Proven Opportunities at the Component Level

Office of Industrial Technologies

Compressed Air Systems Fact Sheet #11

In some cases, taking a systems approach to analyzing compressed air systems can facilitate the analysis of an individual component as well as performance issues relating to individual system components. In general, compressed air systems contain five major subsystems: (1) compressors; (2) prime mover; (3) controls; (4) air treatment equipment and other accessories; and (5) the air distribution subsystem. Performance aspects of each of these subsystems are discussed in detail below.

Compressors

While there are many different types of compressors, all compressor types theoretically operate more efficiently if they are designed to include multiple stages. With multiple stages, the final discharge pressure is generated over several steps, thereby saving energy. Many multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. In spite of this, many industrial compressors only have a single stage because equipment manufacturing costs are lower. Performance and efficiency issues of the three most common types of compressors -- single- and double-acting reciprocating compressors, rotary positive-displacement compressors, and centrifugal compressors -- are discussed below.

Single- and Double-Acting Reciprocating Compressors. In the past, reciprocating air compressors were the most widely used compressors in industrial plant air systems. Single-acting reciprocating compressors are generally air-cooled, in the smaller hp sizes, and do not require substantial foundations. However, these compressors are less efficient than other types. Double-acting reciprocating air compressors are generally water-cooled and require substantial foundations. Multi-stage versions are usually considered to be the most efficient air compressors but have high initial and installation costs and higher maintenance requirements.

Rotary Positive-Displacement Compressors. Today, lubricant-injected rotary screw compressors are used in most industrial plant air applications and for large applications in the service industries. They have some advantages over reciprocating compressors, including lower initial installation and maintenance costs; smaller size; reduced vibration and noise; reduced floor space requirements; and the ability to be installed on a level industrial plant floor. Rotary screw compressors provide continuous flow and do not have the type of pressure pulsations typically associated with reciprocating compressors. Two-stage rotary-screw compressors are more efficient than single-stage units. Lubricant-injected rotary screw compressors are typically less efficient than two-stage double-acting reciprocating compressors or three-stage centrifugal compressors. In general, rotary screw compressors are also less efficient at part-load than reciprocating compressors.

A wide range of models is usually available from different manufacturers for any given application. Users should try to select the most efficient model available (see the Fact Sheet titled *Packaged Compressor Efficiency Ratings).*

Centrifugal Compressors. The use of centrifugal compressors is usually limited to high-volume industrial plant applications, such as chemical manufacturing, textile plants, petroleum refining, or general plant air systems in large manufacturing facilities. The compressors operate at high speeds and therefore use smaller, more compact equipment. Three-stage centrifugal compressors are generally more efficient than rotary screw compressors and can approach the efficiency levels of double-acting reciprocating compressors. Centrifugal air compressors are available for 100 psig discharge pressure from 100-hp, but most are 300-hp or larger, with an increasing number of stages and improving efficiency as size increases. Centrifugal compressors are best suited to applications where demand is relatively constant or in industrial plants where they can be used primarily for base-load operation, allowing other compressor types to be as used as trim machines to meet peak demands.

Lubricant-Free Compressors. Lubricant-free versions of reciprocating and rotary air compressors are available. Centrifugal air compressors are inherently lubricant-free. Lubricant-free compressors may be appropriate for specific applications or to meet specific environmental regulations. Lubricant-free rotary screw and reciprocating compressors are generally less efficient than lubricant-injected machines.

Prime Movers

The majority of industrial compressed air systems use electric motors as the prime mover. Standard, three-phase squirrel-cage induction motors are used in 90% of all industrial compressor applications due to their reliability, level of efficiency (85-95%, depending on size), and excellent starting torque, and despite their high inrush current requirements. Inrush current is the amount of current that is required to start the motor and motor-driven equipment. Most major manufacturers of industrial packaged compressed air systems now offer both standard and energy-efficient motors. As of October 24, 1997, standard three-phase induction motors between 1 and 200 hp are required to meet minimum federal efficiency levels. This means that all general-purpose motors are at the efficiency levels of those formerly labeled "high efficiency" or "energy-efficient." Even with these new minimum efficiency levels, there is a range of efficiencies available for any given application, and manufacturers will likely offer lines of premium-efficiency motors that have higher efficiencies than standard-efficiency motors.

Motors can be flange mounted, connected with a v-belt, or direct coupled. Proper alignment is critical for all applications. Direct coupling results in the least loss of efficiency, while v-belt applications may allow for more compact packaging. V-belts should always be inspected and tensioned per manufacturer's specification to avoid increased power transmission losses.

Due to the heavy duty and load cycles on most compressors, it almost always makes sense to buy the most efficient motor available. The incremental cost for a more efficient motor is typically paid back in less than one year from the resulting energy savings. Users should be aware that new energy-efficient motors sometimes have lower available starting torque than standard motors and often have slightly higher operating speeds because of reduced slip. Match operating speeds as closely as possible when replacing a motor.

Controls

Compressor control mechanisms are used to match the compressed air volume and pressure delivered by the compressor with facility demand. Compressor controls are often the most important factor determining a compressor's ability to perform at part-load efficiently. Controls are frequently configured poorly, and proper control strategies can lead to substantial reductions in energy consumption.

For more information on controls and compressed air system performance, see the Fact Sheet titled *Compressed Air System Controls*.

Air Treatment Equipment and Other Accessories

Air treatment equipment must provide for both contaminant removal and preparation of the air for equipment use. The level of air conditioning and accessories needed is often dependent on air quality requirements. For optimum performance, air treatment equipment should be operated as close to manufacturers' design conditions as possible. A discussion of important compressor system accessory equipment and performance follows.

Dryers. Compressed air system performance is typically enhanced by the use of dryers, but since they require added capital and operating costs (including energy), drying should only be performed to the degree that it is needed for the proper functioning of the equipment and the end-use.

Single tower chemical deliquescent dryers use little energy, but provide pressure dewpoint suppression of 15 to 50EF below the dryer inlet temperature, depending on the desiccant selected. They are not suitable for some systems that have high drying needs.

Refrigerant-type dryers are the most common and provide a pressure dewpoint of 35 to 39EF, which is acceptable for many applications. In addition to the pressure drop across the dryer (usually 3-5 psid), the energy to run the refrigerant compressor must be considered. Some refrigerant-type dryers have the ability to cycle on and off based on air flow, which may save energy.

Twin tower desiccant-type dryers are the most effective in the removal of moisture from the air and typically are rated at a pressure dewpoint of -40EF. The purge air requirement can range from 10 to 18% of the total air flow, depending on the type of dryer. This energy loss, in addition to the pressure drop across the dryer, must be considered. The heated-type requires less purge air for regeneration, as heaters are used to heat the desiccant bed or the purge air. The heater energy must also be considered against the reduction in the amount of purge air, in addition to the pressure drop. Heat-of-compression dryers may be used where the lubricant-free compressor discharge temperature is sufficiently high to achieve regeneration of the desiccant. There is no reduction of air capacity with this type of dryer since hot, unsaturated air from the compressor discharge is used for regeneration, then cooled and some of the moisture is removed as condensate before passing through the drying section. Vacuum-assisted regeneration is typically the most efficient, with unheated purge air flow the least efficient.

Compressed Air Filters. These include particulate filters to remove solid particles, coalescing filters to remove lubricant and moisture, and adsorbent filters for very fine contaminants. A particulate filter is recommended after a desiccant-type dryer to remove desiccant "fines". A coalescing-type filter is recommended before a desiccant-type dryer to prevent fouling of the desiccant bed. Additional filtration may also be needed to meet requirements for specific end-uses.

Compressed air filters downstream of the air compressor are generally required for the removal of contaminants, such as particulates, condensate, and lubricant. Filtration only to the level required by each compressed air application will minimize pressure drop and resultant energy consumption. Elements should also be replaced as indicated by pressure differential, and at least annually, to minimize pressure drop and energy consumption.

Air Receiver. Air receivers are designed to provide a supply buffer to meet short-term demand spikes which can exceed the compressor capacity. They also serve to dampen compressor pulsations, separate out particles and liquids, and make the compressed air system easier to control. Installing a larger receiver tank to meet occasional peak demands can even allow for the use of a smaller compressor.

In most systems, the receiver will be located just after the dryer. In some cases, it makes sense to use multiple receivers, one prior to the dryer and one closer to points of intermittent use.

Storage can be used to control demand events (peak demand periods) in the system by controlling 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. 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. Storage can also help systems ride through a compressor failure or short energy outages.

Condensate/Lubricant Separators. It is no longer acceptable to discharge condensate from a compressed air system to sewer lines without treatment to remove contaminants such as entrained lubricants (except for condensate from some lubricant-free compressor systems). Condensate/lubricant separators are available in the marketplace to achieve separation by means of settling tanks and/or permeable membranes. This equipment helps to avoid the potentially high costs of contaminated waste disposal, although some lubricants are water soluble and biodegradable and can be disposed of in the sewer system (check local regulations).

Air/Lubricant Separators. The air/lubricant separator in a lubricant-cooled rotary screw compressor generally starts with a 2-3 psid pressure drop at full-load when new. Maintenance manuals usually suggest changing them when there is a 10-12 psid pressure drop across the separator. In many cases it may make sense to make an earlier separator replacement, especially if electricity prices are high.

Heat Recovery Systems. Most systems do not employ heat recovery, even though economics can be good, with typical paybacks of less than one year. Heat recovery systems require electricity for fans or pumps, but can decrease the need for fossil fuels usually used for heating. See the Fact Sheet titled *Heat Recovery with Compressed Air Systems* for more information on this energy saving opportunity.

The Air Distribution Subsystem.

The air distribution subsystem, which connects the major components, is one of the most important parts of the compressed air system. It is made up of main trunk lines, hoses and valves, drops to specific usage points, pressure regulators and lubricators, additional filters and traps, and supplementary air treatment equipment. It is throughout this subsystem that most leaks occur, energy is lost, and maintenance required. Equipment should be chosen to avoid excessive pressure drops and leakage. In addition, consideration of appropriate sizing of equipment and layout will provide for proper air supply, good tool performance, and optimal production. The complete drying, filtration, and distribution system should be sized and arranged so that the total pressure drop from the air compressor to the points of use is much less than 10% of the compressor discharge pressure.

Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and should never be undertaken. If a float-operated automatic condensate drain is not functioning properly, clean and repair it instead of leaving it open. If maintenance of float-operated drain traps is a burden, consider replacing them with more reliable demand-type drain traps.

The efficiency of the entire system can be enhanced by the proper selection, application, installation, and maintenance of each component.