cost when compared to fixed speed.
- Reduced efficiency at full load.
- Part-load "sweet spot" where maximum efficiency is achieved; efficiencies at other part-load points may vary in energy efficiency.

Factors Influencing Compressor Efficiency with Advanced Control Systems

Operating Pressure

- Maintaining precise operating pressure is critical for compressor efficiency.
- Control systems should dynamically adjust to changes, ensuring the compressor operates within optimal pressure ranges.

Factors Influencing Compressor Efficiency with Advanced Control Systems

Air Demand Fluctuations

- Efficient control systems respond seamlessly to variations in air demand.
- Adaptive controls prevent overloading during peak demand and minimize energy consumption during low-demand periods.

Factors Influencing Compressor Efficiency with Advanced Control Systems

Temperature Conditions

- Smart control systems consider temperature fluctuations.
- Adjustments based on temperature variations optimize compressor performance across diverse operating conditions.

Control System Considerations

Proper Sizing & Selection

- Proper sizing and selection of controls are crucial for optimal efficiency.
- Matching controls to the compressor's characteristics and capacity improves overall system performance.

Integration with Other Systems

- Seamless integration with auxiliary systems
(e.g., dryers, filters) boosts overall efficiency.
- Collaborative operation among different components maximizes the effectiveness of the entire compressed air system.

Regular Maintenance & Calibration

- Scheduled maintenance and calibration are critical for sustained control system efficiency.
- Routine checks and adjustments prevent degradation, ensuring continuous peak performance.

Advanced Control Strategies for Efficiency Gains

Adaptive Control Algorithms

- Adaptive algorithms continuously learn and adjust to changing operational conditions.
- Optimizing compressor efficiency in real-time, adaptive controls adapt to load variations for peak performance.

Predictive Maintenance

- Predictive maintenance algorithms anticipate potential issues, minimizing downtime.
- Proactively replacing components based on predictive analytics prevents unexpected failures, enhancing overall system reliability.

Remote Monitoring and Control

- Remote monitoring, like FS-SmartConnect, provides real-time oversight for prompt adjustments.
- Remote control capabilities allow immediate responses to changing operational needs, reducing energy wastage.

Unlocking Efficiency through Precision Control

- Ensuring your control system aligns seamlessly with your pressure requirements, demand fluctuations, operating conditions, and system configuration is essential for achieving optimal compressed air operations.
- Investing in advanced compressor control systems is not just a technical upgrade; it's a strategic move toward sustainable and cost-effective industrial operations.

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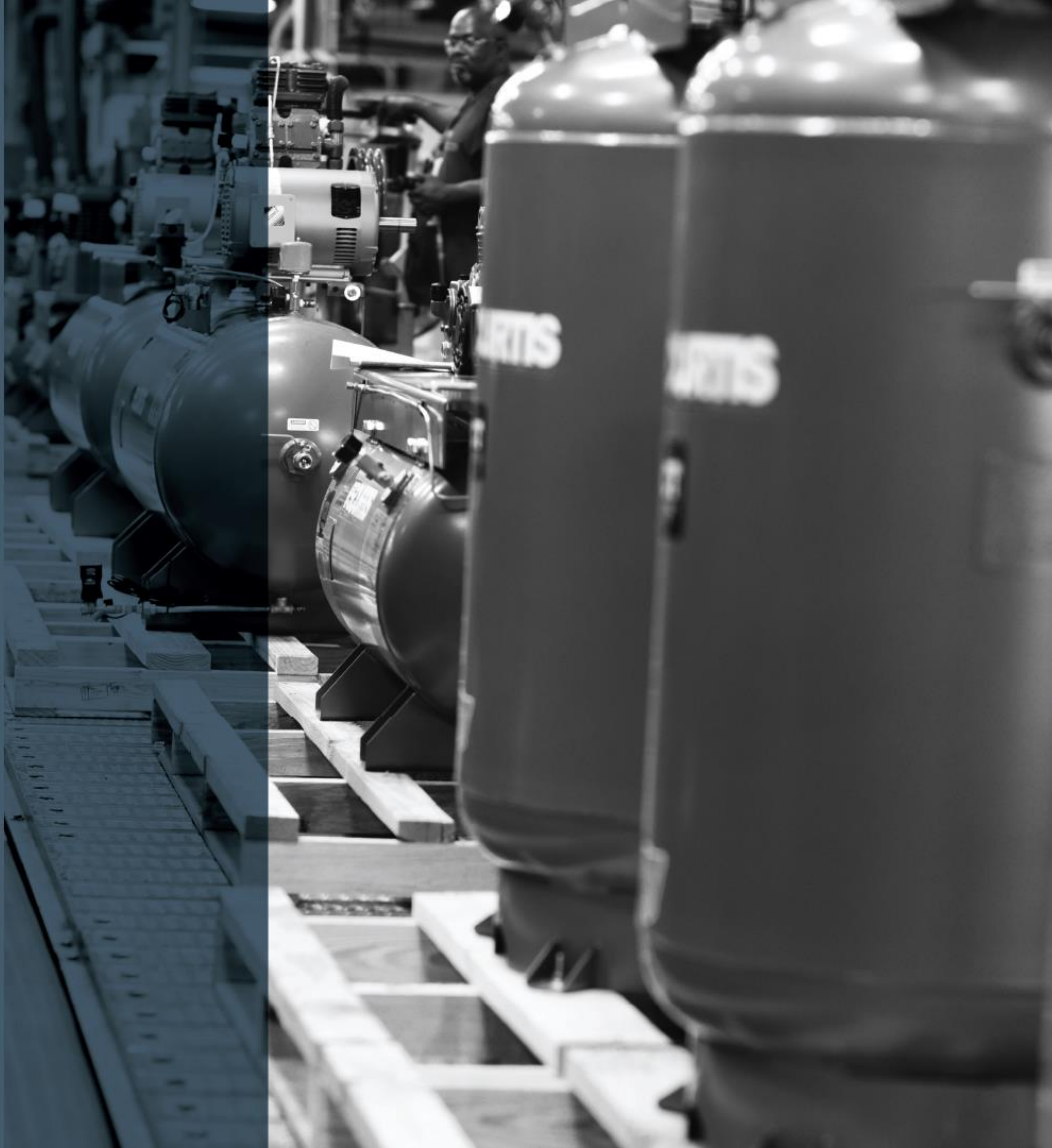

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Q&A

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Julie Gass, P.E.
Black & Veatch
Keynote Speaker

Hiran de Mel
Jacobs
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