MAINTENANCE I RELIABILITY I ENGINEERING I PRODUCTION

SPECIAL REPORT ON COMPRESSED AIR SYSTEM EFFICIENCY

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THE 14 RS OF COMPRESSED AIR EFFICIENCY:

Install, operate, and maintain a system that makes the best use of resources

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Educational institutions have realized the need for emphasizing the basics, sometimes referred to as the three Rs — reading, 'riting and 'rithmetic. There are also several basic Rs to be kept in mind if you want to install, operate, and maintain an efficient compressed air system:

- 1. reduce leakage losses
- 2. reduce pressure at points of use
- 3. reduce pressure at source (compressors)
- 4. reduce system pressure fluctuations using adequately sized and located air receivers and controls
- 5. reduce number of partially loaded compressors to only one
- 6. remove inappropriate applications
- 7. reduce system pressure drop losses with properly sized piping and valves
- 8. remove moisture content of compressed air with the proper type and size of dryers
- 9. remove condensate without loss of compressed air
- 10. reduce downtime through preventive maintenance
- 11. record system data and maintenance
- 12. review air usage patterns regularly
- 13. recover heat
- 14. reduce energy costs (return on investment and cost of operation).



REDUCE LEAKAGE LOSSES

In a typical plant compressed air leaks amount to 20-30% of the total of all the compressed air produced.

In worst case scenarios, where no detection and repair programs exist, leakage levels can be more than 50%. A ¼-in. leak in a 100 psi system having a pressure of 100 psig, will allow more than 3 million ft³ of free air to escape in one month. At an average specific power of 18 kW/100 cfm, this amounts to 107,000 kWh of lost energy or \$10,700 in energy cost per year at \$0.10/kW. This problem is worsened in systems operating at even higher pressures.

Leakage rates drop with lower operating pressures. If the system pressure could be reduced to 80 psig, for example, the leakage flow, and energy use in a well controlled system, would drop by 17% not including additional savings due to compressing to a lower pressure, which could amount to additional savings of 10%.

Leaks can be both intentional and unintentional.

- Intentional leaks include open condensate drain cocks and valves.
- Unintentional leaks include leaking pipe joints and valves, damaged hoses, and inexpensive poor-fitting quick-disconnect couplings.
- Equipment not in use may also be using some compressed air. Such equipment should be isolated from the distribution system by a valve.

One way to determine the leakage rate in a system is to do special testing when all of the production equipment in the plant is shut down. If the compressors can be run in load/unload mode, the time loaded as a percentage of total running time will represent the percentage of total capacity going to leaks. Alternatively, for compressors with other than load/unload controls, you can do a volume bleed down test. This method requires the use of a pressure gauge downstream of the receiver and an estimate of total system volume, including any downstream secondary air receivers, air mains, and piping (V, in cubic feet). The system is then started and brought to the normal operating pressure (P1), and the compressor is turned off. Measurements should then be taken of the

time (T) it takes for the system to drop to a lower pressure (P2), which should be a point equal to about one-half of the operating pressure. Leakage can be calculated as follows:

Leakage (cfm free air) =[V x (P1-P2)/(T x 14.7)] x 1.25

Where:

- V is volume in cubic feet

- P1 and P2 are starting and ending pressures in psig

- T is time in minutes

The 1.25 multiplier corrects leakage to normal system pressure, allowing for reduced leakage with falling system pressure to 50% of the initial reading. Again, leakage of greater than 10% indicates that the system can likely be improved. These tests should be carried out once a month as part of a regular leak detection and repair program. A description of these tests can be found at:

http://www.compressedairchallenge.org/ library/factsheets/factsheet07.pdf

Unfortunately, leaks are not a problem with a one-time cure. Maintaining a lower leak level requires ongoing vigilance and a mindset that will not allow leaks to be tolerated. Recognized leaks must be tagged and repaired as soon as possible.

CASE STUDY

At a large automotive manufacturing plant an energy team consisting of volunteers, mostly union labor from the shop floor, was led by an energy coordinator. The first step in initial mission was to reduce energy waste by targeting air leaks. Baseline data was gathered during normal production and during a Christmas shutdown. From this information, a leak reduction program was developed and approved by management, based upon estimated potential savings.

In the next step, leaks were identified and tagged for repair. The results of the efforts were published each weekend, and news of the success spread through the plant. Each team member was given a red "Energy Team" jacket. They developed a procedure for all employees to report leaks and be rewarded for their efforts. Bulletin "leak" boards were installed, and progress in fixing leaks was posted. Messages were displayed on TV monitors throughout the plant. Soon, everyone was aware and involved in the program, which produced a cultural change. The initial baseline showed a compressed air usage rate averaging almost 12,260 cfm. Within four years, this had dropped to 6,250 cfm, saving approximately \$2,000 per day. The reduced rate remained relatively constant with the increased awareness.

RULES OF THUMB

RELATING DISCHARGE PRESSURE TO ENERGY CONSUMPTION

For systems in the 100 psig range, for every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (check performance curves for centrifugal and two-stage lubricant-injected rotary screw compressors).

There is also another penalty for higher-than-needed pressure. Raising the compressor discharge pressure increases the demand of every unregulated usage, including leaks and open blowing. Although it varies by plant, unregulated usage is commonly as high as 30-50% of air demand. For systems in the 100 psig range with 30-50% unregulated usage, a 2 psi increase in header pressure will increase energy consumption by about another 0.6-1.0% because of the additional unregulated air being consumed (in the worst-case scenario, the extra flow could cause another compressor to start).

The combined effect results in a total increase in energy consumption of about 1.6-2% for every 2 psi increase in discharge pressure for a system in the 100 psig range with 30-50% unregulated usage.



REDUCE PRESSURE AT POINTS OF USE

Many plants use a single common compressed air distribution system to supply a variety of end-use

applications. When this is the case the total system must maintain a pressure that is high enough to satisfy the equipment having the highest pressure requirement, even though the majority of the equipment might require a much lower pressure. This higher pressure causes all the unregulated compressed air equipment in the plant to use more air and also increases the power required by the air compressor by 1% for every 2 psig in higher pressure.

When specifying new equipment requiring compressed air, it's often possible to specify a lower required operating pressure, such as 70 psi, to minimize the system pressure requirements. It also may be possible to retrofit existing equipment for lower pressure operation by replacing less-than-optimal components. On existing equipment, once retrofits are done, it is often possible to progressively reduce the main air supply pressure to determine the

minimum pressure at which the equipment will operate efficiently. For equipment that can't be optimized, it may then be possible to segregate equipment onto a separate system, so the majority of the compressed air system can be operated at a lower pressure. The portion requiring a higher pressure could then be supplied by a dedicatedcompressor air system, or by a booster compressor drawing air from the lower pressure system.

The pressure drop across air treatment equipment at the end use must also be taken into account and should be monitored to prevent a forced increase in compressor discharge pressure or an unintended decrease in pressure at the points of use. Filters, in particular, should have element pressure drop monitored and changed regularly.

A major consideration is how accurately the minimum desired pressure at the point of use can be maintained. Fluctuating system pressure can cause production quality problems, including torque variations of tools and inconsistent paint spray. Pressures that are higher than necessary can be caused by compressor control problems and, when they occur, can boost end-use air flows by causing artificial demand. Artificial demand occurs because unregulated end uses will use more air at higher pressure.

CASE STUDY

A lumber mill sorting machine had various kicker and lifter cylinders installed to move the lumber into position and perform additional lifting operations. It was found that most of the machine actuation cylinders required a power stroke in one direction only and the unloaded return stroke needed much less power. Pneumatic circuitry was installed that supplied 100 psi air to the cylinders on the power stroke, but only 40 psi air was used for the retract stroke. This operation was found to use 60% less air on each retract stroke and 30% less compressed air overall.

COMPRESSED AIR CHALLENGE

The Compressed Air Challenge (www.compressedairchallenge.org) is a voluntary collaboration of manufacturers, distributors, and their associations; industrial users; facility operating personnel and their associations; consultants; state research and development agencies; energy efficiency organizations; and utilities. The mission of the CAC is to be the leading source of product-neutral compressed air system information and education, enabling end users to take a systems approach, leading to improved efficiency and production and increased net profits.



REDUCE PRESSURE AT SOURCE (COMPRESSORS)

Real savings will not be realized unless the discharge pressure at the compressors can be reduced.

A rule of thumb commonly used for a typical 100 psi compressed air system is that the energy requirement of the compressors is reduced by 1% for every 2 psi decrease in system pressure. In some cases, due to undersized piping, some of these savings may be lost due to increased velocity at the lower pressure, through dryers, filters, and piping.

Some air compressors are purchased with a pressure rating substantially higher than required at the points of use. Running the compressors at an elevated pressure may compensate for pressure drop across filters and dryers and negate any restriction in the distribution piping and valves, but to save energy the control pressure set points and their operating band should be set as low as is practicable, not to the maximum allowable.

The pressure drop across individual components and sections of the distribution system should be measured to determine if they are within acceptable limits. These pressure drops force compressor discharge pressures higher to compensate. Corrective action should be taken where indicated. This may include changing types or size of pipes, valves, dryers or filters. The pressure drop from the compressor discharge to the points of use should not exceed 10% of the compressor discharge pressure.

Changing a main filter element at a pressure differential of 6 psid instead of the typical 10 psid will save energy costs during the time the drop would have been above 6 psid. This change would save about 1% if it results in lower compressor discharge pressure. Or better still, the use of mist-eliminator-style filters designed to have a pressure differential not exceeding 3 psid at end of filter life can save substantially more energy.

CASE STUDY

A U.S. Postal Service processing and distribution center, operating 24 hours per day and 365 days per year, had a peak demand of 620 scfm. All equipment, with the exception of flat sorting machines (FSMs), required an air supply of 100 psi. The FSM required 118 psi, and the whole system was operating at a nominal compressor discharge pressure of 128 psi. The compressor discharge pressure was lowered to 100 psi and a 3 kW air-operated booster installed to provide 118 psi for the FSMs, resulting in a total system energy savings of approximately 12%.

Rules of Thumb for Relating Discharge Pressure to

Energy Consumption: For systems in the 100 psig range, for every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (check performance curves for centrifugal and twostage lubricant-injected rotary screw compressors). There is also another penalty for higher-than-needed pressure. Raising the compressor discharge pressure increases the demand of every unregulated usage, including leaks and open blowing. Although it varies by plant, unregulated usage is commonly as high as 30-50% of air demand. For systems in the 100 psig range with 30%-50% unregulated usage, a 2 psi increase in header pressure will increase energy consumption by about another 0.6-1.0% because of the additional unregulated air being consumed (in the worst-case scenario, the extra flow could cause another compressor to start). The combined effect results in a total increase in energy consumption of about 1.6-2% for every 2 psi increase in discharge pressure for a system in the 100 psig range with 30-50 unregulated usage.



REDUCE SYSTEM PRESSURE FLUCTUATIONS USING AD-EQUATELY SIZED AND LOCATED AIR RECEIVERS AND CONTROLS Systems with inadequately sized re-

ceivers and distribution piping can experience significant fluctuations in system pressures and can have problems with compressor cycling that waste considerable energy.

Reciprocating air compressor pressure pulsations can be dampened by an air receiver close to its discharge. The receiver also shields the compressor and the system from fluctuations in demand for compressed air that momentarily exceeds the capacity of the compressor. Other compressor types also benefit from a receiver close to the discharge.

An air receiver placed before a compressed air dryer can provide effective radiant cooling and promote the fallout of condensate and entrained lubricant. However, since the dryer is normally sized to match the output from the compressor, a demand for compressed air in excess of the compressor and dryer rating will result in the dryer being overloaded by air flow from the fully loaded compressor and the air stored in the receiver. An air receiver placed after the dryer will contain already dried air; during peak demands the dryer sees only the output from the compressor, so is never overloaded.

Sizing of the primary air receiver is extremely important and can affect the choice of compressor capacity control system. Figure 1 shows the effect of different receiver sizes on an installation with a lubricated rotary screw compressor having a load/unload capacity control system. The calculations include the time necessary to blow down the sump/separator vessel to prevent foaming of the lubricant (40 s) and the time to re-pressurize the vessel (3 s). A fully unloaded bhp of 25% is used, but this can vary depending on the compressor cooling method and the condition of the compressor unloading controls. Receiver capacity is shown per unit of compressor capacity. One can see on the graph that a compressor with only 1 gal of storage per cfm output consumes more than 80% of its full load power when loaded at only 40% capacity. The same unit with 10 gal of storage per cfm would consume a much lower 60% of full load at the same flow. Unless there is ample receiver capacity and/or very light load demand, load/unload may not be the most efficient means of capacity control. With multiple fully loaded compressors, and only one part loaded unit, the required receiver capacity relates to the capacity of the partly loaded (trim) compressor, not the total capacity of all of the compressors.

A properly sized receiver close to the compressors is essential but may not be sufficient to prevent erratic system pressures. Intermittent demands for relatively large volumes of compressed air can draw down the pressure of the whole distribution system in a short period of time, causing problems for other applications requiring stable pressure. An air receiver located close to these points of use can provide the required demand with stored air, which will prevent the large demand from significantly affecting the overall system pressure. This allows more stable system pressure and more response time to replenish the air receivers more efficiently.

Pressure/flow controls can be placed after the primary receiver to maintain a stable downstream system pressure within +/- 1 psi. Due to the accurate pressure, the effect on product quality alone is well worth the initial investment. The constant system pressure also allows lowering of pressure at points of use and at the compressors with considerable reduction in energy requirements. In some cases, a compressor can be shut down.

CASE STUDY

A mineral processing facility was experiencing inefficient compressor operation due to a poor compressor control strategy. The facility had one large base 350 hp and two trim 150 hp compressors installed but only 400 gal of main system storage. Because the storage was inadequate the trim compressors could not be run in the more efficient load/unload mode. Larger storage of 4,000 gal was installed, which resulted in better compressor

control; however, when the plant maintenance personnel tried to lower the pressure, some problems were experienced at a baghouse that needed a large pulse of air at a high pressure to work properly. Investigation revealed low pressure at the baghouse manifold was caused by a high flow of air requirement passing through small baghouse feed lines after each cleaning pulse. Local storage of 60 gal was added at the baghouse manifold which was protected with a check valve and restricted through a needle valve. This restriction reduced the flow so the new storage tank charged slowly, but still allowed a large pulse of air to flow to each cleaning pulse. The local storage provided enough air that the baghouse could operate at 60 psi allowing the main system pressure to be turned down.



REDUCE NUMBER OF PART-LOADED COMPRESSORS TO ONLY ONE

The specific power (kW/100 cfm) of a compressor increases at partial

loads, regardless of the type of capacity control system used. In the past, water-cooled, double-acting reciprocating compressors were readily available and generally had discrete steps of capacity output that achieved very good energy turndown at partial loads. Inlet valve unloading allows steps of 100%, 50% and 0%. The addition of clearance pockets can provide additional steps of 75% and 25%. This offered the best mode of trimming overall capacity with other compressor types operating at full capacity. Newer, more modern variable-speed-drive (VSD) compressors are now available that have turndown ranges that are equal to or better than multistage reciprocating compressors making these compressor a good choice for trim duty.

Where oil-injected rotary screw compressors are operating in parallel, each with inlet valve modulation, it is very inefficient to have all of them modulating at the same time. Controls should be set to have all but one compressor on load/unload control, with the set points arranged so that only the one compressor at a time will trim. This provides the most efficient control mode. Care must be taken to ensure that the compressors on load/unload control are capable of full capacity up to the unload set point. The compressors on load/unload control also should have a timer to stop the compressor when it has been running unloaded for a period of time, usually 10 min to avoid too-frequent starts, but keep the compressor armed for automatic start if the compressor is needed.

AVERAGE KW VS. AVERAGE CAPACITY WITH LOAD/UNLOAD CAPACITY CONTROL



Figure 1. With multiple fully loaded compressors, and only one part loaded unit, the required receiver capacity relates to the capacity of the partly loaded compressor.

Centrifugal air compressors are best used as base load compressors, with another type to accommodate the load swings. The use of inlet guide vanes is more efficient than an inlet butterfly valve on centrifugal compressors, but provision is still needed to start blowing off air at partial loads to avoid surge. Centrifugal compressors operating in discharge bypass control, blowing excess capacity to atmosphere to avoid surge, waste a significant amount of energy. Where possible, unloading the compressor is preferred.

The majority of new compressors of all types are equipped with microprocessor controls, which can be arranged for more precise monitoring and control. Most modern controls readily allow sequencing and can be easily tied in with centralized plant control systems. They also allow better tracking of required maintenance and more energy savings.

CASE STUDY

A large aerospace manufacturer had a system of three 350 hp, 1,500 cfm centrifugal compressors feeding its large aircraft parts plant. The plant had typical loads averaging 750 cfm during the day and 350 cfm during night and weekend operation. Due to a very high flow when the plant filled its autoclaves for parts, curing 3,000 cfm of compressed air for 10 to 15 min was required. Fill operations happened less than 10% of the time during the main shift. Unfortunately, due to the characteristics of the compressors, this fill required two running compressors all the time because compressor failures occurred when they tried shutting down one of the compressors on automatic start. The compressors would not run reliably in load/ unload mode so the units ran in inefficient modulation mode with blow-off. Operation in this control mode made the system specific power 55 kW/100 cfm, an extremely inefficient level.

The plant replaced these compressors with a system of four rotary screw compressors, two of which used VSD technology. The system used an efficient master compressor controller that matches the compressors to the load. The peak loads are now being supplied by a highpressure storage system. The new specific power for the system is 21 kW/100 cfm. The project is saving 2,380,000 kWh/year.



REMOVE INAPPROPRIATE APPLICATIONS

In general it takes the equivalent of 7-8 hp at the air compressor to produce 1 hp of shaft output at a

compressed-air-powered tool. At best this means the use

of compressed air for end uses is about 10-15% efficient, and much less if leakage is included. Due to this inefficient conversion of energy, it's expensive to use compressed air inappropriately for uses that could better be powered by some other energy source.

This applies to end uses that use high-pressure air for a low-pressure requirement. The energy used to compress air is not recovered when passed through a pressure regulator for outputting a lower pressure. Where the pressure has to be reduced below 80% of the compressor discharge pressure for a specific application, the application should be reviewed for an alternative air supply at a reduced pressure.

Equipment requiring air at 22 psi or less should be supplied by a blower rather than from a compressed air line. This includes air lances, agitation, blow guns, mixing, and pneumatic conveying. Blowers also may be used for regeneration of desiccant type dryers.

Fans, rather than vortex tubes, should be used for cooling electrical cabinets.

A vacuum pump should be used rather than a compressed air venturi tube.

An extensive list of potentially inappropriate applications can be found at:

http://www.compressedairchallenge.org/ library/tipsheets/tipsheet02.pdf

CASE STUDY

A large cabinetry plant was using compressed-airpowered vortex coolers on various electrical control panels to prevent overheating. Each cooler consumed 20 cfm continuously 24 x 7 at about 100 psi. An industrial engineer studied the coolers and found they were consuming the equivalent of 5 kW/cooler costing \$3,140/ year to operate. The engineer replaced the compressedair-powered coolers with thermostatically controlled refrigerant-style cabinet coolers that had the equivalent Btu capacity cooling, yet consumed only 0.5 kW, costing \$135/year to run. Simple payback on the conversion was 1.3 years.



REDUCE SYSTEM PRESSURE DROP LOSSES WITH PROPERLY SIZED PIPING, VALVES

Many existing compressed air systems weren't designed for their

present state but simply grew to meet plant expansion

needs, resulting in systems that aren't adequately sized for current demand. Many distribution piping systems are based upon the size of the discharge connection at the compressor and may be totally inadequate for the flow rate and length of pipe.

Air velocity at any point in the distribution piping should not exceed 50 ft/s (fps). To avoid moisture being carried beyond drainage drop legs in main distribution lines, branch lines having an air velocity of 50 fps shouldn't exceed 50 ft in length. Hoses and their connections often are inadequately sized, causing excessive pressure drop. The operating pressure drop between the air compressor discharge and the points of use shouldn't exceed 10% of the compressor's discharge pressure. A loop-type distribution system is recommended. Gate valves are preferred for their minimal pressure drop.

Aftercoolers, dryers, and filters should be sized for the full capacity of the compressors, and pressure drop across each item should be minimal. Particulate and coalescingtype filter pressure drop should be monitored regularly, and elements should be replaced before the pressure drop becomes excessive with substantial energy loss. Early element replacement costs can be recovered quickly by energy savings.

ONE WAY TO DETERMINE THE LEAKAGE RATE IN A SYSTEM IS TO DO SPECIAL TESTING WHEN ALL OF THE PRODUCTION EQUIPMENT IN THE PLANT IS SHUT DOWN.

CASE STUDY

A fiberglass parts manufacturer was having production issues with some air-powered cutters used to free the fiberglass parts from their molds. Tool performance was adequate at the start of the cut but the production rate fell steadily in a short period of time, especially if more than one cutter was used at the same time.

An air auditor studied how the tools were connected to the system. He found that the plant designers preferred to use long 50-ft hose reels to provide compressed air to the tools. These reels were connected to the main distribution system using quick-connect couplings at the input to the reel and at the tool.

The tools were rated to provide full performance at a pressure of 90 psi at the tool. To test the actual pressure, the auditor made up a pressure test gauge so the tool could be connected in series. The pressure at the tool with no air flowing measured about 110 psi. When the trigger of one of the cutters was pulled, the pressure fell to 55 psi, much lower than the tools needed. The pressure at the tool was improved to 90 psi through optimization of the connectors and hoses feeding the tool by removing component, shortening hoses, and increasing the size of the components.



REMOVE MOISTURE CONTENT OF COMPRESSED AIR WITH THE PROPER TYPE AND SIZE OF DRYERS

Different applications require different levels of pressure dew point. Air should be dried only to the level required by a specific application. Systems often have a dryer immediately after the compressor, drying all of the compressed air to a level not needed at many of the points of use. This is an unnecessary use of energy. Each application should be reviewed to determine the amount of drying necessary. Very often a refrigerant-type dryer having a pressure dew point of 38 °F is adequate for the majority of applications, although consideration must be given to distribution piping and drains, which may be exposed to temperatures below freezing. Only the air going to an application requiring a lower pressure dew point should receive further treatment.

The location of a dryer relative to an air receiver is debatable. An air receiver between the compressor and the dryer may provide some radiant cooling and separation of condensate and lubricant. However, an intermittent demand for compressed air in excess of the compressor and dryer rating, will result in the dryer being overloaded and an increase in the pressure dew point. Location of the air receiver after the dryer ensures that the air flow through the dryer doesn't exceed its rating and dry air is stored in the receiver to meet any intermittent demand. In some systems, a receiver at both locations can be worth the investment.

The pressure drop through the dryer also should be determined and monitored as the resulting back pressure can cause the air compressors to cycle more frequently, resulting in less efficient operation.

A refrigerant-type dryer may not require any filtration before or after it, whereas a desiccant-type dryer requires a coalescing filter before it to protect the filter bed and a particulate filter after it to stop carryover of desiccant fines. These filters cause additional pressure drop and must be maintained. Desiccant-type dryers also require the use of purge air for regeneration, and the quantity of purge air must be considered in sizing of the air compressors. Dew point control systems and other strategies are available to minimize the amount of purge air needed. In some cases, a blower or a vacuum purge system can be used more economically.

CASE STUDY

A tire shop had a small compressed air load made up of the tools and equipment required to service automobiles, large trucks, and tractors. One compressed air line went outdoors to feed a tire-filling station. A main desiccant air dryer removed moisture from all the compressed air in the shop to a level of -40, so the line would not freeze in winter months. An air audit at the shop showed that, while the average compressed air load in the facility was only 9 cfm, the compressor actually produced an average of 28 cfm. An investigation showed that the uncontrolled heatless air dryer installed in the shop was consuming an average of 19 cfm or 68% of the total output of the compressor. A refrigerant air dryer was purchased and a small point-of-use zero purge air dryer was installed for the outdoor supply line. The reduction in compressed air demand saved 70% in compressed air electrical costs.



REMOVE CONDENSATE WITH-OUT LOSS OF COMPRESSED AIR Various means are used to drain off condensate from dryers, air receiv-

ers, filters, and header drop legs.

The amount of condensate will vary with geographic location and atmospheric conditions of temperature and relative humidity. Drain traps should be sized for the anticipated rate of accumulated condensate and chosen for the specific location and anticipated contamination by lubricants being used.

The relatively common practice of leaving a manual drain valve cracked open shouldn't be tolerated as it wastes compressed air. For all types of drain traps, bypass piping is recommended to facilitate proper maintenance.

Float-type drain traps. The mechanical nature of floattype devices combined with the contaminants present in condensate make these devices an ongoing maintenance item, often neglected. The float is connected by linkage to a drain valve, which opens when an upper-level setting is reached and closes when the drain is emptied. The float device varies from a simple ball to an inverted bucket, but the basic principle is the same. An adequately sized drain valve is essential for satisfactory operation and to prevent blockage. A float which sticks in the closed position won't allow condensate to be drained, while a float which sticks in the open position will allow the costly loss of compressed air. Electrically operated solenoid valves ("time cycle

blowdown"). A solenoid-operated drain valve has a timing device that can be set to open for a specified time and at specified intervals. Again, the size of the valve and any associated orifices must be adequate to prevent blockage. The valve is set to operate without reference to the presence of condensate or lack of it. The period during which the valve is open may not be long enough for adequate drainage of the amount of accumulated condensate. On the other hand, the valve can operate even when little or no condensate is present, resulting in the expensive loss of compressed air.

No air loss or zero air loss drain valves. These use a magnetic reed switch or a capacitance device to detect the level of condensate present and operate only when drainage is called for. When an upper-level inductance sensor detects liquid, the microprocessor opens a solenoid. A lower-level inductance sensor signals for the drain to be closed.

It's vital to maintain traps and drains in good operating condition. If the drains and traps are clogged, condensate will fill vessels and pipes in a short period of time and be carried over into the system in the form of liquid water, and may:

- cause corrosion and deposits in the air receiver
- prematurely exhaust the capacities of pre-filters and desiccant dryers
- overload refrigerant-type dryers
- cause moisture accumulation in the system piping, resulting in corrosion
- cause malfunction of air-operated valves, making operation sluggish or erratic
- wash away lubricants from operating cylinders of air-operated valves or other similar equipment
- cause some of the lubricants used on solenoid valve
 O-rings to become sticky or gummed up, causing the solenoid valve to become inoperable.

Also, some of the system piping may be installed outdoors and exposed to varying ambient temperatures. Accumulated water may freeze during winter and cause damage to piping and instruments.

CASE STUDY

A timer drain at a pharmaceutical company was set to drain the air dryer water separator at regular intervals to avoid water carryover. The backup compressor feeding the air dryer had a sophisticated control designed to sense rapid changes in pressure and start the compressor in response to ensure the compressor could rapidly

load before the pressure fell below its load set point. The timer drain had a large drain orifice that consumed a significant amount of air, enough to cause a change in pressure when it drained. Due to this pressure fluctuation, the compressor would start but not load. The timer drain frequency was such that the compressor constantly ran unloaded consuming 90,000 kWh/year.



REDUCE DOWNTIME THROUGH PREVENTIVE MAINTENANCE Prevention is better than cure.

Neglect can lead to costly downtime of production equipment and

more extensive repairs. Manufacturers' recommended maintenance items should be required, documented, and reviewed regularly for the development of any trends.

The use of compressor synthetic lubricants, stated to be good for 8,000 hours of operation, doesn't mean the associated lubricant filter and air-lubricant separator also are good for the same period. The pressure drop across lubricant filters and separators should be monitored regularly. Records may indicate a normal interval between changes, which may then be planned. Some compressor microprocessors will signal required maintenance, and this should not be ignored.

Automatic condensate drains must be checked regularly to ensure satisfactory operation.

CASE STUDY

A foundry making railway wheels couldn't keep the pressure up in the plant, even with all four of the compressors running. The liquid coolers in their compressors had become so dirty that the compressors couldn't run at full load so had to be modulated down to lower output. The overly hot air produced by the compressors and dirty dryer coolers caused the air dryers to constantly trip off. The plant loading had increased to a point where low pressure was a constant problem. The site was forced to rent and operate three expensive diesel compressors just to keep up.

Investigation revealed that inadequate management had allowed the leak level to increase to a point where 1,100 cfm of compressed air was being used on the weekend, even with no production. Poor maintenance practices had allowed the compressor set points to drift so badly that one compressor wasn't even loading when pressure was low. Another had developed a problem that kept its inlet valve closed, greatly reducing its output.

Repairs, replacements, and adjustments were done to coolers, cooling water quality, compressor controls, and

leakage levels, including finding and fixing a 550 cfm leak in a baghouse. Annual savings were measured at \$90,000/year, not including diesel compressor fuel and rental costs. The plant is now running on three compressors.



RECORD SYSTEM DATA AND MAINTENANCE

All maintenance items should be recorded and the records analyzed, so that timely preventive measures

can be established. In addition, records should be kept of all operating pressures before and after major components and at strategic points in the system. These will indicate potential problem areas requiring corrective action.



REVIEW AIR USAGE PATTERNS REGULARLY

Recording operating pressures at strategic points throughout the system can reveal changes in usage

but may not adequately indicate the rate of change of pressure due to changes in demand. Data logging can help in this area.

Over time, new production machines may be added, while others may be eliminated. The person responsible for the compressed air supply needs to be kept informed of such changes, which may require upgrades to the compressed air system, including plant expansion, rather than waiting until a problem develops. Low pressure at a point of use may not require additional compressor capacity; the problem may be due to fluctuating demand at another point of use, and the problem could be solved by the addition of a secondary air receiver close to that application.



RECOVER HEAT

The majority of rotary air compressor packages are air-cooled, and it's estimated that, of the total power, 80% results in heat to the oil cooler

and an additional 13% to the air aftercooler. This provides a substantial potential for heat recovery.

The atmospheric air blown across radiator-type coolers can be used for space heating of plants in cold weather conditions. An additional fan may be needed to supply the necessary pressure head for ducting and distribution of this air.

In some water-cooled compressor applications, water heating has been accomplished for use in the plant.

CASE STUDY

A small company reconditions propane bottles for resale at various depots throughout its territory. The plant uses a 25-hp air compressor that produces the equivalent of about 15 kW of heat in average conditions. During reconditioning, the propane bottles are painted and dry while hanging on an overhead conveyor. The compressor heat is captured and redirected to the propane bottles to assist in heating the make-up air and drying the paint. The remainder of the heat is redirected to the facility production areas to help to displace building heat. The building has all electric heating so the compressor heat displaces the equivalent kW loading. Estimated savings are \$2,500/ year in electric heating costs.



REDUCE ENERGY COSTS (RETURN ON INVESTMENT AND COST OF OPERATION)

The whole objective of The Compressed Air Challenge is to reduce

the energy consumed by compressed air systems. Implementation of the recommendations can result in some compressors being shut down and used for standby. The resulting savings in the cost of operation go right to the bottom line of a company's financial statement.

In addition, the right amount of air at the right pressure and of the right quality will enhance product quality, reducing defects, scrap, and warranty costs. Customer satisfaction will be improved.

Following the 14 Rs results in an efficient compressed air system that pays dividends. ©

This article is based on a paper by David M. McCulloch, retired, and modified by Frank Moskowitz, Draw Professional Services, and Ron Marshall, Manitoba Hydro.



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Marshall is a certified engineering technologist in the province of Manitoba and has received certification as an energy manager, demand side management and measurement and verifica-

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COMPRESSOR PROBLEM SOLVING

2 case studies with a centrifugal compressor and an integrally geared compressor

By Amin Almasi, Rotating Equipment Consultant

It's critical to look properly at all potential causes for a compressor problem in a plant. It's amazing how much we don't know about what we don't know. It's interesting how much operators don't know about compressors they've operated for many years. It's also amazing how much compressor engineers don't know about the operation of the rest of the plant where they've worked for years. Therefore, it's critical to get input from other engineers and technicians who notice the problem, who are affected by it, and who are actually related to it.

It's often useful to collect input from other engineers one at a time. Otherwise, for example, in a formal meeting, engineers or operators tend to be inhibited about offering their impressions of the real causes of problems.

It's generally a good practice to identify alternatives for approaches to resolve a compressor problem. In other words, brainstorm for solutions to a problem. Brainstorming is collecting as many ideas as possible. And the next step is screening them to find the best idea. Other important aspects of the compressor problem-solving process is continual observation and feedback.

CASE STUDY 1

This case study is about the inter-section temperature measurement for a centrifugal compressor with a sidestream to measure temperature inside the compressor before and after the sidestream. The operator team claimed that inter-section temperature measurements weren't provided and they were unable to determine the actual compressor performance and monitor the compressor operation. They also highlighted they were unable to detect emerging problems or properly adjust the anti-surge system because of the lack of the intersection temperature measurement. This is a request that a machinery engineer may face for any compressor with a sidestream.

A quick assessment of any conventional-type centrifugal compressor with a sidestream can show that installing temperature measurement sensors inside the compressor is a very risky task that requires lots of effort. It's an extremely difficult task to provide direct temperature sensing for the process gas inside a compressor in predefined locations of a complex mixing section. The compressor can be seriously damaged or even destroyed in the modification process at site.

Investigations showed that temperatures inside the compressor, before and after sidestream mixing, aren't necessary to estimate power and performance of a centrifugal compressor with a sidestream. The following equation can be used to calculate the power and efficiency of a centrifugal compressor with a sidestream (Figure 1).

$$PCOM = m_3 h_3 - m_1 h_1 - m_2 h_2$$
 (Equation 1)
= $(m_1 + m_2) h_3 - m_1 h_1 - m_2 h_2$

Where:

PCOM represents compressor power (with a sidestream) m represents mass flow h represents enthalpy

The isentropic efficiency could be calculated by comparing the ideal power and the actual power.

To better explain the presented method, the compressor performance can be viewed as an overall performance — a compressor overall efficiency — which includes the stages (impellers) from the inlet to the sidestream (Section 1), the sidestream mixing section, and the stages (impellers) from the sidestream to the outlet (Section 2). For a compressor with a sidestream, there are some losses at the sidestream mixing section. The overall efficiency of a centrifugal compressor with a sidestream is lower than one for a comparable centrifugal compressor without a sidestream.

Based on experiences, unfortunately, some compressor manufacturers calculate the efficiency of compressors with sidestreams, neglecting the sidestream mixing section losses. They just simulate impellers and sections without any losses in sidestream mixing sections. Alternatively some other vendors may consider these losses but with inaccurate methods, which result in losses lower than actual ones. This also helps vendors to claim better efficiency and performance, which may be good for their sale and advertising. The compressors with sidestreams are usually used in special processes such as ammonia, syngas, or propane, where the ASME PTC-10 type-1 performance test cannot be implemented in the vendor shop. The ASME PTC-10 type-2 test has many shortfalls for compressors with sidestreams, and this test can't identify the above-mentioned efficiency gap. The unrealistic efficiencies claimed by vendors never tested before the commissioning of the plant. This efficiency gap between the actual performance and the vendor-claimed efficiency, due to sidestream mixing section losses, has been identified for many compressors. A machinery engineer should always expect this efficiency gap for any compressor with sidestreams.

The compressor theoretical efficiency depends on many details such as the impeller specific-speed and impeller design, as well as details of sections, but this is usually limited to approximately 70–79% for a compressor with traditional 2D impellers. Many compressors with sidestreams, using conventional 2D impellers, have claimed efficiencies in the range of 72-77%. However, the actual efficiency for these machines could be 65-71%, and for some machines even below 65%. The reason is the losses in mixing sections. These losses are relatively high if mixing sections were not designed properly or in cases that there are operational deviations. When operating process conditions in inlet or sidestream don't fully match with design conditions, much higher losses, compared to losses at design conditions, can be expected. For example, pressure deviations at a sidestream — sidestream pressure lower or higher than the rated pressure — can result in great losses and operational problems.

Another issue is that the operation team needed the temperature after the sidestream to properly operate and adjust the anti-surge system. The fact is the gas tem-

perature after the sidestream can be properly estimated using compressor formulations — no need for the direct measurement. The following equations can be used for the mixing section:

$$P_{A}=P_{B}=P_{C} (Equation 2)$$

$$m_{C}=m_{A}+m_{B} (Equation 3)$$

$$h_{C}=(m_{A} h_{A}+m_{B} h_{B})/m_{C} (Equation 4)$$

Where:

A represents the discharge of Section 1 B represents the sidestream C represents the mixed suction to Section 2 m represents mass flow P represents pressure T represents temperature h represents enthalpy T_c can be found by working back through the gas property — for example, Mollier diagram — knowing h_c and P_c : $h_c = (m_A h_A + m_B h_B)/m_c$ (Equation 5) T_c may also be approximated by the following rough formulation:

 $T_c = (m_A T_A + m_B T_B)/m_c$ (Equation 6) Section 1: from suction to sidestream. Section 2: from sidestream to discharge.

INTEGRALLY GEARED COMPRESSOR

An integrally geared compressor for a critical service in a plant could not achieve 99% availability defined by the risk assessment team for the commercial viability of the plant (Figure 2). The team asked what should be done to this machine to achieve availability greater than 99%. Investigations showed a backup, or standby, compressor for this machine is necessary, if 99% availability should be achieved. There are many options — for example, an oil-flooded screw compressor, another similar integrally geared compressor, or a conventional-type centrifugal compressor. After a study of all options, the best recommendation was to buy a backup, or standby, compressor that uses the similar compressor model with an improved packaging concept. The new compressor will be a standby, or backup, machine. This should be similar to the existing compressor model to reduce spare parts and operational and maintenance complexity. This selection can also provide a reasonable cost because an integrally geared compressor is cheaper than a comparable conventional-type centrifugal compressor.

The following improvements were recommended for the compressor package:

- Two identical E-motor driven lubrication oil pumps should be used instead of a single pump in the existing compressor package (electric power supplied from different electrical sources).
- The existing compressor used an inlet throttle valve (ITV) for the capacity control. A better capacity control method, inlet guide vane (IGV) system, should be used.
- 3. Combined anti-surge/control system is recommended. The proposed control option is a combined control system, rather than two independent control loops, used in the existing package. This control solution should use the anti-surge valve (bypass) only for the anti-surge application. This can eliminate the root cause of some control issues. Trip and alarm parameters and limits should also be improved for a better operation.
- 4. An optimum and improved system of condition monitoring for the package, including compressor and electric motor, should be considered. Online vibration monitoring should be provided for the electric motor.

This new compressor skid can also be used as an example to improve the existing skid.

Another proposal was to purchase a spare bare compressor (compressor frame) and keep it in the warehouse for a quick compressor replacement in case of any issue. This proposal was rejected.

More than 65% of all compressor package issues and problems are related to auxiliaries and accessories, rather than the compressor frame itself.

A spare machine, not a spare part, should always be installed and operational. It is a mistake to buy a machine, such as a pump or a bare compressor, and keep it in the warehouse. There were cases in which a spare machine in the warehouse couldn't be matched inside its package. In most cases, machines were damaged or destroyed in the warehouse. Machines are complex and delicate systems and require constant attention and monitoring to make sure they will work when needed.

CASE STUDY 2

The operations team reported a poor temperature control of a lubrication oil system in a critical compressor package. They asked for a new three-way temperature control valve with internal thermostat to replace the existing two-way valve and modify the existing lubrication oil system. The lubrication oil system of this machine has a two-way temperature control valve (TCV) supplied by a



POWER AND EFFICIENCY

Figure 1. This schematic shows a conventional-type centrifugal compressor with a sidestream.

reputable valve vendor in a cooler bypass line. There is a separate temperature sensor at downstream and a dedicated control loop. This TCV and temperature control arrangement is acceptable as per API-614. Changing this valve to a three-way temperature control valve cannot be a good idea. The three-way temperature control valves with internal thermostat had been used in lubrication oil systems of many rotating machines. The operations team had experiences with those machines and assumed that those lubrication systems didn't have temperature control problems because they used three-way valves with a special trade name. However, the performance and reliability of these three-way temperature-control valves with internal thermostat are actually not better than the two-way temperature control valves in the cooler bypass line, such as one installed in this oil system. It should be noted that, as per API-614, the oil bypass valve should be a flanged and pneumatically operated (air-to-open fail-close), and both a two-port or three-port temperature control valve are acceptable. In fact a two-way temperature-control valve installed in the cooler bypass line is the recommended design in API-614, and theoretically this could be considered a better solution compared to some three-

IN A FORMAL MEETING, ENGINEERS OR OPERATORS TEND TO BE INHIBITED ABOUT OFFERING THEIR IMPRESSIONS OF THE REAL CAUSES OF PROBLEMS.



INTEGRALLY GEARED COMPRESSOR Figure 2. This integrally geared compressor is a well-designed package that can achieve a high availability.

way temperature-control valves with internal thermostat. The three-way temperature control valve with an internal thermostat is also acceptable, but as an alternative option.

The operation of the TCV and control system was investigated. The operational investigations showed the twoway valve needed maintenance and some adjustments after many years of operation. The valve performance was acceptable after this brief adjustment. @



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MONITOR TO KEEP THE AIR PREDICTABLE

PdM keeps compressed air systems running efficiently

By Mike Bacidore, Editor in Chief

Operating a compressed air system can be costly, if routine monitoring isn't done. PdM technologies and strategies can be used to improve efficiency and avoid failures.

Clogged compressed air filters and leaking or failed condensate drains can cause contamination problems in downstream components and even contaminate the product itself, if it comes in contact, explains Ron Marshall, member of the project development committee, Compressed Air Challenge (www.compressedairchallenge.org). "Pressure differentials on main filters can be monitored during regular maintenance and changed before they cause problems," he says.

Equipment monitoring is an effective strategy to improve compressed air system efficiency and avoid costly downtime, says Brian Blum, CTS optimization marketing/Department of Energy - Airmaster+, Atlas Copco Compressors (www.atlascopco.us). "Compressed air systems can consume up to 40% of the total energy a plant consumes on a yearly basis," he explains. "Advanced data monitoring provides plant operators with the tools to recognize and react in real time."

Compressed air systems can be the source of large hidden expenses within a facility, warns Trent Phillips, condition monitoring manager, Ludeca (www.ludeca. com). "A lot of facilities install additional compressed air systems, because their existing systems are unable to supply the required demand," he explains. "However, no one ever asks why the additional capacity is required. Have additional processes been added or other things that require additional air capacity? Or is it simply due to a lack of maintenance?" Proper maintenance of compressors would include monitoring of the bearings, explains Maureen Gribble, director, UE Systems (www.uesystems.com). "Ultrasound is commonly used to monitor bearings and provides early indicators of bearing failures," she says. "With bearings comes the need for lubrication, another area where ultrasound is an extremely effective tool. By utilizing ultrasound as a part of a reliability-centered lubrication program, you can determine exactly when your bearing requires lubrication."

Most leaks are found at pipe, hose, or tube connections, says Kirk Edwards, application engineer, Exair (www. exair.com). "Make certain to apply thread sealant correctly and install the connections per their instructions," he explains. "Leaks can also be minimized by making sure to use as low an air supply pressure as possible; the lower the working pressure, the less air will escape a leak."

Checking the compressors and pumps using vibration analysis will provide lots of benefit, says Michael D. Howard, MSc, CMRP, director, reliability solutions, Mobius Institute (www.mobiusinstitute.com). "An online vibration monitoring system may provide critical analytical data to allow you to plan and schedule maintenance on your terms, rather than the machine's," he suggests. "At the very least, regular monitoring using route-based

EQUIPMENT MONITORING IS AN EFFECTIVE STRATEGY TO IMPROVE COMPRESSED AIR SYSTEM EFFICIENCY AND AVOID COSTLY DOWNTIME.

vibration analysis will enable the organization to ensure the asset is running at design efficiency between scheduled data collection intervals."

Using an adaptive system master controller helps spread out maintenance intervals, offers Waheed Chaudhry, engineering manager, Kaeser Compressors (us.kaeser. com). "In addition to selecting the most energy-efficient combination of units to meet current demand, they also balance load hours among multiple units," he explains.

Pipe thinning is a hidden defect, and it takes place before a leak develops, says T.J. Garten, subject matter expert — electrical, Allied Reliability (www.alliedreliability. com). "Pipe thinning usually occurs in the area of elbows and where the pipe size changes step up or down; the air turbulence is greater in these areas," he explains. "By monitoring and detecting pipe thinning, piping can be scheduled to be replaced before leaks occur." The most common faults with rotating machines are imbalance, misalignment, looseness, and roller bearing wear, explains John Bernet, vibration product specialist, Fluke (www.fluke.com). "Using vibration meters to quickly screen these machines will give the operators and technicians the peace of mind they want that the machine will keep running, or they may need to take a closer look," he says.

Each PdM technology provides benefits to maintaining and operating a compressed air system, explains Daniel J. Hogan, vibration/oil analyst, Azima DLI (www.azimadli.com). "However, these technologies are best leveraged when used together in an integrated manner," he says. @

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PDM APPLICATIONS TO IMPROVE COMPRESSED AIR EFFICIENCY

By Mike Bacidore Editor in Chief

Compressed air systems comprise some of the most necessary and the most expensive equipment in an industrial plant. It just makes sense to monitor their condition with predictive-maintenance (PdM) technology to ensure operation is optimized. While no system is 100% perfect, getting as close to perfect as possible can be a big money saver.

Detecting air leaks is a given. That hiss is the sound of profits escaping and floating off. Lubrication and pump issues also are prime candidates for monitoring in a PdM program. But there might be a few applications of PdM technology that you hadn't considered for making your compressed-air system more efficient.

"On the electrical side, infrared cameras can detect electrical issues, such as loose or corroded connections revealed by temperature differences seen by a thermal camera," says Joe LiPetri, communications manager, Flir Commercial Systems (www.flir.com). "Technicians often perform quick hotspot scans of systems such as primary switchboards, distribution boards, control panels, fuse boxes, electrical cabinets, and motor control systems."

Thermal cameras are most effective in company cultures that embrace preventive practices engineered to increase uptime, as opposed to reactive programs designed to respond only when something goes wrong, explains LiPetri. "Evaluating equipment on a periodic basis provides more insight by establishing a baseline reference of equipment operating under normal conditions, which enables technicians to see right away when systems are not running properly," he says. "PdM professionals who use thermal cameras often use them in conjunction with test equipment to monitor power quality and electrical factors, such as current loads. Combining temperature data from a thermal camera with electrical readings from a clamp meter, for example, can provide more insightful troubleshooting and reporting so that repairs are made correctly and quickly. The combination of thermal imaging and test and measurement enables PdM professionals to detect emerging issues and keep systems operational, according to their schedules. This organized approach to PdM can significantly reduce and prevent premature and unexpected equipment failures of air compressor systems, thus maintaining production levels, reducing unplanned failures, extending equipment life, and ensuring worker safety."

All of the standard PdM technologies apply to the motor side, says Scott Dow, senior instructor, Mobius Institute (www.mobiusinstitute.com). "Infrared can also be useful in finding hotspots on the high-pressure piping side and other areas," he explains. In those cases, you won't necessarily know what you're looking for until you find it."

Analysis of performance indicators, such as pressure drops in an area of the system, helps predict problems and reveals where production can be optimized to increase efficiency and save energy, advises Brian Blum, CTS optimization marketing/Department of Energy -Airmaster+, Atlas Copco Compressors (www.atlascopco. us). "If knowledge is power, knowing exactly how the compressed air system is performing at any time gives facility managers the power to identify ways to improve the system quickly and easily," he says. "A 24/7 real-time monitoring system provides the information needed to accurately assess system performance and determine a course of action to improve system usage and efficiency while minimizing downtime."

Applying condition monitoring to compressed air systems ensures on-demand availability and eliminates the hidden costs that occur when these systems are not correctly maintained, explains Trent Phillips, condition monitoring manager, Ludeca (www.ludeca.com). "Several condition monitoring technologies can be utilized to ensure the availability and manage the costs associated with compressed air systems," he says.

Regularly checking condensate drains and pressure drop across filters are also simple examples of predictive maintenance, suggests Waheed Chaudhry, engineering manager, Kaeser Compressors (us.kaeser.com). "If you notice that the condensate drains need to be drained more frequently, this could be indicative of problems with an aftercooler, or that the compressor is not coming up to a high enough operating temperature," he advises. "Likewise, pressure drop across filters can indicate that the filter cartridge needs to be changed. If you are changing filters more often than normal, you should consider looking for the cause of the extra contaminates — perhaps piping is corroded or a receiver tank is rusted. Pressure drop often creates production issues, such as poorly operating equipment and high scrap rates."

Most compressor air systems are driven by ac induction motors, notes Daniel J. Hogan, vibration/oil analyst, Azima DLI (www.azimadli.com). "Motor current analysis (MCA) can be an effective, powerful, and complementary tool to monitor the motor end of a compressor system when used with vibration analysis," he explains. "Motor current analysis can be used to confirm and accurately qualify the severity of cracked rotor bar condition with ease. Together, MCA and vibration analysis can help justify the removal and overhaul before a failure, avoiding the possible complete destruction of the motor end."

Ron Marshall, member of the project development committee, Compressed Air Challenge (www.compressedairchallenge.org), reminds us of the importance of ensuring compressor controls are fully functional. "Mr. Fixit resides in every plant," he explains. "He can easily screw up the operation of the simplest compressed air system control by pushing the buttons with his curious fingers or tweaking the controls with his handy-dandy pocket screwdriver. Monitoring compressor power and flow over time and calculating the compressor 'gas mileage' or specific power can be an excellent indicator of problems due to misadjustment or control failure." @





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WALK THE BASELINE

By Mike Bacidore Editor in Chief

A compressed air audit is the first step toward figuring out a baseline and then determining how to fashion a more efficient system, but many plant managers don't know how to begin that process. Sometimes, it's as simple as picking up the phone or surfing the Internet.

"The first step in having a compressed air audit done is finding a competent compressed air auditor," says Ron Marshall, member of the Project Development Committee at the Compressed Air Challenge, which has a resource document located at www.compressedairchallenge.org/ library/guidelines.pdf to help users to decide on a service provider. "Consider having a low-cost walk-through audit done first to help determine if any major issues exist that would justify the cost of a more expensive full compressed-air audit. The most attractive service providers are independent operators with significant proven experience in providing successful solutions. Some energy organizations or utilities have grants to help pay the cost of the studies; your local auditors will know about these."

Communication at the beginning of the process is critical, says Rick Stasyshan, technical consultant at the Compressed Air and Gas Institute (CAGI, www.cagi.org). "We have found it's essential that user and auditor be in synch with the audit's objectives and understand the possible outcomes. It's also important that the facility understands that achieving optimum performance from their compressed air system will most likely take some paradigm shifts," he says. "This may include modifying some current plant practices causing system inefficiencies, improving the maintenance of the system, and potentially investing in some system upgrades. While this last point sometimes causes some anxiety with the system owner, the audit results often demonstrate amazing return on investment with energy saving paybacks when implemented. It is also key to alert the entire location staff about the purpose and intention of the compressed air audit, thus preventing data loggers from being turned off or tampered with."

The first step is to identify specific problems and goals, explains Neil Mehltretter, system design manager at Kaeser Compressors (www.kaeser.com). "Are there specific problems that need to be addressed, or are you hoping to discover opportunities for improvement?" he asks. "Examples include fixing pressure fluctuations to improve system reliability, reducing energy costs, moisture issues, finding leaks, supply side controls, and demand side waste. If multiple managers are involved, get agreement on the priorities. Knowing what you want to do will help you select the right auditor and ensure they apply the right tools."

Gather all information you have on your system, including the type, model, size, and age of compressors, controls, dryers, tanks, and other air system components, piping schematics, system or building drawings, if available, suggests Mehltretter. "Identify the uses of compressed air and provide a brief history of any significant air-related problems in the plant," he offers. "Most equipment suppliers offer quick, low-cost surveys intended to open the door for sales opportunities. Many of these also offer more detailed, customer-focused audits. In both cases, these are supply-side studies. They only look at the compressed air system. Demand-side studies address the uses of the compressed air, looking for wasteful practices, but there are relatively few compressed-air professionals who have the experience to evaluate plant processes, as well. Leak-detection studies straddle the supply/demand line, because leaks occur all the way from the main header to points of use."

The first step toward having a compressed air audit conducted at your plant is determining who you will hire to perform the audit, reminds Bob Baker, senior marketing support specialist, Atlas Copco Compressors (www. atlascopco.com). "Energy audits come in all shapes and sizes, and providers should be considered carefully," he says. "Before hiring a company to perform a compressed air audit, ask questions. Be cautious of how the audit will be performed and by whom. Find out if the company will evaluate the complete system, including both the supply and demand sides. Ask what kind of report will be provided following the audit, and find out whether or not the company offers a post audit or an annual PM check-up study. Also, ask if the company will help fix inefficiencies that are discovered during the audit. Most importantly, make sure the audit can be performed when the systems are running normally, ensuring that there is no need for any downtime." @

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AIR AUDITS ON A BUDGET

Low-cost, low-tech ideas to improve compressed air system operation and efficiency

By Ron Marshall, Compressed Air Challenge

Is your budget so tight you can't afford to bring in a compressed air auditor? There are a number of low-tech and low-cost ways to assess your system to get a good idea of your current operating costs, system efficiency, and level of system waste. Once you know your numbers, you can even predict possible savings for some common compressed air efficiency measures. Why wait when you can do it now and start the process of harvesting some low-hanging fruit?

A definite first step in understanding your system is to understand the supply side and how the compressed air is produced. Effective assessment methods should look at the supply and demand parts of the system. A good learning opportunity is to take part in one of Compressed Air Challenge's Fundamentals of Compressed Air Systems seminars.

DRAWING A BLOCK DIAGRAM

The first step in assessing your system is to draw out a block diagram of your supply side and some elements of the demand side so you can start to understand how things are connected and how the compressed air flows through to the end uses. On your block diagram, you'll need to collect and record relevant information about your compressors, air dryers, filters, and storage receivers (Figure 1). This will give you a resource from which you can do calculations or ask questions of your compressor supplier or service provider. An important piece of information is compressor nameplate data. Through this information you can learn the type of air compressors you have, their pressure ratings, their rated power consumption, and how much air they can produce.

CONTROL MODE

One of the things students of the CAC's Fundamentals seminar learn is the differences in the various compressor control modes. These modes of operation and the way each compressor is set up to operate within a system often are the most important elements in producing compressed air efficiently. In fact, one of the key ways to optimize your compressed air system is to produce the compressed air in the most efficient manner possible.

For the purposes of this article, we will deal with lubricated rotary screw compressors, the most common type of compressor in the industrial market. This leaves out centrifugal compressors and multistage reciprocating units. Lubricated rotary screw compressors can operate in one of five capacity control modes:

- start/stop
- inlet modulation
- Ioad/unload
- variable displacement
- variable speed

To complicate matters, some compressors can operate in a number of these modes at the same time. Let's assume for our purposes that any compressors used in examples will be in one mode only.

An air compressor has to be controlled because, if you think about it, it is very rare that a fully loaded compressor will exactly match the plant load in a facility. If the compressor were left uncontrolled, it obviously would

not start when there were low pressure; if it were manually started and left to run at full load, it would push the pressure up to extreme values until something blew up. Of course this is not what we want, so the compressor manufacturers have figured out various ways to control the compressors automatically by limiting the output in some way to match the compressed air load. Determining which control mode you're using is important because each has different characteristics. If you don't know, you should ask your compressor supplier.

BASELINE ENERGY AND COST

Making a block diagram tells you what you have; the next items you need to calculate are how much energy the system is consuming and how much it's costing. The second step in the road to improvement involves creating a baseline for determining your energy consumption. This step involves taking basic electrical measurements or estimating the electrical consumption. In addition, determine annual operating hours. For more accurate cost estimate results, you'll also need a copy of your most recent electrical bill.

For most operating modes, it's fairly easy to get a rough idea of each compressor's energy consumption. The tricky part is estimating how much compressed air flow each compressor is producing so you can estimate the supply system efficiency, expressed as specific power (kW per 100 cfm produced). The method of measurement depends on how accurate you want to be, with the highest accuracy costing the most money.

Measuring the compressor power consumption is best done using a three-phase kW meter. If measuring an air compressor for baselining without a kW meter, there is a standard formula to use to estimate the power consumption from measured Amps and Volts:

$kW = (A \ x \ V \ x \ 1.732 \ x \ PF) \ / \ 1,000$

Where:

- A = average Amps of all three phases
- *V* = average line-to-line voltage
- PF = measured or estimated power factor (Power factor at full load often can be taken from the main compressor nameplate. If not known, use 0.85 at full load and 0.6 in the unload position.)

Measuring electrical parameters shall always be done by qualified personnel using the appropriate personal protective equipment and approved safety procedures.

BLOCK DIAGRAM



Figure 1. The first step in assessing your system is to draw out a block diagram of your supply side and some elements of the demand side so you can start to understand how things are connected and how the compressed air flows through to the end uses.

PRESSURE PROFILE



Figure 2. Pressures can be measured at the various points and should be taken at the same time and frequency as the power readings; therefore, the best accuracy is gained using data loggers, but careful manual readings can suffice.

To estimate the power consumption of compressors in start/stop, modulation, capacity control, and VSD modes, a number of measurements need to be taken at various times to estimate the power for the full operating profile. For these control modes, the power factor used in the formula remains fairly constant and would be near nameplate values. For compressors in load/unload mode if the Amps fall below about 70% of full load, the power factor used in the formula should be reduced to about 0.60. Measurements can be done manually, but for best accuracy, data loggers should be used and average Amps and voltage determined from the data output based on many measurements over a long period of time.

SUPPLY AND DEMAND





PRESSURE BAND



Figure 4. Compressors with modulation control operate within a fixed pressure band, typically 10 psi wide. At the low end of the pressure band, a compressor with a functional and properly maintained control system will be outputting full load. At the high end of the pressure band, the output of the compressor will be at its fully modulated flow.

To calculate annual kWh consumed by the compressor you need to determine how long in a year the compressor is running in the average conditions. This can be estimated using the compressor hour meters, if these have been recorded for maintenance purposes, or simply by observing the compressor operating hours and sitting down with a calendar and counting the days of operation per year. From this, the annual hours and energy costs can be calculated:

Annual cost = average kW x annual hours x blended power rate

The blended rate can be estimated by looking at your monthly power bill and doing some basic calculations.

Taking the total billed amount and dividing by the number of kWh used is a good estimate to use for initial cost analysis. Power companies complicate matters by charging for time of use, charging different rates for different blocks of power, and applying demand charges, but for these rough blended cost calculations, we will ignore this.

Other items in your compressor room consume power, the most significant of which are the air dryers. If the air dryers are the refrigerant type, the power consumption of these should be measured and added to the baseline power and energy calculations, too.

BASELINE PRESSURE PROFILE

The most important issue in a compressed air system is providing the end user with adequate pressure to do the intended job. One or two end users will seem to need higher pressure than all the rest. These can cause the compressor discharge pressures to rise to higher levels. The higher the pressure, the more it costs to produce the air, because, for systems operating near 100 psi, for every 2 psi in higher pressure, the air compressors consume about 1% more power.

Pressures can be measured at the various points as indicated in Figure 2. These measurements should be taken at the same time and frequency as the power readings; therefore, the best accuracy is gained using data loggers, but careful manual readings can suffice. Accurate calibrated pressure gauges should be used; digital units are fine, but often, quick variations in pressure can't be detected without using standard mechanical gauges.

The more readings taken, the more accurate the profile. Since you're looking for the worst case pressure profile —because this is what sets the required compressor discharge pressure—the pressure readings should be taken during the highest system flows. These readings are useful in determining what savings might be gained by optimizing your system through reducing pressure differentials and compressor discharge pressure.

Be aware that many end users are connected to the system. To truly optimize the system, the most pressure-critical end users must be found out of hundreds, perhaps thousands, of compressed air consuming equipment. To find the needle-in-a-haystack involves asking a lot of questions and thoroughly going through the system. The values in Figure 3 show a typical worst case pressure profile in an industrial plant where the compressors are producing pressures of more than 100 psi, but the final end user is only getting a pressure of 70 psi.

ESTIMATING OR MEASURING FLOW

Estimating average flow often is a difficult process, especially for compressors operating in modulation or variable displacement modes. If you have these types of compressors, the best bet is to purchase and install a low-cost thermal mass flow meter. If this isn't possible, a rough estimate of compressor output flows can be done using average Amps/kW readings or by observing the average output pressure at the discharge.

Compressors with modulation control operate within a fixed pressure band, typically 10 psi wide. At the low end of the pressure band, a compressor with a functional and properly maintained control system will be outputting full load. At the high end of the pressure band, the output of the compressor will be at its fully modulated flow. This relationship can be seen in the chart in Figure 4. Note that fully modulated flows vary with compressor type; consultation with the manufacturer may be required in creating an accurate relationship for your particular compressor.

The calculation of the estimated compressor flow is fairly straightforward using simple ratios. For example, if the compressor is halfway into its modulation band (5 psi in the case of a 10 psi range), it will be producing the rated output at the halfway point of its curve. If the type of compressor you have modulates between 0% and 100%, then the pressure/flow relationship would be extended to the full compressor range, not between 40% and 100%, as shown on the chart.

Either pressure or Amps/power can be used to roughly estimate the output flow of a modulating compressor using this typical curve:

$$Ave.cfm = \left(\frac{Ave.Amps - Full Mod.Amps}{FL Amps - Full Mod.Amps} \mathbf{x} range cfm\right) + Mod cfm$$

Where:

- Average Amps = recorded average Amps during the period, not including off time
- Full Modulation Amps = Amps when the inlet modulation valve is fully closed
- FL Amps = Amps when inlet valve is fully open
- Range cfm = flow range in the modulation band = full load cfm full modulation cfm
- Modulation cfm = flow at full modulation (varies with compressor modulation setting)

Or if average pressure is used:

$$Ave.cfm = \left(\frac{Full \ Mod.psi - Ave.psi}{Full \ Mod.psi - FL.psi} \ \mathbf{x} \ range \ cfm \right) + Mod \ cfm$$

Where:

- Average psi = recorded average psi during the period, not including off time
- Full modulation psi = psi when the inlet modulation valve is fully closed
- FL psi = psi when inlet valve is fully open
- Range cfm = flow range in the modulation band = full load cfm - full mod cfm
- Modulation cfm = flow at full modulation (varies with compressor setting)

These formulas are only valid for operation within the range of the compressor modulation control. For example, if the compressor unloads or turns off during the period measured, the result of the calculation is incorrect. Also, if the compressor is in draw down, that is, if it is at full output but can't keep the pressure within the modulation range, then the formula is inaccurate and will produce a flow higher than the rated capacity of the compressor. As a result of these limitations, the interpretation of the results is tricky; this is where good compressed air auditors earn their keep.

For compressors running in load/unload mode, estimating the average compressed air output is much easier. Most modern controls have hour meters that measure the time the compressor has been loaded and running. Calculating the average output between two points in time is then a very simple calculation:

Ave.cfm =
$$\frac{Loaded hours}{System hours} \mathbf{x}$$
 rated flow

Where:

- Loaded hours = number of hours between readings
- System hours = number of hours the system was active (compressors turned on) between readings
- Rated flow = cfm flow from the compressor nameplate or CAGI data sheet

These calculations are nice, but the best way to get an accurate picture of the flow output of a compressor station is to actually measure it with a flow meter. There are many inexpensive insertion style thermal mass flow meters available on the market that are easy to use. It's possible to get a self-contained meter for less than \$1,000 in 3-in. size and less than \$2,000 for up to 8-in. pipe.

Thermal mass flow meters must be installed properly in a dry straight section of pipe or they won't read correctly. On systems with highly varying loads, or in load/ unload mode, instantaneous readings can be inaccurate because of the fast changes in flow. It is best to use longterm averages that match the duration used in measuring the compressor power consumption.

LEAKS AND END USES

Another basic way to reduce compressed air costs is to use less. We must first measure how much compressed air is being used on average and estimate what part of that flow is useful and what is wasted or used inappropriately.

To figure this out, an important measurement of a compressed air system is the level of leaks. If you have load/ unload compressors, there is a simple test that can be done using a few basic tools — a wristwatch and a calculator. During a plant shutdown, where all production machines have been shut down and the only remaining load is leaks, conduct a test of the compressor load/unload cycles. From these cycles, the percentage loading of the running compressor can be calculated:

$$\% Leaks = \frac{T}{T+t} \times 100$$

Where:

- % Leaks = percentage of capacity of the running compressor (flow can be calculated if capacity is known)
- -T = compressor loaded time in seconds
- -t = compressor unloaded time in seconds

The leakage flow is then estimated by multiplying the percentage leaks by the rated compressor output capacity. Estimating leaks using compressors with modulating or variable capacity controls can be performed using the procedure in Fact Sheet 7 on the Compressed Air Challenge website. If your compressor is a variable-speed-controlled unit, the percentage flow will be a simple ratio of the speed during the test divided by the rated full speed. @



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ADDITIONAL RESOURCES

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Have you joined the discussion? The Compressed Air Blog is your tool for industry tips, group discussions and insights, and access to the Compressed Air Manual written by engineers for engineers. Check in today.



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Aluminum Piping White Paper

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Traditionally, engineers have specified a variety of piping materials for compressed air systems, including black iron, galvanized steel, copper, stainless steel and even plastic. More recently, aluminum piping has become an option considered by many contractors, architects and engineering firms. Aluminum piping makes sense for compressed air systems in many different applications. Read this white paper to get five key reasons why aluminum piping is a superior material to use for most compressed air installations today.



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Vortec Technical Bulletin on Electronic Equipment Failures



High temperatures cause over 50% of electronic equipment failures, according to a study by the US Air Force Avionics Integrity Program. Vibration and humidity each contribute an additional 20% of failure says the same study. Long term weather forecasts for 2014 predict temperatures in many areas will be hotter than normal beginning in May and continuing through August with temperatures peaking in late June through late August. To prevent loss of productivity this summer, take preventative action now to address thermal management of electrical components, electronics, control systems and VFDs.