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Improving Energy Efficiency of Compressed Air System Based on System Audit

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Abstract

Industrial electric motor systems consume more than 600 billion kWh annually, accounting for more than 50% of China's electricity use. The International Energy Agency estimates that optimizing motor systems results in an improvement of 20-25%, which is well-supported by experience in both the U.S. and China. Compressed air systems in China use 9.4% of all electricity. Compressed air use in China is growing rapidly, as new industrial plants are built and the production processes of existing plants expand and change. Most of these systems, whether existing or new, are not optimized for energy efficiency.

This paper will present a practitioner's perspective on the emergence of compressed air auditing services in China, specifically as it pertains to Shanghai and surrounding areas. Both the methodology used and the market development of these compressed air system services will be addressed. Finally, the potential for energy saving opportunities will be described based on highlights from over 50 compressed air system energy audits completed by Shanghai Energy Conservation Service Center, both during the United Nations Industrial Development Organization (UNIDO) China Motor System Energy Conservation Program, and after this training program was completed.

Introduction to Compressed Air System

Due to its cleanness, availability, and ease-of-use, compressed air is used widely throughout industry, and is often considered the "fourth utility" at many facilities. Compressed air is probably the most expensive form of energy available in a plant, because only 19% of the power used by a compressor can be converted to useable work, and the other 81% is lost as waste heat. This is a theoretical calculation because other system losses are not taken into account ^[1]. According to the total life cycle costs (LCC), equipment initial investment and maintenance represent only a small portion of the overall cost of compressed air, and the power required to operate the compressor is usually 75%, or more, of the annual cost of compressed air ^[2]. Compressed air use in China is growing rapidly, as new industrial plants are built and the production processes of existing plants expand and change. In China, which consumes about 9.4% of all electricity ^[3]. Most of these systems, whether existing or new, are not optimized for energy efficiency. According to the experience of US Compressed Air Challenge™ and UNIDO China Motor System Energy Conservation Program, most compressed air systems use considerably more energy than is needed to support the demand, Improving compressed air system can achieve 20~50% energy saving.

Compressed Air System Audit

Auditing the compressed air system is the first step to effective compressed air demand management. A compressed air system audit based on the 'systems approach' can baseline the overall compressed

air system and highlight the true costs of compressed air and identify opportunities to improve efficiency and productivity. An audit requires comprehensive system measurement and analysis according to actual needs of system. System measurements include power, pressure, flow, and temperature under different operating conditions, and also estimating leak load. Each is discussed below.

Power measurement

Energy is measured in order to estimate the annual electricity consumption of a compressed air system. A hook-on amp/volt meter or a wattmeter will be required. The current and voltage into the compressor should be measured. Full-load and no-load input power to the compressor should be measured. For three-phase systems, power can be estimated by the following equation:

$$kW = (1.73 \times \text{volts} \times \text{amps} \times \text{power factor}) / 1000$$

Using a wattmeter provides a direct reading of kW with no calculation or power factor adjustment.

Pressure measurement

Pressure is measured to give feedback for control adjustments, and to determine pressure drops across equipment. The calibrated pressure transducers are required. Normally pressure measurements should be taken as following figure when baselining a system.

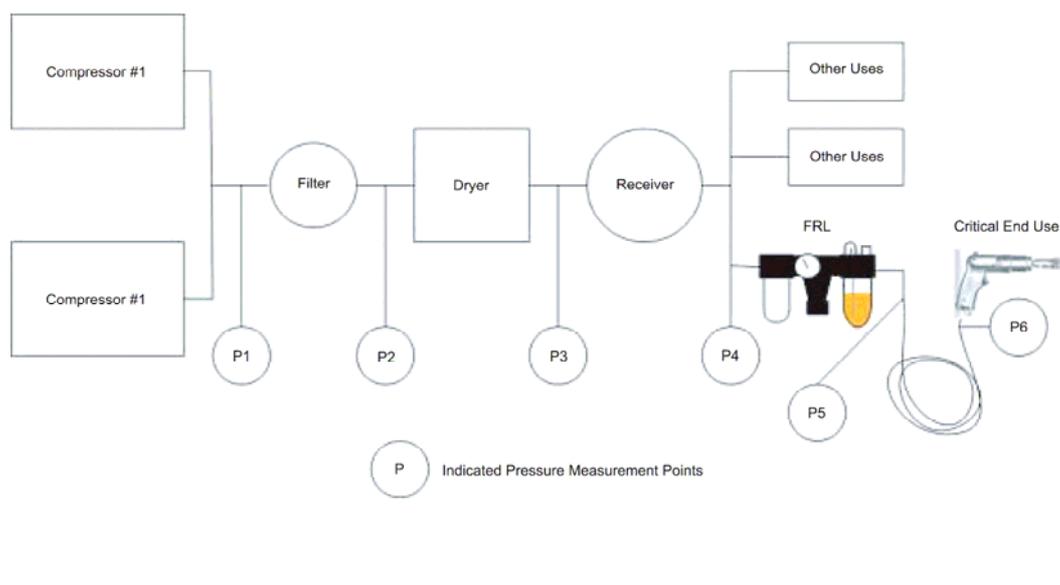


Figure1 compressed air system pressure measurement ^[4]

Flow measurement

Flow meters are necessary to measure total flow and to determine consumption. Flow should be measured during various shifts and for leaks during non-production periods. There are a number of ways to measure this air consumption, such as direct measurement of flow in the pipe, or via calculation based on the inlet vacuum on modulating machines, load cycles on load/unload machines, and airtend speed on variable speed machines. The best way to measure how much air is in the pipe and where that air is going is with a flow meter^[3,4]. This can be done with a flow meter that has permanently mounted measuring devices in a properly calibrated length of pipe or portable insertion-type mass flow meter. These methods are not designed to accurately measure the output of a compressor against its rating, but rather to document approximate usage, rate of change, and changes in flow associated with events in the system.



Figure 2 flow measurement with insertion-type mass flow meter

Temperature measurement

Temperature measurements help to indicate if equipment is operating at peak performance. Generally, equipment that runs hotter than specified parameters is not performing at peak efficiency. The following temperature measurements should be taken when baselining a system.

- Aftercooler and intercoolers cold temperature difference or approach temperature of cold water inlet to cooled air outlet.
- For rotary-lubricated compressors, the air discharge temperatures must be maintained for reliable compressor performance. Normal operation requires temperatures below 200°F.
- Inlet air temperature.

Performance Improvement Opportunities

Optimization recommendations can be implemented to balance supply side and demand side, and to improve the system efficiency of overall compressed air system. Over 50 compressed air system energy audits completed by Shanghai Energy Conservation Service Center, both during UNIDO China Motor System Energy Conservation Program, and after this training program was completed. The potential performance improvement opportunities are addressed in the following sections.

1. Eliminating Inappropriate Uses of Compressed Air

Compressed air is probably the most expensive form of energy available in a plant. Compressed air is also clean, readily available, and simple to use. As a result, compressed air is often chosen for applications for which other energy sources are more economical. Inappropriate uses of compressed air include any application that can be done more effectively or more efficiently by a method other than compressed air. Examples of potentially inappropriate uses of compressed air include^[6]: Open blowing, Sparging, Aspirating, Atomizing, Padding, Dilute-phase transport, Dense-phase transport, Vacuum generation, Personnel cooling, Open hand-held blowguns or lances, Diaphragm pumps, Cabinet cooling, Vacuum venturis, etc. Improper uses of compressed air are also including unregulated end uses and those that supply air to abandoned equipment.

Users should always consider more cost-effective forms of power before considering compressed air. Many operations can be accomplished more economically using alternative energy sources. Fig. 3 is the flow & pressure profile of a workshop developed according to the data collected by data logger in Shanghai SACHS Company. There is a machine in this workshop which uses unregulated compressed air to dry metallic parts when they pass through by on transportation chains. When the machine was started at 15:22, the flow increased from 3.5m³/min to 6.6 m³/min.. This drying application requires very low pressure and represents an inappropriate use of compressed air. A blower can meet the drying requirement and more than 50% energy can be saved.

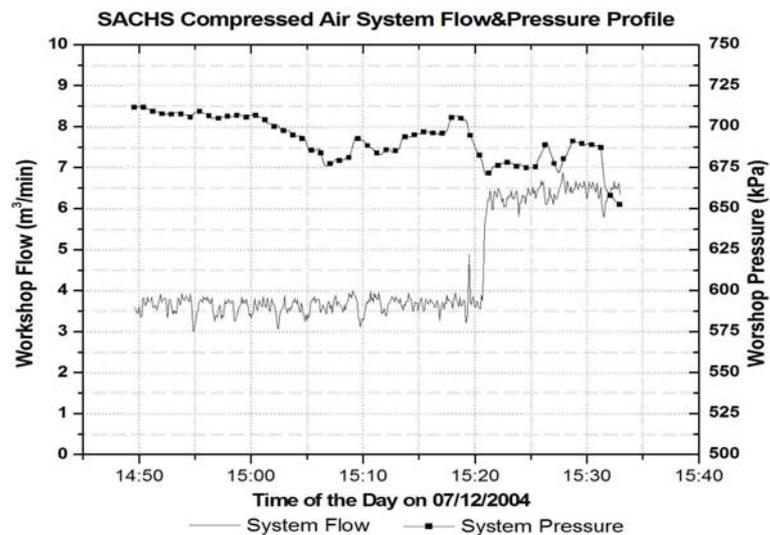


Figure3 inappropriate uses of compressed air

2. Minimizing Compressed Air System Leaks

Leaks can be a significant source of wasted energy in an industrial compressed air system, sometimes wasting 20 to 30 percent of a compressor's output. A typical plant that has not been well maintained will likely has a leak rate equal to at least 20 percent of total compressed air production capacity. Power Losses caused by leaks are listed as following table. Taking a 4mm hole with a well rounded orifice as an example, if the system operates 8000 hours per year at 6 bar and energy rate is 0.6 RMB/kWh, then 31,200 RMB have to be paid for the leaks of this hole.

Table1 compressed air system leaks power consumption table

Hole diameter (mm)	Air consumption at 6 bar (g) □m ³ /min□	Loss □kW□
1	0.065	0.3
2	0.240	1.7
3	0.980	6.5
4	2.120	12.0

Figure 4 is two typical leaks photos which were taken during compressed air audits in two different plants of Shanghai. In addition to being a source of wasted energy and money, leaks can also contribute



a. leaks at rubber hose connection



b. leaks at open valve to drain water

Figure 4 Places where leaks usually happen

to other operating losses. Leaks cause a drop in system pressure, which can make air tools function less efficiently, adversely affecting production. In addition, by forcing the equipment to run longer, leaks shorten the life of almost all system equipment. Increased running time can also lead to additional maintenance requirements and increased unscheduled downtime. Finally, leaks can lead to adding unnecessary compressor capacity.

The best way to detect leaks is to use an ultrasonic acoustic detector. Fixing found leaks is the best way to reduce leaks. American Visteon's Monroe plant^[6] implemented a leak management program, compressed air system consumption was reduced by more than 50% on a per production unit basis, which represents savings of over \$560,000 per year and an 11.5% reduction in annual electricity costs. Shanghai Turbine Company installed control valves at header to different workshop and closed the valve when there is no air use in any workshop, which allowed the company to shut off a 10m³/min compressor at night. Another way to reduce leaks is to lower the demand air pressure of the system. Stabilizing the system header pressure at its lowest practical range will minimize the leakage rate for the system.

3. Minimizing Pressure Drop and Controlling System Pressure

Pressure drop occurs as the compressed air travels through the treatment and distribution system. A properly designed system should have a pressure loss of much less than 10 percent of the compressor's discharge pressure, measured from the receiver tank output to the point-of-use. Excessive pressure drop will result in poor system performance and excessive energy consumption. A rule of thumb for systems in the 6.9 bar range is: for every 0.14bar increase in discharge pressure, energy consumption will increase by approximately 1 percent at full output flow. There is also another penalty for higher-than-needed pressure. Raising the compressor discharge pressure increases the demand of every unregulated usage, including leaks, open blowing, etc. Although it varies by plant, unregulated usage is commonly as high as 30 to 50 percent of air demand^[5]. For systems in the 100 psig range with 30 to 50 percent unregulated usage, a 0.14bar increase in header pressure will increase energy consumption by about another 0.6 to 1.0 percent because of the additional unregulated air being consumed. The combined effect results in a total increase in energy consumption of about 1.6 to 2

percent for every 0.14bar increase in discharge pressure for a system in the 6.9 bar range with 30 to 50 percent unregulated usage. Over treatment to air will also lead to excessive pressure drop, which can be illustrated as figure 5. An oil filter found installed in oil-free compressor system in Shanghai Gaoyang int'l Tobacco Co. Ltd. resulted in 0.4 bar excessive pressure drop, accounting for about 3.2% of system energy wasted.

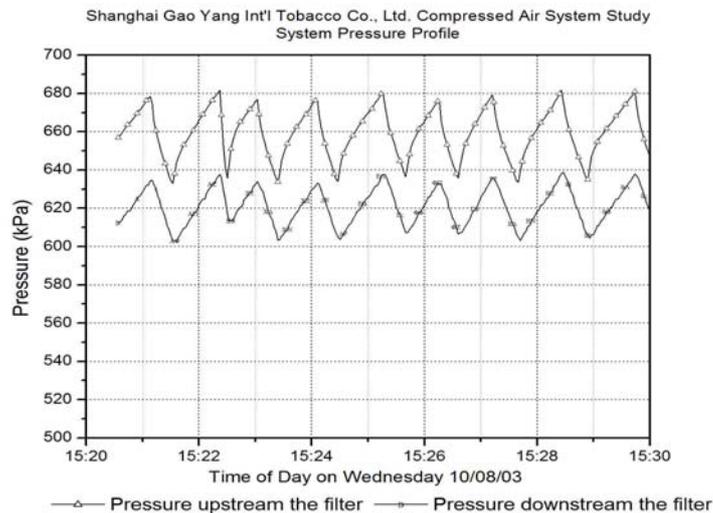


Figure 5 Excessive pressure drop example

4. Optimizing Compressed Air System Configuration

Each compressed air system has a different configuration. Sometimes there are two or more independent systems with same or different pressure level in one plant. When more than one compressor operates at part-load condition in a system, a plant will spend more than necessary to produce compressed air to meet the production requirement. An audit in a tobacco materials plant, revealed that two rotary screw compressors with the capacity of 10m³/min and 20m³/min separately operated two individual systems at the same pressure level. According to the measurement results, the sum of average flow rate is just 9.5 m³/min and the maximum flow rate is also less than 16 m³/min. If two systems are connected together, one big compressor can cover the maximum system demand. The similar successful cases also happened in both Shanghai G. T. Micro Fiber Company and Shanghai SAE Company, where one 20 m³/min rotary screw compressor and one 50 m³/min centrifugal compressor were shut off after two systems were connected together.

5. Optimizing Compressed Air System Control Strategy

Each compressed air system differs in supply, distribution, and demand aspects. Compressor systems are typically comprised of multiple compressors delivering air to a common plant air header. The combined capacity of these machines is generally sized to meet the maximum plant air demand. Few air systems operate at full-load all of the time. System controls are almost always needed to orchestrate a reduction in the output of the individual compressor(s) during times of lower demand. A frequently encountered operating scenario has two or more compressors operating in part-load condition in a system. Fig 6 is the compressors power profile of Shanghai KSB Pumping Company. When compressor 1 was modulating to reduce air output, compressor 3 began to load and unload to meet system pressure changes. Two of three compressors were in part-load condition.

Today, faster and more accurate microprocessor-based system controls have been successfully applied, such as VFD controls, single master controls and multi-master control, which allows compressors to be operated at or near their optimum pressure for maximum efficiency and lower system average pressure

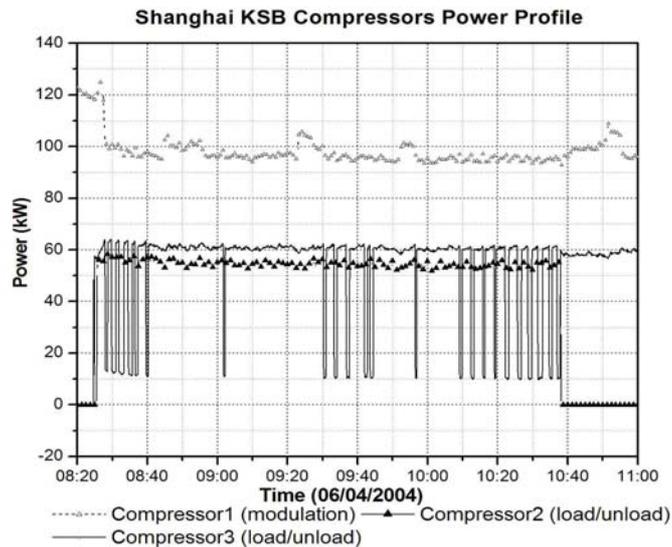
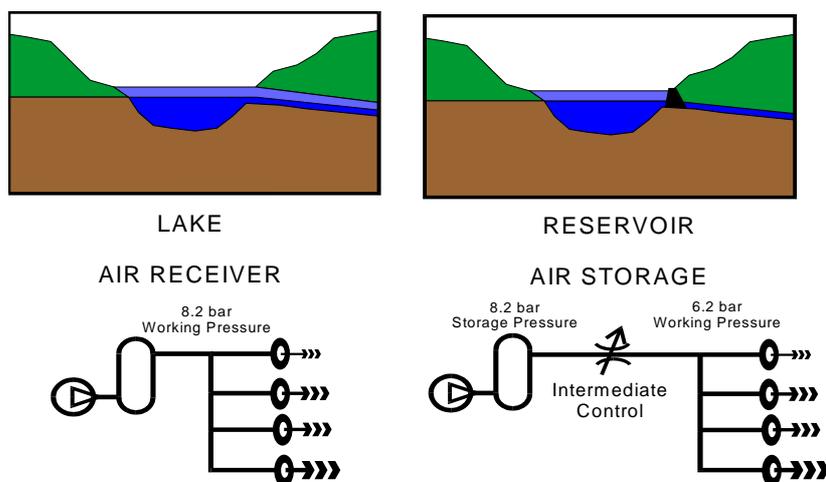


Figure 6 Multiple compressors control response

6. Engineering controlled Storage System

Every compressed air system has receivers to serve to dampen compressor pulsations, separate out particles and liquids, and make the compressed air system easier to control. Receiver volume alone does not create useable air storage. Pressure/flow controller^[7] can help to establish controlled storage, which can be illustrated as Fig.7. An air receiver is like a lake, while air storage is more like a reservoir. As the lake level rises, water runs out faster and everything downstream floods. In most compressed air systems compressor controls are set higher than target pressure. The receiver is maintained at this high pressure and useable air is available from storage. But the higher pressure causes every thing



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Figure 7 Engineering controlled storage system

downstream to floo

d. If on the other

hand a dam is built at the outlet of the lake, the lake becomes a reservoir. As the water level rises, the outflow from the lake is controlled and the downstream flood is prevented. In a compressed air system, the pressure/flow controller (intermediate control) is the dam, and flood control gate. As receiver pressure increases, the intermediate control throttles the outflow of air and prevents downstream pressure rise and artificial demand is prevented. Download time become longer than before, which can be illustrated as fig.8. Shanghai Gaoyang Int'l Tobacco Company installed a pressure/flow controller, which maintains the downstream average pressure between 6.6bar to 6.05bar while increasing the downtime of compressor, achieving 8.17% energy savings of system energy cost.

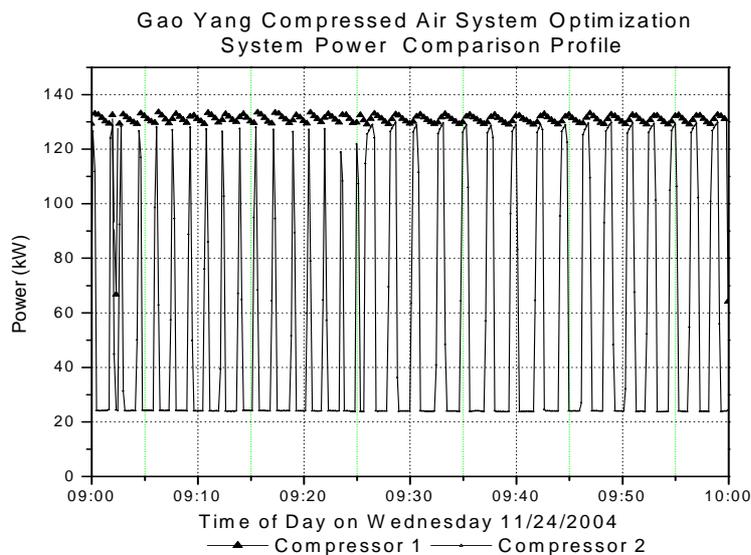


Figure 8 Pressure/Flow Controller energy

Opportunities for Compressed Air Energy Efficiency Services

The market for compressed air energy efficiency services in China is still relatively new, but the opportunity is great^[8]. The average percentage energy savings found as the result of compressed air energy audits conducted by the Shanghai Energy Conservation Service Center is 10-50%, which is a significant opportunity for any industrial facility. Frequently, these energy savings can also result in improvements in system reliability and support for production.

In 2005, the Chinese government announced a plan to reduce energy consumption per unit of GDP by 20% over 2005 levels by the year 2010. A major initiative included in this plan is Monitoring and Guiding of Energy Efficiency Improvements of Top 1000 Energy-Consuming Enterprises in China. A total of 1000 large energy using enterprises from nine sectors have been selected for participation. Their estimated 2004 final energy use was 673 Mtce or 18.7 Quads which represents almost 50% of China's industrial energy consumption and 30% of China's total final energy use. Under the plan, the enterprises participating in the Top 1000 Energy-Consuming Enterprises program are required to report annually on energy use, and, within the first five years and every five years thereafter, conduct an energy audit, develop an energy conservation plan, formulate energy efficiency goals and adopt energy conservation measures. Application of the types of compressed air best practices described here could

assist these plants in meeting their energy saving goals.

Now, Shanghai Government is developing some policies, such as reducing tax, to support plants to implement energy saving projects, including compressed air system energy program.

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