Motor Systems Optimization Case Studies in the Peoples Republic of China

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ABSTRACT

The *China Motor Systems Energy Conservation Program* is a three-year effort organized by the United Nations Industrial Development Organization, the US Department of Energy, the Energy Foundation, and the Chinese government. This is a pilot program in two Chinese provinces, Shanghai and Jiangsu, and consists of training, case study development, standards development, and planning for a national motor systems optimization program. By the Spring of 2003, an international team of motor system optimization experts had completed training twenty-two Chinese experts in the areas of motors, drives, fan systems, pumping systems, and compressed air systems. These Chinese engineers are now conducting sixteen industrial plant assessments in each province (including both private and public sector facilities), identifying opportunities for efficiency improvements in motors and drives, pumping, fan, and compressed air systems. From these assessments, four to six case studies will be developed in each province. Two of these case studies are nearing completion and are described in this paper.

Introduction

Industrial electric motor systems consume more than 600 billion kWh annually, accounting for more than 50% of China's electricity use (Hinge, et al 1996). Optimizing system efficiency in concert with improving equipment design and operations and maintenance practices, can reduce motor system energy use by at least 20% typically, providing substantial energy and emissions savings while often improving plant productivity, maintainability, and safety. For example, if 50% of the industrial electric motor systems in China are optimized to achieve 20% average energy savings, the nationwide savings will be the equivalent of US$3-4 billion annually and carbon dioxide emissions will decline by more than 25 MMT annually. (McKane et al. 2003)

To that end, the United Nations Industrial Development Organization (UNIDO), the US Department of Energy (USDOE), the Energy Foundation, and the Chinese government established the China Motor System Energy Conservation Program. This pilot program is developing an infrastructure in two provinces (Shanghai and Jiangsu) to provide technical training, build awareness, conduct plant assessments, and implement industrial motor system optimization projects. The program is introducing a variety of educational materials, analysis tools, and standards to Chinese industry. (McKane et al. 2003).

The development and publication of project case studies that highlight successful motor system optimization projects is an important component of this program. The lessons learned from the pilot program will inform the development of Phase II of this effort, currently under development, and ultimately, a national program. Within approximately ten years, the Chinese government plans to establish and train a network of motor system optimization experts throughout China, and to use these experts to assist individual factories to implement motor system improvement projects.

Program Overview

The primary goal of the China Motor Systems Energy Conservation Program is to assist the Chinese in controlling the growth of greenhouse gas emissions by establishing a national program to promote motor system improvements in factories throughout China. The first portion of the program has focused on developing a training curriculum, training a group of Chinese engineers, training factory operators, conducting motor system field measurement and data analysis, and developing case studies on motor system efficiency improvement projects. The training of the Chinese experts took place between April 2002 and March 2003, with separate workshops covering 1) pumping systems, 2) motors, drives, and fan systems, and 3) compressed air systems. The role of the International Experts has been to develop the training curriculum (primarily based around existing optimization training in the US and UK), provide instruction to the Chinese experts, observing these experts conducting training for Chinese factory personnel, observing and assisting in field measurement and data analysis by the experts, and providing technical assistance in the preparation and documentation of case studies.

The program seeks to transfer and demonstrate to the Chinese the "systems approach", an assessment and analysis methodology recommended in the US by the BestPractices effort within the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). The systems approach looks at the motor system beginning with the load that it serves, and working back through the various portions of the system, not merely looking at the motor efficiency or the fan efficiency. For instance on fan systems, a proper analysis will consider:

- Pressure and flow requirements of process
- Distribution system - ductwork, dampers, fittings
- System control type - outlet damper, inlet damper, variable inlet vane, etc.
- Fan type - vane axial, backward inclined, airfoil, etc.
- Fan capacity - size, rotational speed
- Drive - belt drive, adjustable speed drive
- Motor - type
- Electrical supply

An important aspect of the China Motor Systems program is the development and publication of case studies. These case studies:

1) document to UNIDO that the program requirements are being met,
2) will be disseminated through the China Energy Conservation Information Dissemination Center to industrial facilities throughout China,
3) validate the importance of energy centers such as the ones in Shanghai and Jiangsu as a resource for industry,

4) will provide proof to the Chinese government that the program is worth expanding into a national program.
5) provide documentation for UNIDO concerning the benefits of taking a systems optimization approach to industrial energy efficiency.

These four to eight page case studies will summarize the opportunity and the improvements implemented in a facility. The case studies include an overview of the facility and the system(s) chosen for evaluation, a summary of the systems analysis and recommendations, a summary of the implemented project, the measured results of the project, and lessons learned. Such case studies have been successfully used in the US and UK to demonstrate the technical and economic benefits of energy systems efficiency improvements, particularly for electric motor systems (Lung 2003). Many of these case studies can be found on the BestPractices website (www.oit.doe.gov/bestpractices). Similarly, the case studies being created for this program by the Shanghai Energy Conservation Service Center and the Jiangsu Energy Conservation Center are to be available in print and via the internet.

Yangzhou Weiheng Heat and Power Plant Combustion Air Fans

One facility visited as part of the hands-on training for the Chinese experts was the Yangzhou Weiheng Heat and Power Plant, which produces both electricity and steam district heating from coal. There are three 65-ton coal-fired steam boilers and two sets of steam turbines and electricity generators with a capacity of 15 MW each. Only two boilers are in operation; both are damper-controlled and tracking 65 tons/hr. Each boiler has a 6 kV, 355 kW forced-draft fan and a 160 kW induced-draft fan. There are also 2 secondary air fans per boiler, as well as tertiary air fans that are used occasionally. The secondary air and tertiary air fans provide additional air to help complete combustion. These fans are sometimes called over-fire air fans, since they inject air after (over) the primary combustion zone, and are sometimes used to shape the flame and protect the boiler walls from direct flame impingement.

At first it appeared that the 55 kW secondary fan was merely a good place to let the students try their hand at performance testing. There was straight ductwork and safe access, so the fan was chosen more for convenience than for apparent optimization opportunity. However, the performance test showed a significant pressure drop across the inlet butterfly damper and the elbow.

Field performance test. As part of the hands-on training, the Chinese experts conducted a full performance test of one of the six secondary air fans (McKane et al. 2002b). Students measured the inlet and outlet cross-section, they measured temperature and static pressure at the inlet and the outlet. At the traverse plane, just upstream of the inlet damper, they measured temperature, static pressure, and conducted a pitot traverse to measure velocity pressure, and establish flow rate.

Three test planes were identified (see Figure 1):

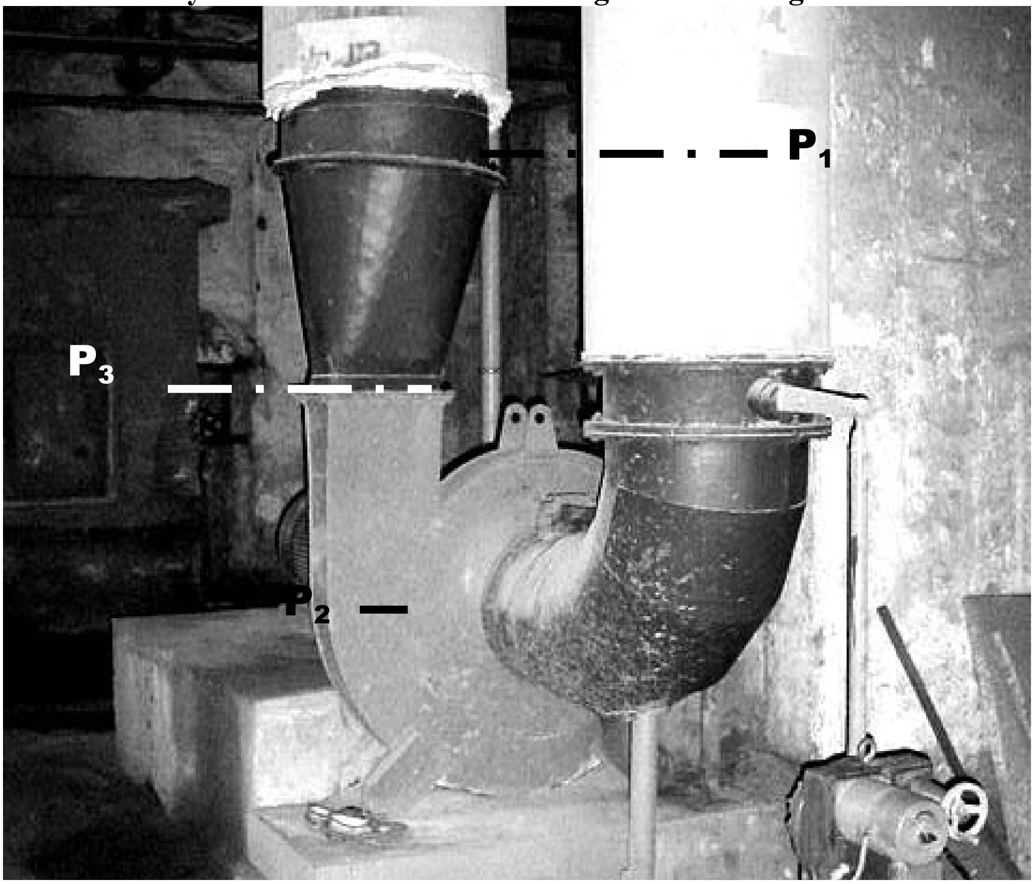
- P_1 the traverse plane just upstream of the butterfly damper on the inlet ductwork
- P_2 the inlet to the fan

- P_3 the outlet of the fan

At the time of the performance testing in conjunction with the training, the Chinese made the following conclusions:

- Need more information about the operating pattern of the boiler
- Need to do additional testing and investigate the relationship between the secondary and tertiary fans
- The secondary fan is probably oversized
- Dismantle the damper
- Recommend installing a variable speed drive
- Recommend installing a reducer at the inlet
- Recommend changing the discharge duct configuration

Figure 1. Secondary Combustion Air Fan at Yangzhou Weiheng Heat and Power Plant



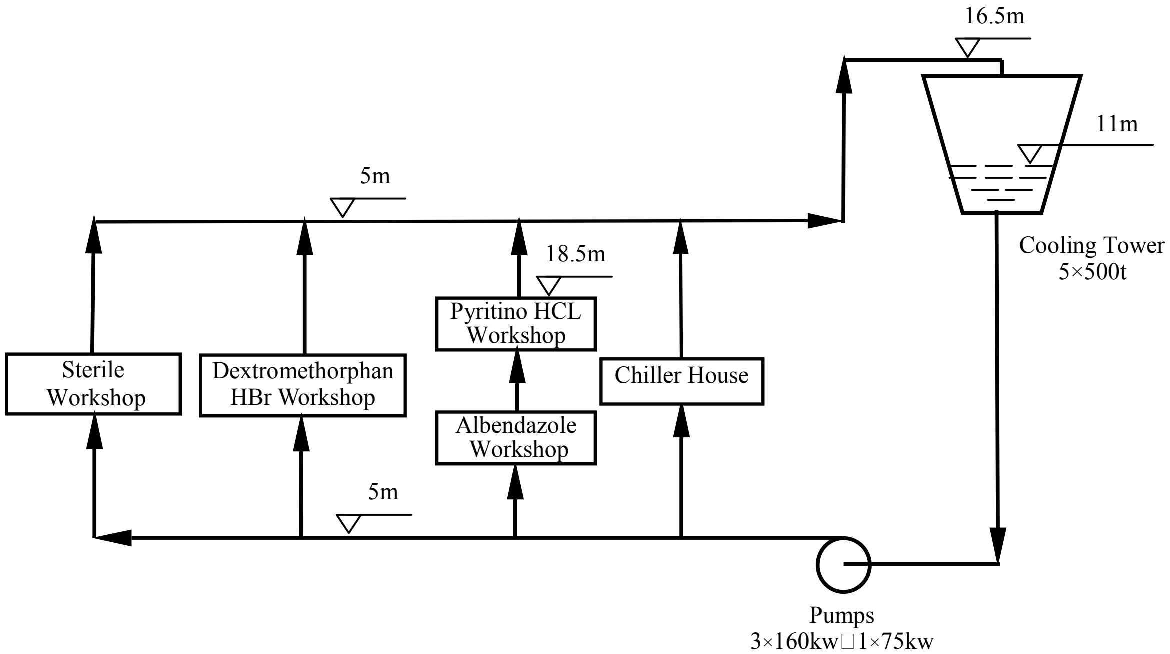
Optimization opportunities. This secondary air fan system at the Yangzhou Weiheng Heat and Power Plant was later selected for a systems analysis by the Jiangsu Energy Center, and based on that analysis, the center decided to pursue a project for implementation. Another basis for the decision to pursue this project is the potential for replication – it is one of six identical fan systems at the facility. The Jiangsu Energy Center reports that a project involving a variable frequency drive has been installed on the 55 kW electric motor serving this fan. Additional data are being collected to assess the performance of the completed project.

Pumping System Optimization at a Pharmaceuticals Company

The Shanghai New Asiatic Pharmaceuticals Company, Ltd. (SNAPC) is a large facility producing over 120 different pharmaceutical products. SNAPC has been expanding rapidly- about 50% per year, and has now exceeded the design capacity of the facility by 100%. The facility currently consumes about 17 million kWh per year. About 13% of this electricity consumption (over 2 million kWh/year) is consumed by the plant's cooling water system (Wang et. al. 2002). This system was also selected as a site for the hands-on training of the Chinese experts because the cooling water system was known to have potential for optimization.

The cooling water system consists of four parallel pumps and five cooling towers. Three of the pumps are powered by 160 kW motors and one by a 75 kW motor. Each cooling tower fan is powered by a 15 kW motor. See Figure 2.

Figure 2. Pumping System Diagram



The cooling towers are located on the top of a building of 11 meters high, and the water pumps are mounted in the first floor. Two 160 kW pumps usually operate at the same time and another one is used for a backup. These two pumps run 5,000 hours annually and consume about 1,788,000 kWh of electricity per year. The 75 kW pump operates 4,000 hours every year and consumes about 243,000 kWh of electricity annually. Based on discussions with facility staff, it was determined that the winter operation is one pump running with one tower and summer operation consists of operating both pumps with all five towers in operation. Control is manual with additional pumps started up by the operator in response to a decline in the head observed by monitoring the pressure.

This cooling water system is mainly responsible for cooling chillers, compressors, vacuum pumps and production processes such as the Sterile Workshop, Dextromethorphan HBr Workshop, and the Pyritino HCL Workshop. Approximately 90% of the circulating water is used for chillers. Facility staff indicated that the other 10% used for process water is removed from the system (to drains after used for cooling) to minimize the load on the cooling system since this water was at a higher temperature. The design parameters of the pumps are listed in Table 1.

Table 1. Original Pumps Design Parameters

Model	Quantity	Flow rate (m^3/h)	Head (m)	Speed (rpm)	Efficiency (%)	Power (kW)
350S-44A	3	864	41	1450	84	160
300S-32A	1	551	31	1450	80	75

There are four chillers in this system, the design parameters of which are listed in Table 2. Normally, three parallel chillers operate at the same time, and one is used for back up.

Table 2. Designed Parameters of the Chillers

Flow rate (m^3/h)	Pressure Drop (Mpa)	Inlet Temp. (°C)	Outlet Temp. (°C)
328.6	0.0786	32	37

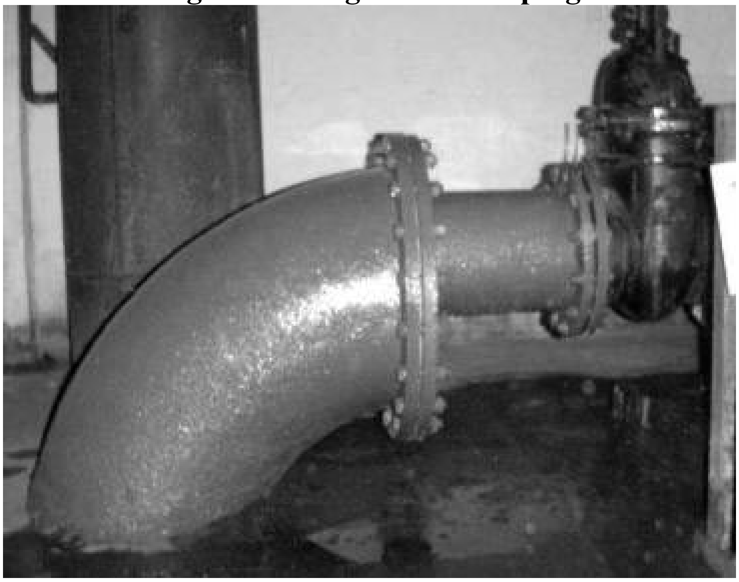
Project evaluation. Field measurements were taken various conditions to simulate seasonal variations in the operating scheme. The results of the measurements are given in Table 3. Also, it was observed that the flow control valves are partially closed to regulate flow, which averages 700 m^3/hour, but peaks at 1,350 m^3/hour in the warmest weather. The pumps also have several installation problems, most notably a drastic change in pipe size both at the pump inlet and outlet (Figure 3). Such sudden changes in diameter cause large point losses and probably disturb inflow conditions to the pump.

Table 3. Measurement Results Table

Operation Combination	2*160kw	1*160kw+1*75kw	1*160kw
Power (kw)	312	220	158
Head (Mpa)	0.4	0.35	0.31
Flow rate (m^3/hr)	2200	1750	1100

Based on these measurements and analysis, it was determined that the pumps operate at an overall system efficiency of about 37% (McKane et al. 2002a). Further, the experts concluded that the pumps are oversized, flow regulation is difficult, and the quality of the circulating water cannot satisfy the requirements of the heat exchangers.

Figure 3. Original Inlet Piping



Project implementation. Based on recommendations from the Chinese and International Experts, the facility decided to proceed with an optimization project that included:

- installing two new pumps
- applying variable speed control
- cleaning the piping system

Two new pumps with proper head and flow rate were installed to replace original pumps. The nameplate parameters of new pumps are listed as Table 4. Normally, only one pump can match the system requirements, and it can be switched to another one automatically when something wrong happens with this pump. One 160 kW pump and one 75 kW pump operated before optimization, which overall consumed about 220 kW electricity per hour. After optimization, one pump consuming only 70 kW electricity per hour can satisfy the total system requirements. Moreover, the inlet and outlet of the pumps were re-designed to further improve the efficiency of the system. In place of a sudden direction change at the inlet of the pump, some long radius elbows were installed at the upstream of the pumps, which created a more even velocity profile and minimized the head losses on the inlet side of a pump (see Figure 4).

Table 4. New Pumps Nameplate Parameters

Model	Flow rate (m^3/h)	Head (m)	Speed (rpm)	Efficiency (%)	Power (kW)
350-380	1424	31	1450	85.5	160

To address the large range of system load change, variable frequency drives (VFDs) and an automatic control system were applied to pumping system, providing a means to improve operating efficiency of the pumps. The automatic control system directs the VFDs to regulate the speed of the pumps to match the system requirements according to process requirements and the temperature of water returned to cooling tower.

Additionally, the interiors of the piping system and heat exchangers have been cleaned. As a result of this cleaning, the resistance of the piping system was lowered and the quality of cooling water was improved. Originally, the resistance loss of the chiller's condenser ranged from 0.15 Mpa to 0.20 Mpa. The pressure drop has been reduced to only 0.01 Mpa after cleaning. In addition, the cleaning also improved the heat transfer efficiency of the heat exchangers, with the temperature difference between the inlet and outlet of the condenser increased about 1.5°C under the same flow rate.

Figure 4. New Pumping Systems

Project funding. The Shanghai Energy Conservation Service Center provided financing for this project and entered into a shared-savings arrangement with SNAPC. Based on an investment of $145,000 and estimated annual savings of $80,000, the simple payback for this project is about 1.8 years. The annual energy savings is calculated at 49%, over one million kWh/year.

Additional Resources

For more information on the systems approach, motor systems-related case studies and best practices resource guides, contact the EERE information clearinghouse at 800-862-2086, or visit the website (www.oit.doe.gov/bestpractices). In addition, www.ProductiveEnergy.com is another website that contains information about the systems approach, and on-line assessment tools for evaluating fan, pump, blower and compressed air system optimization opportunities. The website also contains a motor repair/replace policy tool writer that writes a sample repair/replace policy for a facility based on the BestPractices methodology.

Conclusions

The China Motor Systems Optimization Program is off to a good start with these and other case studies that are still in the works. Many of the potential projects identified in the early plant visits are very good optimization opportunities, but these are just two examples. Many motor system optimization opportunities exist in China, and they seem to be fairly similar in nature to the types of system opportunities found in US industry.

References

Hinge, Adam, Steven Nadel, Dai Yande, Zhang Jin Lan, and Sun Chunxuan. 1996. *The Chinese Market for Electric Motors and Motor Speed Controls*. Washington, DC: American Council for an Energy-Efficient Economy.

Lung, Robert Bruce, Aimee McKane, Mitch Olzewski. 2003. *Industrial Motor System Optimization Projects in the US: An Impact Study.* Washington, DC: American Council for an Energy-Efficient Economy.

McKane, Aimee, Robert Williams, Vestal Tutterow, Steven Nadel, and Zou Guijin. 2003. *Motor System Optimization in China: A Capacity-Building Model for Industrial Energy Efficiency*. Washington, DC: American Council for an Energy-Efficient Economy.

McKane, Aimee, Vestal Tutterow, Gunnar Hovstadius, and Steven Bolles. 2002. *China Motor System Energy Conservation Project, Technical Report: Second Mission of the CTA.* Vienna, Austria. United Nations Industrial Development Organization.

McKane, Aimee, Ronald Wroblewski, Hugh Falkner, Gunnar Hovstadius, and Steven Bolles. 2002. *China Motor System Energy Conservation Project, Technical Report: Third Mission of the CTA.* Vienna, Austria. United Nations Industrial Development Organization.

Wang, Wenkang, Zhang, Tiechang, and Qin Hongbo. 2002. *Performance Optimization of Pump System of a Pharmaceuticals Company*. unpublished Case Study. Shanghai, China. Shanghai Energy Conservation Service Center.