Improving air system efficiency

by: Scot Foss, Plant Air Technology

Part 2: How demand-side management, general storage considerations, and point-of-use logic can help you to properly design a compressed air system.

The conventional approach toward the development of a new compressed air system is filled with guesswork and usually involves little effort. The users simply guess what capacity they need and then add a little more.

To do the job properly, it is critical to develop an agenda with priorities that you wish to apply to the design and can live with comfortably. However, keep in mind that what is important to production people may not be important to maintenance people. These interactive issues should be considered by all parties involved:

- **Operating cost of the system (Remember, it will cost more to operate the system in the first year than what it cost to buy and install it.)**
- **Accuracy and repeatability of the system, which will produce the desired end results**
- **Maintainability of the system for day-to-day operation**
- **Minimizing the risk of interruption to the system, and**
- **Capital cost of the project.**

Point of use

The point of use is the logical place to begin developing a profile of the standards that will be used in the design. As demand volume is a function of supply pressure, it is important to control the pressure at the point where the air is used.

The differential established between the highest pressure at which air is removed from the system and the lowest supply pressure is called general storage, or stored energy in the overhead piping system and receiver. Properly maintained, general storage prevents one air user from interfering with another.

An important criterion for the design of the point-of-use standards is the differential of the installed components. All components have a resistance to flow - this resistance is called pressure drop, or DP. Pressure drop can be inconsequential or devastating to a system, often depending upon the original equipment suppliers. Pressure drop cannot be ignored, because a corresponding amount of supply energy will have to compensate for it.

Unlike electricity, where installation components can be matched to the amperage and voltage of the user, little thought is usually given to the proper selection of compressed air point-of-use components. Hose, fittings, disconnects, filters, and regulators are all rather standard fare for the user. Lubricators, check valves, dedicated storage, and metering valves may also be required.

Selection criteria should be based on the differential pressure generated at the highest flow and lowest supply pressure. Selection should be made one component at a time backwards from the article pressure, which is the pressure required at the inlet to the pneumatic device. It is important to establish a maximum allowable differential that can be applied between the lowest initial pressure, P4, and the highest article pressure in the system, P5.

Often, these components such as miniaturized or interlock filters, regulators, and lubricators are selected based on ease of installation. Hose, tube, and fittings are too often chosen for ergonomic, spatial, or appearance issues. If the consequences of differential are not considered, the system may have to operate at a much higher pressure to compensate. The financial consequences of uninformed installation decisions could result in a six-figure utility operating penalty.

One note about the regulator - the differential appears on the upstream side. If there is a 10 psig differential at rated flow and pressure across the regulator, and the desired setting of the regulator is 80 psig, the regulator will need to be supplied 90 psig. If the supply drops from 90 psig to 89 psig, the regulator will drop from 80 psig to 79 psig. This is called tracking supply.

Of the components at the point of use, the regulator is the most sensitive to differential. This problem is compounded with miniature regulators. There are many systems that must operate at 30 psig higher pressure because of a miniature regulator on an application.

General storage

Between the highest initial pressure and the lowest initial pressure there is a differential referred to as general storage. The purpose of this storage is to provide transparency between users in the system and to support demand events until control storage from the supply can reach a new event (a useage of air) in the system.

The new event will deplete volume, causing a drop in pressure. It is assumed that there is a source of stored energy at the supply at a higher pressure, which can spill over to the lower general storage. The integrity of the users is dependent on keeping the overhead system's pressure from dropping into the highest initial pressure requirement. Useful storage is a function of the capacity to store air plus the controlled differential pressure - in this case, the capacity of the piping plus any supplementary vessels plus the maximum change in pressure between the demand controller and the lowest overhead or initial pressure. The approach towards solving this requirement requires the following information:

- the largest event which could occur in the system when demand exceeds supply. This should be measured as both volume in scf per cycle and rate of flow in scfm. Example: 300 scf for a cycle time of 30 sec. Rate of flow of 600 scfm

- the distance from the event and the supply in linear feet of piping. Example: 1250 linear ft from demand event to supply

- the fastest delivery speed needed to support a particular event. Assuming the overhead piping system will have a nominal 1 psig differential, the speed of the air will be about 250 ft/sec. Example: Any event in the system needs to be supported with a ramp in 1Ú2 sec. This implies that the initial volume requirement can be met within 125 ft of the unit location and can be supported continuously until the event is completed. Any effort to reduce or slow down the ramp rate into the event would also reduce the needs for general storage and the event's effect on other users, and

- the linear feet of header and subheader piping in the overhead system. Example: 2000 ft of loop header and 4000 ft of subheader.

A critical issue at this time is the flexibility needed in the overhead design. If equipment must be moved around the system in the future, the entire system must be designed to accommodate this possibility. Otherwise, sectors and storage can be designed specifically for the events in each sector of the system.

Demand control

The purpose of demand control is to control the maximum pressure that the using side of the system can remove. In addition:

- it is the primary system control. All parts respond to it, including the compressor control. It is always set lower than the lowest compression pressure

- it guarantees that the production user will receive an accurate, consistent pressure at variable volume; more accurately, it will maintain constant density at variable mass

- it will limit the pressure and therefore the volume of all users (including leaks in the system). By limiting demand, supply energy can be unloaded as actual demand drops

- **it creates storage on the supply side of the system. This storage is potential energy, which will immediately cascade to the downstream side of the demand controller whenever demand exceeds supply, and**

- **it does not require operator adjustment and leak management to maintain balance in the system.**

The demand controller basically expands the stored gas from a higher pressure to a lower controlled pressure at which it will be used. The analogy in electricity would be a transformer, with the regulator at the point of use being a circuit breaker. Without the transformer, the voltage would fluctuate as a function of amperage draw.

Demand control only allows displacement of the exact amount of mass or work energy which has been consumed at the user end of the system. Expanding the mass to a lower pressure maintains mass which has the same energy, which has increased in volume, while reducing to a lower control pressure. Do not confuse a demand controller with a pressure regulator, which restricts mass to control pressure - the function is similar in terms of throttling, but the way it is sized and controlled can be very different.

Normally, base-load compressors are operated based on their higher pressure rating. With demand controls, the lowest pressure-rated compressor is the base, provided the demand control is set at a higher pressure than other demand controllers in the system. The compressors can be operated independently from the demand requirements, optimizing the system.

This may seem to be a lot of effort to design and manage the system correctly. I have heard people say that every 1 psig increase in system pressure only requires increasing the connected compressor brake horsepower by 1Ú2%. The problem with this statement is that depending on the amount of unregulated demand (including leaks) as a percent of the total demand, the elevation of the pressure will increase the unregulated demand linearly to the rise in pressure.

***Example 1*: A system has a total demand of 2000 scfm of equivalent supply energy at 100 psig at various use pressures. Of the total amount of demand, 400 scfm are leaks and 800 scfm are used in production, but there is no regulation or the regulators are wide open. It it were possible to increase the supply pressure to 110 psig, the leaks and unregulated demand would increase by about 120 scfm - this in turn would increase the entire demand to 2120 scfm at 110 psig. If there was only capacity for for 2000 scfm at 100 psig, the demand would exceed supply and the system pressure would drop back to 100 psig or less. If the energy were available, the total energy would increase 5% from the initial value of 480 bhp to 504 bhp - plus the energy to supply the artificial demand created by operating the demand at 110 psig. That was 120 scfm at 100 psig, which would take about 35 bhp of compressor. The total increase, assuming the power was there to waste, would be about 59 bhp, or 12% of the original horsepower.**

This, of course, assumes that the amount of added horsepower was available from one compressor, which was trimming or could be discretely added. Unfortunately, most compressors work together in such a way that the problem in example 2 will more than likely occur.

Example 2: Four compressors, either rotary-screw- or centrifugal-type, are all operating in the throttling mode. As the compressors reduce in displacement, the pressure rises. Without changing the dead band for each compressor, elevating the pressure on the compensators would reduce the total displacement and cause the pressure to drop. If an attempt is made to raise the pressure, the capacity of the compressors will be reduced and the pressure will fall. It will appear that the supply is insufficient. If another compressor is added to the mix, the same load will be

spread over five units, each doing a little less; the pressure will increase by only a small amount. The proper solution would have been to adjust the dead bands on the compressors and the arrangement throttling band.

Principles of demand-side air system management

1. Limit air usage based on applicability and economic alternatives.

2. Specify using equipment based on minimum possible pressure, never exceeding the maximum agreed standard for initial or article pressure.

3. Equipment selected for the system will include volume at the standard pressure or less.

4. Do not alter the system for the sake of one or a few users. OEMs can accommodate slightly lower pressures, although it may cost a little more.

5. Carefully select the P5 installation components to control the D pressure. Be particularly careful of the regulator selection based on initial pressure required to hold the pilot seat pressure. Don't forget to allow for increased cycles, filter dirt loading, and light leaks. The total differential should meet the maximum standard differential.

6. Protect users from being affected by other users by carefully designing storage between the demand controller set pressure and the lowest allowable initial pressure serving the highest regulator set pressure. Size for the largest demand of event, speed of response, and length of transmission. The intent of general storage is to control the maximum change in overhead piping until control storage or supply energy can stop the decay.

7. Control 100% of demand including leaks at a set pressure, which is lower than the lowest compression pressure. This will not only limit demand and allow for control of potential energy expansion, but it allows you to control the compressors at their optimum operating pressure.

8. Waste cannot be created and usage in demand cannot be elevated when it is controlled. Only the precise amount of air that has been removed from the system can be supplied. A demand controlled system will unload supply in a linear fashion with demand requirements.

9. Maintaining potential energy in the system will avoid the need to service demand with direct energy. The more stored energy, the fewer peaks and valleys, and the lower peak power.

R. Scot Foss is president of Plant Air Technology, Charlotte, N.C., a company specializing in system auditing and designing. This series of articles is based on his book, “Compressed Air System Solution Series”. A portion of the proceeds from sales of the book is donated to children’s charities. The book can be ordered through Southern Corporation.