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Controls for Industrial Compressed Air Systems

Minimize equipment run times, maintain stable air pressures, and reduce power consumption



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When it comes to plant air systems, the fundamental needs of facilities are usually quite similar. The biggest requirements are to meet specific pressure, flow, and air quality targets to ensure that the quality of the end-products remain predictably high at all times.

Beyond this, air system reliability is also critical so as to avoid costly process line maintenance or unscheduled shutdowns.

Last but certainly not least, optimizing energy consumption is important at a time when cheap energy is a thing of the past.

In most industrial plant applications, multiple compressors rather than a single unit are supplying the total air flow. Lower efficiencies can occur when compressors that are part of multi-unit air systems operate on their own individual control settings, rather than operating in concert to deliver maximum performance at the highest level of efficiency.

When compressors are operating independent of one another, system pressure is likely to be inconsistent. Independent control also leads to energy being wasted in a number of ways:

- Running more machines than are necessary at a given period of time
- Running compressors at higher pressures than are needed
- Excessive idling or modulating

In addition to the operational inefficiencies and unstable pressure, there is the likelihood of increased maintenance requirements (and the related costs) due to excessive valve cycling and motor starts.

Individual Compressor Unit vs. Compressor System Controls

The purpose of any compressor control system is to match the compressed air supply to the demand as efficiently as possible. There are two levels of control: controls for individual compressor units and master controllers that support an entire air system installation of compressors plus ancillary components like filters, dryers, and drains.

Both types of controls are important to optimizing the efficiency of your facility's compressed air function.

Individual compressor controls have come a long way over the past two decades. The most advanced types combine safe and efficient internal supervision of the machine with important maintenance-related information, such as:

- Airend discharge temperature
- Direction of rotation
- Motor temperature
- Internal pressure
- Electrical overload status
- Oil filter differential pressure
- Service and load hours
- Compressor alarm and operating history

The most advanced controls also offer the ability to monitor and control compressed air equipment remotely via built-in web servers or connecting into existing plant monitoring systems via EtherNet/IP or industrial bus options (DeviceNet™, Profibus®, etc).

Further, there are a number of control options to manage part-load operating conditions. These control schemes (see sidebar on page 3 for more information) can perform well in single compressor systems, but individual compressor controls only go so far.

Master controllers take operational efficiencies a step further by controlling all compressors and accessory equipment in an air system installation together, and in relation to each other.

In short, master controllers leverage the advantages of each type of compressor control and take air system operations and energy efficiency to new heights.

Why Master Controllers?

Boiled down to basics, master controllers improve the pressure stability and reliability of a compressed air system by turning the individual compressor units on and off only when needed to meet a specified pressure. This greatly improves specific performance (cfm/kW) while balancing compressor load hours for more effective maintenance scheduling.

How effectively your plant O&M personnel can address changes in demand within a multi-compressor air system is dependent on choosing the correct type of master controller. Here are the important considerations when evaluating capabilities:

- The master controller should be able to maintain system pressure within a narrow pressure band.
- It should monitor the rate of change of air pressure to determine the change in flow demand – and then calculate the most efficient response to that change.
- It should monitor the starting frequency of all compressors in the system so that they can be switched on or off quickly to minimize idle-mode running.
- It should be programmable with each compressor's capacity and specific performance characteristics.
- It should provide historical data to facilitate energy performance analysis.

By using the correct combination of a master controller and properly sized compressors, concerns about part-load efficiency of fixed speed compressors are effectively eliminated. They won't idle for any significant time – instead running at full load or on standby.

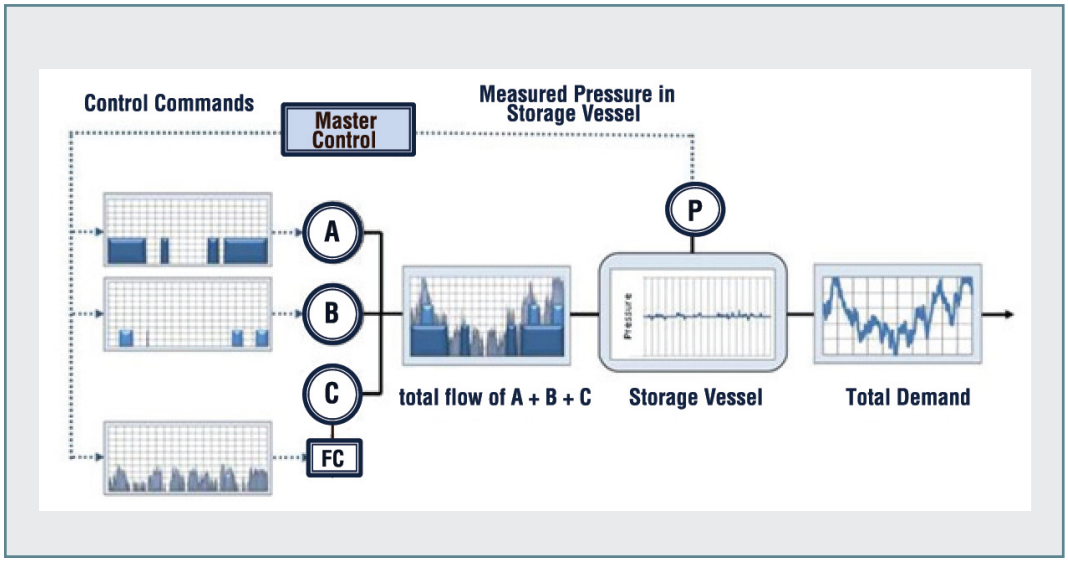


FIGURE 1: Typical master controller operation

Adaptive Control

This advanced functionality adapts to the demands of a compressed air system in three ways:

- Monitoring the rate of change in pressure for more rapid and accurate response
- Predicting when to turn on additional compressors
- Learning and adapting to patterns of system behavior to minimize idling and pressure swings

The key is continuous monitoring of current air pressure, the rate of change in demand for air, and the response times of the air compressor units. Such monitoring is able to identify factors that affect the operational efficiency of the air system – and then immediately trigger actions to optimize the efficiency.

The most significant actions that are triggered by continuous monitoring include:

- Increasing loaded run time to decrease switching losses
- Equalizing compressor usage to decrease maintenance costs
- Choosing the correct compressor based on its capacity to match the demand
- Lowering air pressure to save energy and related costs

Figure 2 shows the difference in the effectiveness of advanced master controllers compared to less sophisticated control algorithms – and the degree to which adjustments are made in response to changing air demands:

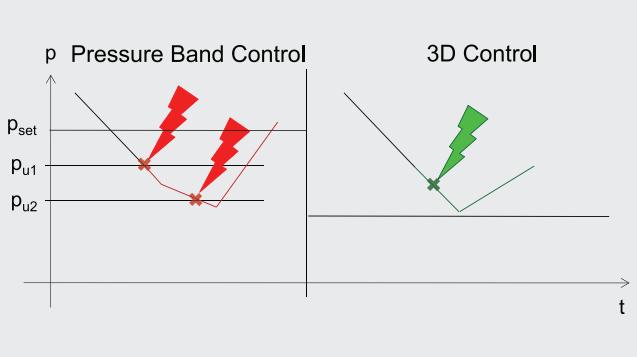


FIGURE 2

Advanced control switches the status of individual compressors just in time to maintain better pressure control while using the least energy. The properly sized compressor is chosen. Additionally, the control system is adaptive, responding to the system's changing demands rather than reacting at specified points (see Figure 3).

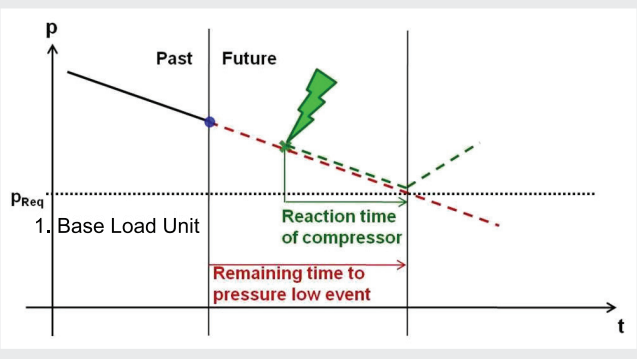


FIGURE 3

The system controller "learns" the system behavior, thereby making the control process progressively more precise and more effective. By accurately estimating future pressure behavior, the master controller addresses the change in demand before fluctuations occur … knows the reaction time of the compressor … and then determines the precise moment for the proper compressor to load.

The reaction time dynamics may seem like only a minor difference, but the effect over time represents a significant improvement in system efficiencies and pressure stability.

Addressing the "Control Gap" Issue

Variable speed drive (VSD) compressors are now a common sight in industrial air system installations. It's not difficult to understand why: In the right applications VSD compressors adjust the compressor/motor speed and output to match system demand far more precisely than fixed speed units.

Compressor Control Profiles

There are several different ways to control an individual compressor to match output to demand. In single compressor installations, some are better at handling part-load conditions than others. Many newer compressors can be switched from one to the other via their on-board controller. Others (e.g. modulation, variable speed, and rotor length adjustment) require different mechanical and electric configurations. Below are simplified descriptions of the types in use today:

Dual Control: Operates fixed speed compressors at "full load" and "idle mode" via a minimum/maximum pressure switch plus a timer. Pressure band and timer values are preset to match system requirements.

Quadro Control: An enhancement over Dual Control that includes an additional timer to fine-tune the "idle" period, while bypassing "idle mode" after periods of low air demand.

Vario Control: Uses a "smart" timer to vary the idle time based on the frequency of motor starts – resulting in greater energy savings.

Dynamic Control: Allows compressors to switch from "load" to "stop" at low motor temperatures, and to "idle" when the motor is hot. (The control may bypass "idle mode" if the motor temperature is low and more compressor starts are allowable.)

Variable Speed Control: Air flow is controlled to maintain a specified discharge pressure by controlling electrical frequency (and therefore speed of the drive motor) in response to a pressure signal at the compressor discharge. This is the most advanced and energy-efficient type of compressor control.

Modulation Control: This regulates air delivery using a proportional inlet valve to regulate flow and provide a constant output pressure in response to a pressure signal from the compressor discharge. Prior to variable speed/frequency drive, it was a popular part load control.

Rotor Length Adjustment: Constant speed compressor with valves along the length of the airend that regulate volume output in response to a pressure signal from the compressor discharge. Like modulation, this was more popular prior to the widespread use of variable speed drives (VSDs).

Note that VSD, modulation, and rotor length adjustment controls can be effective in maintaining steady discharge pressures in single compressor applications, but systems with multiple units of any type (or mix of types) can experience wide system pressure swings unless all units are controlled together.

VSD units are often found working alongside fixed speed compressors. This can create control challenges. If the control range of the VSD compressor isn't considered when sizing compressors, it can result in one or more units cycling between "load" and "idle" along with the ramping up and down of a VSD unit. When this type of event occurs, it can cause large pressure fluctuations that affect production. This is known as a "control gap."

Fortunately control gap can be easily avoided, if the control range of at least one fixed speed compressor is sized within the VSD compressor's control range. The control range is the difference between a VSD's minimum and maximum flow.

Figure 4 shows an example of a system consisting of a 150 hp VSD compressor plus multiple 100 hp fixed speed units. As illustrated, the system can provide a steady operating pressure throughout the flow range of the system as long as the system is equipped with master controls.

Advanced Energy Management with Master Controls

The more advanced the master controller for a compressed air system is, the more it will optimize energy performance. Smarter controls can manage multiple compressors of different sizes and pick the right mix of units to meet demand as it changes, while reducing energy consumption in three key ways:

Reduced compressor run and idling time – The typical compressor will accrue several minutes of unnecessary run and idle time per each hour of operation. Advanced master controls can save anywhere from 2% to 10% in energy costs by operating only the units needed to satisfy demand, while reducing compressor starts and switching losses. The controls determine the units having the best specific performance, thus maximizing full-load operation and reducing idle time in part-load conditions.

Improved pressure performance – Advanced controls recognize changes in air pressure quickly and accurately, thereby maintaining tighter pressure control. Outdated sequencers, in contrast, employ "cascading" pressure controls with wide pressure bands. Newer, more advanced controllers allow lower average system pressures. With this approach, 10% energy savings are commonly achieved along with better air pressure stability.

Reduced "artificial" demand and leak losses – To compensate for potential leaks and pressure drop, many users set system air pressures higher than actually needed. This "artificial demand" results in a good deal of wasted energy.

How to Avoid a Control Gap

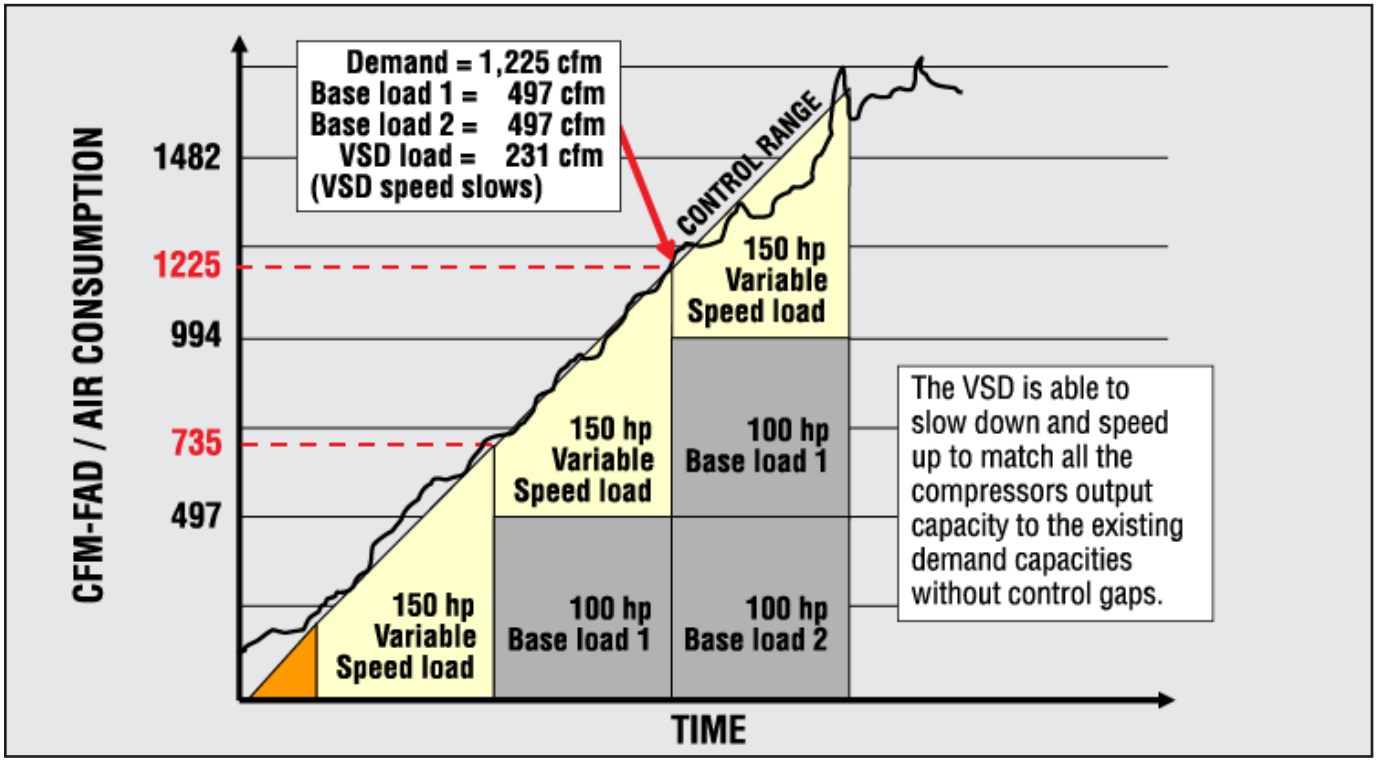


FIGURE 4: The maximum flow of the 150 hp VSD compressor is 735 cfm and the flow at minimum speed is 150 cfm, so the effective control range is 585 cfm. Each of the two fixed speed compressors is rated for 497 cfm, thus fitting within the control range of the VSD unit. Programming the master controller with the cfm output of the fixed speed units and the cfm range of the variable speed unit will enable more precise pressure control.

Advanced adaptive controls allow users to reduce the pressure while avoiding the risk of under-pressurizing tools and equipment. Operating at lower pressure reduces both artificial demand and leak losses. A good rule of thumb is that **every 2 psi reduction in compressor pressure yields a 1% reduction in power consumption.** For example, reducing the operating pressure from 125 psig to 100 psig would reduce the flow rate through a 1/4" orifice from 126 cfm to 104 cfm – nearly 20% in savings. Depending on system size, even a 5% reduction in pressure yields substantial savings.

Advanced Energy Monitoring and Communication Capabilities

Some newer system controllers can be programmed with not only the flow capacities of the individual units but also their specific performance. With the addition of data storage, these controls can track the usage of each compressor and accurately calculate energy consumption.

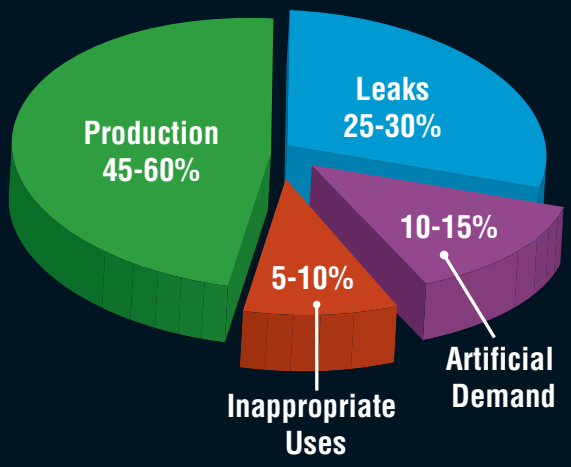
In this way, they provide an ongoing supply side air energy audit. This is very useful when planning production expansions, evaluating (and validating) energy reduction initiatives, etc. The documentation supports ISO 50001 Energy Management targets and decision making for process improvement.

Modern compressed air system controls can also deliver communications capabilities that are hugely beneficial to plant operations personnel. The entire air system can be monitored – either as a standalone network or as part of a larger control system. In many cases, these controls allow access via Internet, giving the manager full access to their system virtually anytime and anyplace.

The information is displayed in real-time on any standard Internet browser interface. HTML pages show easy-to-read screens such as ones showing the operational state of all compressors and system pressure trends, along with communicating any service alerts or system alarm messages.

Remote monitoring also means that technicians can view system status and diagnostic codes prior to undertaking service activities. This capability makes troubleshooting easier, and typically reduces service or repair time as well.

Department of Energy Findings



Here's a statistic people might find surprising: According to the US Dept. of Energy (DOE), air compressors consume as much as 8% of all the electricity generated in the United States. Furthermore, the DOE estimates that as much as half of the energy is wasted – with an average of 25% of all compressed air lost through leaks.

If that weren't enough, an additional 15% to 25% of energy is wasted through artificial demand and inappropriate uses of compressed air.

Power accounts for 70% of compressed air life cycle costs. Considering that just one 100 hp compressor consumes nearly $48,000 in electricity per year*, it's clear how much a plant stands to gain by improving its compressed air system efficiency.

… And master controls are a big part of the solution.

** Based on full-time operation at an average U.S. cost for commercial electricity of 8 cents per kilowatt hour.*

Outbound alerting is another valuable functionality: the ability to automatically notify plant O&M personnel (or the plant's compressed air service provider) of problems or shutdowns. This is particularly useful during third-shift or off-hour



FIGURE 5: HTML pages make it possible to monitor a wide range of system performance data for enhanced energy monitoring.

periods when full staff is not on the plant premises.

Better Efficiencies – Better Decisions

The sophistication of today's compressed air system controls gives plant O&M managers unparalleled access to optimal performance along with robust data reporting. In effect, these controllers are doing the day-to-day managing of proper flow and pressure, while at the same time providing the information needed for O&M staff to make better air system decisions.

That these functionalities also deliver measurable energy cost savings is a major bonus. Industrial managers are doing themselves a disservice if they don't investigate the potential benefits for their facilities.

The past decade has been a time of rapid evolution in compressed air applications technology. Today, with careful evaluation of the various control options that are available, plant managers really can achieve the best of all worlds when it comes to operational excellence – perfectly matching compressed air supply to demand in a way that's seamless, predictable, and highly energy-efficient.

About the Authors

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Technology Meets Tradition

Our compressed air heritage is built on a century of manufacturing experience. Generations of quality craftsmanship guide our engineering principles of efficiency, reliability, and serviceability.

This tradition of excellence also drives new technology development. Advances in airend design, controls, and system design ensure our customers can meet the daily challenges of their manufacturing operations.

Each KAESER product is designed with the future in mind, but we never lose sight of our roots. Technology needs may change from year to year, but the need for quality and reliability will always remain.



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