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Energy efficiency improvements in Chinese compressed air systems

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Abstract

Industrial compressed air systems use more than 9% of all electricity used in China. Experience in China and elsewhere has shown that these systems can be much more energy efficient when viewed as a whole system and rather than as isolated components.

This paper presents a summary and analysis of several compressed air system assessments. Through these assessments, typical compressed air management practices in China are analyzed. Recommendations are made concerning immediate actions that China's enterprises can make to improve compressed air system efficiency using best available technology and management strategies.

Current situation of industrial compressed air systems in China

Compressed air is widely used in Chinese industry. In China, the electricity consumption of a compressed air system usually presents 10% to 40% [1] of the electricity use in an industrial facility or enterprise. With the increasing energy shortage and global warming effects, the Chinese government has emphasized the need to increase industrial energy efficiency. As a result, more attention is being paid to the energy savings potential from optimizing compressed air systems. A central focus of the UNIDO China Motor System Energy Conservation Program (2001-2005) included training motor system experts in the practice of conducting a compressed air system assessments and energy audits based on a system approach.

For small-scale and middle-scale air compressor applications in Chinese industry, the share of reciprocating compressor is about 80%. For new compressed air systems, rotary screw compressor will typically be the first choice. But in an older factories, reciprocating compressors, often several decades old, are often still in use. Over time, energy efficiency decreases and the cost of maintaining these compressors increases as the valves and rings experience wear. In China, load/no load is the most common control method; with this type of control, it is very difficult to maintain a stable system pressure. Without adequate storage, variations in demand can lead to system pressure fluctuations and compressor cycling. If a compressor is unloaded time much of the time, the specific power consumption will high, resulting in wasted energy.

China's economy is growing very rapidly, over 7% per annum. Because of the increase in economy, most enterprises in China are expanding their production and pursuing integrated economic benefits. To satisfy the increased compressed air demand brought about by increased productivity requirements, many enterprises have undertaken retrofits of their compressed air systems, such as increasing the compressors capacity, improving the system piping, etc. However, compressed air system management is largely confined to guaranteeing the compressed air supply for the production. In practice, system pressure is often higher than actually necessary, resulting in inefficient operations. While many enterprises understand that efficient operation of compressors requires avoiding "discharge, emissions, dripping, and leakage", they are typically unaware of the importance of balancing the supply side of the compressed air system with the demand side, including the coordinated control of multiple compressors.

To summarize, enterprises in China have started to carry out retrofits on compressed air systems because of high electricity consumption and costs, unstable air supply and increased air demand. Before the retrofit is done, the opportunities are identified through a system assessment or audit. These compressed air system assessments may be conducted by compressor manufacturers/distributors or energy service companies (ESCOs), but the most common practice is for the enterprises to conduct the assessments themselves. The most frequently implemented energy-saving measures that result from these compressed air system assessments include:

- Purchasing a rotary screw compressor, either for a new system or to replace an existing reciprocating compressor;
- Application of variable speed drives and variable speed drive compressors;
- Changes to the piping system to allow centralized production of compressed air, to supply compressed air in a loop distribution scheme, and /or modify a pipe to one of more suitable size.

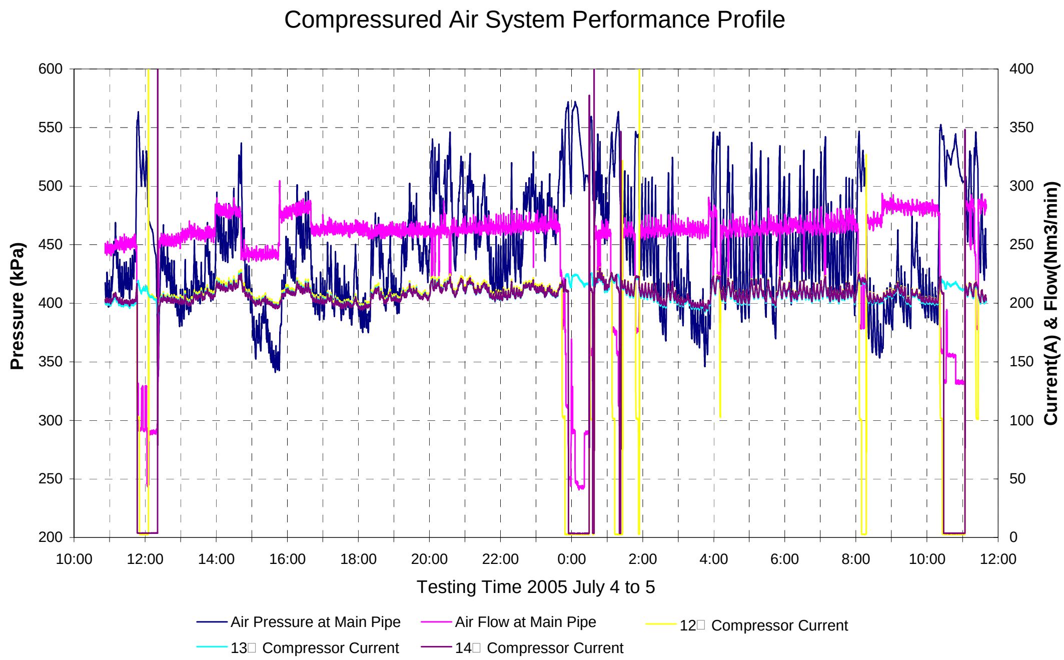
Typical findings through compressed air system assessments

This section describes four common practices in Chinese compressed air system management that offer opportunities for energy efficiency improvements. The energy saving potential is illustrated with the results of compressed air system assessments conducted by the principle authors at Chinese factories using techniques acquired during the compressed air system training offered through the UNIDO Motor System Energy Conservation Program and subsequent study tour.

Overestimating the savings potential from application of variable speed drive compressors is common

A shipment container manufacturer requested testing and evaluation of their compressed air system because it was a large electricity use. The study validated that the compressed air system used 30% of the total electricity consumption in this factory. The compressed air system studied includes six air compressors with a capacity of 40 Nm3/min each (224kW) and one air compressor with a capacity of 20 Nm3/min□110kW□. Testing results documented that the actual system pressure ranged from 3.4 - 5.3 bar and the unload pressure was set at 5.88 bar (see figure 1), so multiple compressors were all working on full load. The factory's production does is not seasonal-- monthly production output is the same except during the month of the Chinese New Year (typically late January-early February). As a result of the current control strategy, multiple compressors are fully loaded throughout most of the year. Before evaluation, the factory planned to install a variable speed drive compressor. The installation was expected to reduce energy use and provide constant pressure by varying the compressor operating power with the demand load.

Figure 1: Compressed air system performance 24 hour profile



Applying a variable speed drive (VSD) compressor to this system may not produce the expected results in energy savings. This type of control works best in single compressor applications or as the trim compressor in a multiple compressor array that must respond to a wide range of loads. Variable speed compressors are most efficient at part load and should be used in situations in which they spend little time at full load. But the existing operating situation in the factory involved multiple compressors running at full load throughout most of the year. Furthermore, compressor variable speed application is different from pump or fan application. While the power required to operate a pump or fan motor is proportional to the cube of the speed, a compressor has constant torque so that the power required to operate its motor is proportional to the speed. The energy savings resulting from a variable speed compressor application can be significant, but is not directly comparable to the savings to be achieved from a pump or fan application.

Through testing, the compressed air system leakage in this factory is roughly 15% of air supply, which due the system size is a large quantity of air. The individual leaks are large enough to be heard or visually detected. Repairing a few large leaks is less labor-intensive than repairing many small leaks. Fixing the leaks would provide the factory with an immediate and equivalent energy savings at a much lower cost when compared with purchase of a VSD compressor.

In addition, the enterprise wanted to apply variable speed to solve the unstable system pressure problem because VSD compressors are able to supply compressed air with little variation in discharge pressure. In fact, a strongly fluctuating system pressure is the sign of system imbalance between the supply and demand. To solve unstable system pressure problems, the enterprise should first consider whether the existing array of compressors can be controlled to match the end use demand efficiently and whether a larger compressed air receiver is required to respond effectively. The fluctuating system pressure could be the direct result of the lack of a master control for the system. The load and unload sequence of compressors should be determine after study of the demand side airflow and duration requirements. The more storage capacity a system has, the more the storage can be used to soften the system pressure variation. If the system requires a high volume airflow requirement of short duration, installing an air receiver with storage refill control dedicated to the high volume use can be considered. This measure can avoid a negative effect on system pressure as the result of the event.

Care must be taken when planning to apply a variable speed drive compressor. In China, many factories take an active interest in using variable speed applications, but sometimes this may not be the best solution to the problem. Energy measures should be implemented based on measurement of the actual system dynamics that seek to identify the true cause of problems like fluctuating pressure, rather than the symptoms. Compressed air system assessments can be an effective tool for helping enterprises to determine how to improve compressed air system efficiency.

Poorly maintained after-coolers result in system inefficiencies and problems

When enterprises focus their attention on their compressed air system, it is mainly on the compressors. The role of properly functioning after-coolers is often ignored. A Shanghai factory was experiencing moisture problems in their compressed air system, which was validated through energy testing and evaluation. Compressed air is used as an energy source in the factory to spray steel grit in order to polish metal surfaces. Due to the moisture problem, the steel grit would not flow freely and became an obstacle to a smooth production. The compressed air system assessment determined that the after-coolers did not cool the compressed air effectively and that the temperature at the air outlet of the after-cooler was high. This led to an excess of entrained water vapor, which was transported into the refrigerated dryers and caused overloading of the dryers. The overloaded dryers could not dry the compressed air to the required dew point. Additionally, the enterprise had not installed automatic condensate traps at the after-cooler, air receiver and point of use. Draining was done manually only once every two hours, which was insufficient. Water was carried over into downstream equipment and resulted in abnormal and inefficient production conditions. The use of manual draining also discharged excess compressed air, further contributing to energy losses.

The after-cooler problem is very typical in old factories in China because the after-cooler area for heat transfer was not designed correctly. With time, the after-cooler efficiency decreased, resulting in an air outlet temperature that was frequently more than 65□. As this air cools down further during distribution to the end uses, the condensate accumulates at various points in the air piping system and can also carry-over into the end use, as illustrated in the polishing process previously mentioned. Therefore, enterprises should not overlook the importance of after-coolers and in maintaining sufficient heat transfer surfaces and cooling efficiency to ensure smooth operation of the downstream equipment.

Enterprises do not realize the cost of leakage

In the same factory evaluation previously described in the variable speed application, nine compressors (7×40 Nm3/min□2×20 Nm3/min) were all working to satisfy the compressed air requirements of a product line. During production downtime, leakage testing was carried out; the results documented leakage amount in a product line of approximately 50Nm3/min, or more than the full-load output of one of the larger compressors. The most significant leak locations were at the quick couplings of tools and air supply, a punctured hole on pneumatic instrument plastic tubing and a poor multi-connection in a hose line.

The enterprise understood the necessity of avoiding leakage, for instance, they already knew to close off the air supply to pneumatic tools when they are not in use; they also had procedures barring use of compressed air to clean the dust from personnel. Even so, the enterprise did not realize the high cost of leaks. Compressed air leaks, even if small, are expensive. For a 2mm diameter hole in a air pipe, if the air pressure is 6 kg/m2, the leak rate from this hole will be 0.24m3/min. the cost for such a hole in a month will about RMB1000yuan□€100□ and there are dozens of such holes in a factory[3]. In this factory, if they can reduce the leak by 80 percent, maybe one of the 40m3/min compressors can be shut down. To be effective, any leak reduction program should include corresponding adjustments to compressor controls to respond to the reduced demand.

If cost of compressed air production is RMB 0.1yuan/Nm3(€0.01/Nm3) then the annual cost savings can be estimated at about RMB1.7 million yuan (€170,000). Leaks can represent 20% to 50% of all air demand [3]. Repairing leaks needs to be a high priority for Chinese enterprises.

Lack of isolation valves and regulation in the distribution system

At present, factories usually have their compressors centrally located for producing and supplying compressed air. Depending on the concentration of end uses, the main distribution system is divided into several branch main pipes, with each branch pipe connected to a loop piping which supplies air for the end use. The piping system is just for supply purposes- it has no control function. Enterprises typically set the system pressure above the minimum pressure to ensure proper functioning of the system. For any compressed air end use equipment, air supply above the required working pressure means more compressed air used and therefore increased energy costs. When the pressure is higher, compressed air systems use a larger amount of air and leakage will increase. This is called artificial demand [2] [3]. Artificial demand is a typical problem in industrial compressed air systems in China but is seldom addressed. The typical action to improve the situation is the implementation of controls to balance the energy supply to the system with the compressed air demand. One easy way is installing valves to close sections of the distribution system when not in use. This method has been applied in many factories but more advanced methods, such as intermediate control, have few examples in China. The reduction of the artificial demand has a large energy saving potential and implementation of controls on piping system is a breakthrough to realize these energy savings.

Conclusions

Based on the above analysis, the following recommendations are made concerning what China's enterprises can do immediately to improve compressed air system efficiency using best available technology and management strategies:

- Repairing leaks is very important. To be effective, this should include corresponding adjustments to compressor controls to respond to the reduced demand.
- System design solutions should be based on an analysis of system needs. Energy auditing can identify the current energy utilization of the compressed air system and give effective advice on choosing suitable technologies for the application.
- Experience in China and elsewhere has shown that these systems can be much more energy efficient when viewed as a whole system and rather than as isolated components. The operation cost is related not only to the efficiency of each compressor, but also to the coordination of the multiple compressors, the efficiency of compressed air treatment equipment and the balance between supply and demand.
- Management strategies must be changed from the current assumptions that:
    - over supply of compressed air is acceptable to a new approach that recognizes that the compressed air system must be in balance with demand;
    - minimum pressure must be maintained and higher pressure is acceptable to a new approach that seeks a stable compressed air pressure, with pressures higher than required deemed unacceptable.

If these strategies are followed, China's enterprises could greatly improve the energy efficiency of their compressed air systems

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