AIRMASTER: COMPRESSED AIR SYSTEM AUDIT SOFTWARE

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ABSTRACT

The project goal was to develop a software tool, AIRMaster, and a methodology for performing compressed air system audits. AIRMaster and supporting manuals are designed for general auditors or plant personnel to evaluate compressed air system operation with simple instrumentation during a short-term audit. AIRMaster provides a systematic approach to compressed air system audits, analyzing collected data, and reporting results. AIRMaster focuses on inexpensive Operation and Maintenance (O&M) measures, such as fixing air leaks and improving controls that can significantly improve performance and reliability of the compressed air system, without significant risk to production.

An experienced auditor can perform an audit, analyze collected data, and produce results in 2-3 days. AIRMaster reduces the cost of an audit, thus freeing funds to implement recommendations. The AIRMaster package includes an Audit Manual, Software and User's manual, Analysis Methodology Manual, and a Case Studies summary report. It also includes a "Self-Guided Tour" booklet to help users quickly screen a plant for efficiency improvement potential, and an Industrial Compressed Air System Energy Efficiency Guidebook.

AIRMaster proved to be a fast and effective audit tool. In seven audits AIRMaster identified energy savings of 4,056,000 kWh, or 49.2% of annual compressor energy use, for a cost savings of $152,000. Total implementation costs were $94,700 for a project payback period of 0.6 years. Available airflow increased between 11% and 51% of plant compressor capacity, leading to potential capital benefits from 40% to 230% of first year energy savings.

INTRODUCTION

Air compressors are a significant industrial energy user, and therefore a prime target for energy audits. Based on our analysis of energy audit reports from 125 northwest plants, air compressors account for an average 10% of total plant energy use. Furthermore, air compression is inefficient, with up to 90% of compressor power dissipated as heat. Thus, even minor improvements in system operation, control strategies, and efficiency can yield large energy savings. Many industrial plants have significant air leaks, or inappropriate uses of compressed air. Because the cost to compress air is high, reducing compressed air losses to system leaks and inefficient uses of air can also produce energy and cost savings.

AIRMaster software

AIRMaster is a spreadsheet-based program that can model part load system operation with up to five rotary screw and reciprocating compressors operating simultaneously with varying control strategies and operating schedules. AIRMaster is intended to enable auditors to model existing and future improved system operation, and evaluate savings from energy efficiency measures with relatively short payback periods. Results can be used to generate a report. Due to their complex operation and modeling, the analysis of centrifugal compressors is not included in AIRMaster at this time (but will be in a future release). On-line help accompanies the software to help the user. A technical staff supports AIRMaster users, and a World Wide Web site (http://www.energy.wsu.edu/org/airmaster) is available for reference.

AIRMaster product line. The AIRMaster package includes the following:

- Self-Guided Tour booklet to help users quickly screen a plant for efficiency improvement potential.
- AIRMaster software.
- User's Manual describing how to use the software.
- Analysis Methodology manual describing analysis methods used by the software.
- Audit Manual describing audit methodology and data collection methods and forms.
- Two sample reports that include a detailed list of leaks to repair and recommended improvements.
- Case Studies summary report and diskette files that summarize the results of seven audits.
- Industrial Compressed Air System Energy Efficiency Guidebook.

AIRMaster capabilities:

- Allows 24-hour load profiles for up to 5 interconnected screw and/or reciprocating compressors for up to 4 typical "daytypes" (for example, peak production, night shift, or cleanup).
- Allows separate operating pressure range, partload efficiency, and control strategy for each compressor.
- Interactive measures, such that each measure selected uses the proposed conditions from the previous measure, to avoid overestimating savings.
- Prints graphs, tables and charts for your reports.
- Extensive on-line help, including step-by-step instructions for entering data from data collection forms.
- A built-in Navigator makes it easy get around in AIRMaster.
- Extensive database of compressor performance and control strategies for 6 manufacturers. User's may add compressors, enter measured compressor performance, or use manufacturers' default specifications.
- A Control Test that ensures that compressor operation is consistent with the control strategy and operating pressure ranges you enter. AIRMaster apportions a given load among operating compressors according to these control strategies and pressure ranges.
- A Load Wizard helps to enter air use or compressor loads for each hour of each daytype. You enter the load for one compressor and the Load Wizard calculates the remaining loads according to the control strategy.
- Analyzes six common energy efficiency measures:
  1. **Reduce plant air leaks**. Determine proposed airflow profiles based on leak reduction and fixed airflow adjustments.
  2. **Adjust manual staging** (no sequencer). Adjust pressure control ranges on modulating compressors to avoid multiple compressors operating inefficiently at partload.
  3. **Use unloading controls**. Install or adjust existing unloading controls with optional automatic shutdown timer to improve partload efficiency. This measure requires adequate receiver capacity to avoid unloading cycle times less than two minutes.
  4. **Reduce system pressure**. Reduce system pressure to reduce compressor power.
  5. **Sequence compressors**. Sequence compressors to turn compressors on and off automatically, as needed, and to allow changing the sequence order to balance wear.
  6. **Reduce run time**. Turn off compressors that are not needed at specified times.

ENERGY BENEFITS

Seven audits of compressed air systems were performed to evaluate and refine AIRMaster and supporting manuals and methodology, as well as to assess savings potential of energy efficiency measures. Results from the case studies will be summarized here[1]. As Table 1 shows, compressors account for a significant portion of plant electricity use, ranging from 8.3% to 33.3%, with an average of 14.7%. Total compressor energy use ranged from 650,144 kWh for the electronics plant to 2,699,518 kWh for the sawmill. Thus, even minor modifications to the compressed air systems have high potential for significant energy savings.

Table 1. Utility Summary

Utility Summary					
Audit	Demand Cost ($/kW-mo)	Energy Cost ($/kWh)	Total Plant Electricity Use (kWh)	Compressor Electricity Use (kWh)	Percent Plant Energy
1. Bakery	$4.35	$0.0237	4,234,800	677,842	16.0%
2. Sawmill	$3.46	$0.0333	15,894,000	2,699,518	17.0%
3. Mill Work	$4.35	$0.0237	6,432,040	831,951	12.9%
4. Metal Fabrication	$4.30	$0.0361	3,358,193	1,119,044	33.3%
5. Foundry 1	$4.30	$0.0361	12,758,324	1,062,167	8.3%
6. Foundry 2	$3.86	$0.0349	10,458,000	1,201,419	11.5%
7. Electronics	$4.35	$0.0237	2,842,800	650,144	22.9%
Total			55,978,157	8,242,085	14.7%
Average/Plant	$4.14	$0.0302	7,996,880	1,177,441	14.7%

Table 2 shows summary results for the standard energy efficiency measures considered during the seven audits.

Table 2. O&M Total Savings Summary

O&M Total Savings Summary							
Measure	Occurrence Rate	Energy kWh	Average* Savings	Maximum* Savings	Cost Savings	Implementation Cost	Payback Years
Reduce Leaks	100%	2,883,408	35.0%	59.3%	$115,656	$75,225	0.7
Unloading Controls	86%	805,670	9.8%	33.5%	$26,573	$17,410	0.7
Reduce Pressure	28%	91,919	1.1%	10.6%	$2,946	$1,849	0.6
Reduce Run Time	28%	274,908	3.3%	15.8%	$6,622	$200	0.1
Sequence controls**	43%	601,268	7.3%	33.6%	$18,458	$29,059	1.6
Total		4,055,905	49.2%	71.2%	$151,797	$94,684	0.6

* Average Savings is the total energy saved by a measure for all plants divided by total annual compressor use. Maximum Savings is for the plant with the greatest energy savings when compared to annual compressor use.
** Sequence compressors is included as an alternative to other measures recommended, therefore savings are not included in the project totals.

Without exception, each plant could realize significant energy and cost savings by fixing air leaks in the air distribution system and at end uses. Savings from fixing air leaks were greater than from all the other measures combined for the seven audits, saving an average 35% of compressor energy with a payback period of 0.7 years. The savings from leaks were high in part because we recommended reducing leaks at all seven plants, as indicated in the occurrence column of Table 2. In many cases, a compressor could be turned off as a result of repairing leaks, which significantly improved savings.

Reducing leaks included eliminating "planned" leaks, which we define as inefficient uses of compressed air such as cooling product or people. Planned leaks are treated the same as normal air system leaks, except that the former may be intermittent and the latter are continuous.

Table 3 shows savings only for eliminating the planned leaks at four plants. Savings and costs for reducing planned leaks are also included in the Reduce Leaks measure in the case studies and in Table 2.

Table 3. Planned Compressed Air Leaks

"Planned" Compressed Air Leaks					
Audit #	"Leak" Description	Energy kWh	Cost Savings	Implementation Cost	Payback Years
2. Sawmill	Efficient Nozzles	400,109	$15,865	$40	0.0
3. Millwork	Dedicated Vacuum Pump	36,242	$1,277	$1,350	1.1
4. Metal Fab.	Low Pressure Blower	270,863	$12,049	$9,000	0.8
5. Foundry 1	Burner Fans	35,686	$3,334	$20,000	6.0
Average		114,264	$5,553	$14,953	2.6

Installing or using unloading controls was the second most frequently recommended measure and was recommended at all plants except the metal fabrication plant that already used unloading controls. Savings for unloading controls were 9.8% with a payback of 0.7 years.

NON-ENERGY BENEFITS

Most investments in energy efficiency measures are based only on energy savings in the economic analyses. However, there are often other "non-energy" benefits of efficiency. Other investigators have noted that non-energy benefits are often the true drivers of the decision to implement measures[2]. Unless these benefits are understood and quantified, the total benefit will be understated, and the resulting payback periods will be overstated.

Quantifiable Benefits. Improving the performance of compressed air systems can have these additional benefits:

1. **Increase available airflow.** Reducing leaks, both planned and unplanned, and pressure drops (and system pressure) will increase airflow available to equipment and tools.
2. **Delay or reduce capital costs.** With more available airflow, a manufacturer may avoid or delay the capital costs associated with purchase of a new compressor to meet growing demand for air.

We estimated these benefits for the seven audits conducted using AIRMaster. Table 4 shows that the increase in available airflow (relative to peak production airflow) ranges from a low of 11% to a high of 51%. More available airflow also means capital benefits.

If we assume compressor efficiency is 4.5 acfm per horsepower at full load, capital cost is $300 per horsepower for a new compressor (installed), energy cost is $0.03/kWh, and demand cost is $4.1/kW-mo, then Table 4 summarizes the quantifiable non-energy benefits. The capital benefits range from 40% to over 200% of first year energy benefits. Note that the capital benefit is most tangible when the plant is short of compressor capacity and purchase of a new compressor is being contemplated.

Table 4. Quantifiable Benefits (Assumes 4.5 acfm/HP, $300/HP Capital Cost, Energy cost $0.03/kWh, and Demand cost $4.1/kW-mo)

Quantifiable Benefits of Air System Efficiency				
Plant Type	acfm Increase	Energy Payback years	Capital Benefits Increase	Net Payback years
Electronics	11%	0.1	40%	<0.1
Foundry 1	26%	1.3	80%	0.7
Foundry 2	37%	0.8	110%	0.4
Mill Work	25%	1.5	120%	0.7
Saw Mill	51%	0.2	70%	0.1
Bakery	18%	1.5	70%	0.9
Metal Fab.	47%	0.7	230%	0.2

Non-Quantifiable Benefits. Improving the performance of compressed air systems can have additional benefits associated with production and reliability:

1. **Extend equipment life** by reducing compressors loads, reducing operating time by turning compressors off when not needed, and sequencing them to balance wear.
2. **Increase system reliability** by increasing available airflow and maintaining equipment to operate under the conditions for which it was designed.
3. **Reduce environmental impact** by reducing greenhouse gas emissions from power generation facilities, and from the energy, material, and disposal costs from purchasing new equipment.

KEY FINDINGS

Several key findings based on case study experience are as follows:

1. **Check compressor operation.** Perform a pre-audit compressor performance check before collecting data that AIRMaster will use. For example, mechanical problems, such as an air inlet valve not opening completely at full load, can lead to errors when estimating savings. However, these problems can often be repaired on the spot. We recommend measuring compressor power before and after correcting problems and including the savings in the total savings estimates.
2. **Check receiver capacity**. This is particularly important in plants for which unloading controls are either used or recommended. While unloading controls are an effective method of improving partload efficiency, receiver capacity must be considered. Inadequate receiver capacity can cause compressors to short cycle, thus increasing cycle losses. Such operation is inefficient and reduces potential savings. We recommend adding receiver capacity if the unloading cycle time is less than 2 minutes.[3]
3. **Reduce system pressure.** Look for high pressure drops in the distribution system. For example, pipe diameter may be inadequate if new compressors are added to an existing system, or restrictions in an air dryer can lead to excessive pressure drops. Raising the compressor discharge pressure to overcome the loss increases power use by over 0.5% for each psi that pressure is raised. Reducing the pressure loss and thereby discharge pressure is generally a more effective method of meeting plant air pressure requirements.
4. **Use simple analysis methods.** Avoid a detailed analysis when the savings are not great. For example, datalogging for several weeks improves accuracy, but estimating air use by interviewing plant staff is often sufficient for useful results. We estimated compressor energy use within 1% using both methods at one plant.
5. **Estimate costs.** While estimating costs for purchasing and installing unloading controls or sequencers is relatively easy, the cost of repairing air leaks is less certain. We have discovered, however, that in all seven cases the cost to repair leaks was less than first year savings. In general, accurately estimating the cost to repair each leak is not necessary, except in cases where costly rebuild kits or parts are required. For most of the easily accessible leaks around hoses and fittings, don't analyze them, *JUST FIX THEM!*
6. **Be specific.** Provide the size, capacity, and function specification for the specific equipment needed to implement your recommendations. Make it is easy for the manufacturer to carry out your recommendations while using their customary consultants and vendors.
7. **Audit while plant is down.** Consider performing at least part of the compressed air system audit when the plant is not operating, such as a weekend or maintenance shift. This will allow you to test compressor performance without interfering with production and to detect air leaks. Leaks are easier to identify when the plant is quiet. You can also get closer to leaks and inside equipment packages safely when the equipment is not moving.

COMPRESSED AIR O&M SERVICE

Compressed air system audits can be performed fast and efficiently using AIRMaster. Our team of two experienced auditors was able to perform the audit and prepare the report in 2-3 days. Variations depend on the size of the plants and system complexity. This includes performing most audit activities in the plant on weekends or late at night to avoid interfering with production.

Plant selection is an important factor for making this service successful. Not all plants have significant savings opportunities, and it will not be effective to conduct full audits for well-maintained systems. Accordingly, the AIRMaster package includes a "Self Guided Tour" that helps manufacturers or auditors determine if a plant would benefit from an AIRMaster audit.

One goal of AIRMaster is to make the audit, analysis, and report easy to learn and fast to use, so that more time can be spent in implementing measures. The goal is not to perform audits, but to realize the benefits. Therefore plans include improvements to AIRMaster and an implementation strategy. For example, compressed air services might be provided by:

- Manufacturers or distributors of compressed air systems bundling efficiency services with compressor sales
- Energy Services Companies (ESCOs) performing efficiency services on a fixed fee or shared savings basis
- Utilities implementing an air audit program for their industrial customers
- Leak Repair "Circuit Riders" who bypass audits and just fix it

CONCLUSIONS

The AIRMaster Compressed Air System Audit Software tool was designed to get results. It is powerful, fast and easy use. AIRMaster provides a straightforward, systematic way to perform a compressed air system O&M audit, analyze collected information, and obtain useful recommendations for air system improvements.

Seven audits of compressed air systems were performed to evaluate and refine AIRMaster and supporting manuals, as well as to assess the savings potential of energy efficiency measures. In these plants, air compressors accounted for 14.7% of annual electrical energy use. Total estimated energy savings for the project were 4,056,000 kWh or 49.2% of annual compressor energy use for cost savings of $152,000. Total implementation costs were $94,700 for a project payback period of 0.6 years. Available airflow increased between 11% to 51% of plant compressor capacity. Additional available airflow resulted in potential capital benefits from 40% to 230% of first year energy savings.

Inexpensive O&M measures can deliver significant savings without significant risk to production. Reducing air leaks not only saves energy but increases available airflow to equipment and tools by up to 50%. Reducing leaks saved 35% of compressor energy use, and can also avoid or delay the capital and operating costs of a new compressor, or allow purchase of a smaller compressor. Installing controls and implementing other measures saved an additional 15% of compressor energy use, and can also increase equipment life and reliability. We conclude that there is adequate motivation for plants to improve compressed air system efficiency without the need for incentives.

REFERENCES

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