# Compressed Air System Controls

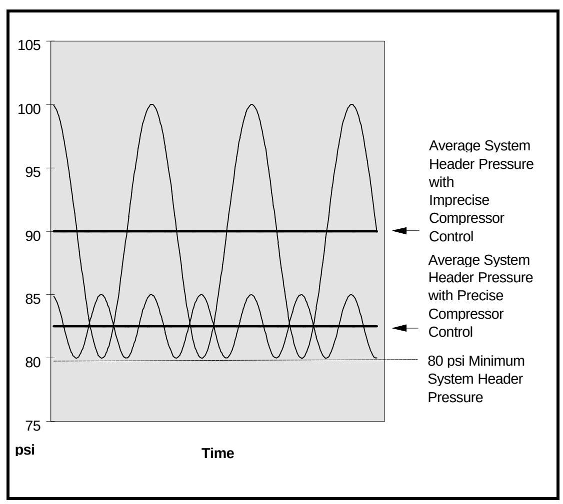
Office of Industrial Technologies

## *Compressed Air Systems Fact Sheet #6*

Compressed air system controls match the compressed air supply with system demand (although not always in real-time) and are one of the most important determinants of overall system energy efficiency. This Fact Sheet discusses both individual compressor control and overall system control of plants with multiple compressors. Proper control is essential to efficient system operation and high performance. The objective of any control strategy is also to shut off unneeded compressors or delay bringing on additional compressors until needed. All units which are on should be run at full-load, except for one unit for trimming.

Compressor systems are typically comprised of multiple compressors delivering air to a common plant air header. The combined capacity of these machines is sized, at a minimum, to meet the maximum plant air demand. System controls are almost always needed to orchestrate a reduction in the output of the individual compressor(s) during times of lower demand. Compressed air systems are usually designed to operate within a fixed pressure range and to deliver a volume of air which varies with system demand. System pressure is monitored and the control system decreases compressor output when the pressure reaches a predetermined level. Compressor output is then increased again when the pressure drops to a lower predetermined level.

The difference between these two pressure levels is called the control range. Depending on air system demand, the control range can be anywhere from 2-20 psi. In the past, individual compressor controls and non-supervised multiple machine systems were slow and imprecise. This resulted in wide control ranges and large pressure swings. As a result of these large swings, individual compressor pressure control set points were established to maintain pressures higher than needed. This ensured that swings would not go below the minimum requirements for the system. Today, faster and more accurate microprocessor-based system controls with tighter control ranges allow for a drop in the system pressure set points. This advantage is depicted in the figure below, where the precise control system is able to maintain a much lower average pressure without going below the minimum system requirements. Every 2 psi of pressure difference is equal to about a 1%




**Impacts of Controls on System Pressure**



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change in energy consumption. Narrower variations in pressure not only use less energy, but avoid negative effects on production quality control.

Caution needs to be taken when lowering average system header pressure because large, sudden changes in demand can cause the pressure to drop below minimum requirements, leading to improper functioning of equipment. With careful matching of system controls and storage capacity, these problems can be avoided.

Few air systems operate at full-load all of the time. Part-load performance is therefore critical, and is primarily influenced by compressor type and control strategy.

## Controls and System Performance

The type of control specified for a given system is largely determined by the type of compressor being used and the facility's demand profile. If a system has a single compressor with a very steady demand, a simple control system may be appropriate. On the other hand, a complex system with multiple compressors, varying demand, and many types of end-uses will require a more sophisticated strategy. In any case, careful consideration should be given to both compressor and system control selection because they can be the most important factors affecting system performance and efficiency.

## Individual Compressor Control Strategies

Over the years, compressor manufacturers have developed a number of different types of control strategies. Controls such as start/stop and load/unload respond to reductions in air demand, increasing compressor discharge pressure by turning the compressor off or unloading it so that it does not deliver air for periods of time. Modulating inlet and multi-step controls allow the compressor to operate at part-load and deliver a reduced amount of air during periods of reduced demand.

***Start/Stop.*** Start/stop is the simplest control available and can be applied to either reciprocating or rotary screw compressors. The motor driving the compressor is turned on or off in response to the discharge pressure of the machine. Typically, a simple pressure switch provides the motor start/stop signal. This type of control should not be used in an application that has frequent cycling because repeated starts will cause the motor to overheat and other compressor components to require more frequent maintenance. This control scheme is typically only used for applications with very low duty cycles.

***Load/Unload.*** Load/unload control, also known as constant speed control, allows the motor to run continuously, but unloads the compressor when the discharge pressure is adequate. Compressor manufacturers use different strategies for unloading a compressor, but in most cases, an unloaded rotary screw compressor will consume 15-35% of full-load horsepower while delivering no useful work. As a result, some load/unload control schemes can be inefficient.

***Modulating Controls.*** Modulating (throttling) inlet control allows the output of a compressor to be varied to meet flow requirements. Throttling is usually accomplished by closing down the inlet valve, thereby restricting inlet air to the compressor. This control scheme is applied to centrifugal and rotary screw compressors. This control method, when applied to displacement compressors, is an inefficient means of varying compressor output. When used on centrifugal compressors, more efficient results are obtained, particularly with the use of inlet guide vanes which direct the air in the same direction as the impeller inlet. The amount of capacity reduction is limited by the potential for surge and minimum throttling capacity.

***Multi-step (Part-load) Controls.*** Some compressors are designed to operate in two or more partially-loaded conditions. With such a control scheme, output pressure can be closely controlled without requiring the compressor to start/stop or load/unload.

Reciprocating compressors are designed as two-step (start/stop or load/unload), three- step (0%, 50%, 100%) or five-step (0%, 25%, 50%, 75%, 100%) control. These control schemes generally exhibit an almost direct relationship between motor power consumption and loaded capacity.

Some rotary screw compressors can vary their compression volumes (ratio) using sliding or turn valves. These are generally applied in conjunction with modulating inlet valves to provide more accurate pressure control with improved part-load efficiency.

***Variable Frequency Drives.*** Historically, the use of variable frequency drives (VFDs) for industrial air compressors has been rare, because the high initial cost of a VFD could not justify the efficiency gain over other control schemes. Cost is no longer a major issue. VFDs may gain acceptance in compressor applications as they become more reliable and efficient at full-load.

## System Controls

By definition, system controls orchestrate the actions of the multiple individual compressors that supply air to the system. Prior to the introduction of automatic system controls, compressor systems were set by a method known as cascading set points. Individual compressor operating pressure set points were established to either add or subtract compressor capacity to meet system demand. The additive nature of this strategy results in large control ranges as depicted in the figure on the first page of this Fact Sheet.

The objective of an effective automatic system control strategy is to match system demand with compressors operated at or near their maximum efficiency levels. This can be accomplished in a number of ways, depending on fluctuations in demand, available storage, and the characteristics of the equipment supplying and treating the compressed air.

***Single Master (Sequencing) Controls.*** Sequencers are, as the name implies, devices used to regulate systems by sequencing or staging individual compressor capacity to meet system demand. Sequencers are referred to as single master control units because all compressor operating decisions are made and directed from the master unit. Sequencers control compressor systems by taking individual compressor capacity on- and off-line in response to monitored system pressure (demand). The control system typically offers a higher efficiency because the control range around the system target pressure is tighter. This tighter range allows for a reduction in average system pressure. Again, caution needs to be taken when lowering average system header pressure because large, sudden changes in demand can cause the pressure to drop below minimum requirements, leading to improper functioning of equipment. With careful matching of system controls and storage capacity, these problems can be avoided (see also flow controller).

***Multi-Master (Network) Controls.*** Network controls offer the latest in system control. It is important that these controllers be used to shut down any compressors running unnecessarily. They also allow the operating compressors to function in a more efficient mode. Controllers used in networks are combination controllers. They provide individual compressor control as well as system control functions. The term multi-master refers to the system control capability within each individual compressor controller. These individual controllers are linked or networked together, thereby sharing all operating information and status. One of the networked controllers is designated as the leader. Because these controllers share information, compressor operating decisions with respect to changing air demand can be made more quickly and accurately. The effect is a tight pressure control range which allows a further reduction in the air system target pressure. Although initial costs for system controls are often high, these controls are becoming more common because of the resulting reductions in operating costs.

## Flow Controllers

Flow controllers are system pressure or density controls used in conjunction with the individual compressor or system controls described previously. A flow controller does not directly control a compressor and is generally not included as part of a compressor package. A flow controller is a device that serves to separate the supply side of a compressor system from the demand side. This allows compressors to be operated at or near their optimum pressures for maximum efficiency while the pressure on the demand side can be reduced to minimize actual usage requirements. Storage, sized to meet anticipated fluctuations in demand, is an essential part of this control strategy. Higher pressure supply air enters a storage tank at a predetermined rate and is available to reliably meet fluctuations in demand at a constant, lower pressure level. A well designed and managed system integrates control strategy, demand control, signal locations, differentials, compressor controls, and storage. The goal is to operate demand at the lowest possible pressure, support transient events as much as possible with stored air, and take as long as possible to replenish storage. This should result in the lowest possible energy consumption.

## Air Storage and Controls

Storage can be used to control demand events (peak demand periods) in the system by reducing both the amount of pressure drop and the rate of decay. Storage can be used to protect critical pressure applications from other events in the system. Storage can also be used to control the rate of pressure drop in demand while supporting the speed of transmission response from supply. For some systems, it is important to provide a form of refill control such as a flow control valve.

Many systems have a compressor operating in modulation to support demand events, and sometimes strategic storage solutions can allow for this compressor to be turned off.