Final Report
Increasing Air Compressor Productivity
While Reducing Maintenance and Repair Costs

U.S. DEPARTMENT OF TRANSPORTATION
MARITIME ADMINISTRATION

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

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FINAL REPORT
INCREASING AIR COMPRESSOR PRODUCTIVIIY
WHILE REDUCING MAINTENANCE AND REPAIR COSTS
SP-1-85-2

TO
SNAME/SHIP PRODUCTION COMMITTEE
PANEL SP-1
FACILITIES AND ENVIRONMENTAL EFFECTS

BY
NATION STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

PROJECT 1-85-2: INCREASING AIR COMPRESSOR PRODUCTIVITY WHILE REDUCING MAINTENANCE AND REPAIR COSTS.

ACKNOWLEDGMENTS

This information is dedicated to the cause of a more and better effective use of Compressed Air as a shipbuilding and repair yard utility, and to a more cost effective operation and maintenance practice of the systems that supply the air.

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INTRODUCTION

Compressed Air like electricity, natural gas, water, special gases and telephone service is a utility to the industry. It is also like these because it <u>costs money</u>. The need to recognize this can become compelling if the cost per year reaches the amounts determined in this study.

We must think of a yard Compressed Air System as a" power plant" which contains capital machinery, a distribution system, a fuel source and supply, an operating plan and strategy, and an operating / maintenance budget. When this vital utility is put into this perspective we can start to deal with the considerations of systems engineering, planning, performance evaluation, cost control and preventive maintenance; the same as any power plant operator.

Do we know what the Air costs that our system produces? This is one of the very first questions that Scot Foss asks when conducting his seminars or engineering consulting projects.

We shall be referring to information found in various publications that were authored by Mr. Foss and will use his very well developed approaches to analyzing compressed air systems, just as was done for NASSCO. The experience with that specific yard system covers some 12 years, identifies key milestones in system improvement, as well as maintenance practices and related costs.

The approach in this study to evaluating maintenance costs determined very early on that the maintenance and operation of most, if not all, shipyard compressor systems are inseparable. At NASSCO, the Maintenance Department is responsible for directly operating and maintaining the air compressors and distribution system. Therefore it was necessary to explore the best thinking in air systems, including engineering, planning, operational strategy, and preventive maintenance strategy.

This report is intended to trace the NASSCO compressed air system evolution through a number of years of history, showing the impact of the changes on costs and operational strategies. These changes mark milestones which relate to specific issues developed by Scot Foss in his programs for improving system performance.

IT'S ONLY AIR !

**A BACKGROUND TO THE PROBLEMS OF MANAGING
COMPRESSED AIR SYSTEMS.**

IT'S JUST AIR!

Wrong! The air we generate to operate the machines and tools of our yards may often be passed off as being *free* like that of our atmosphere and not command our attention so long as the " flow is good and the pressure is sufficient". However, this is simply not the case.

Compressed air is a utility which carries a cost per cubic foot just as electricity has a price per KWH. Since yards operate their own systems that cost can vary from installation to installation. Factors will be quite different:
   * Electricity rate in a given area.
   * System configuration.
   * Compressor equipment age and capacity.
   * Condition of the distribution system.
   * Regulation of the system.
There are others, but one can see that the cost will be system specific.

Therefore the economics of a system deserves early evaluation and analysis, and sets the stage for the other steps which may follow in order to change and improve a system. How many yards know how much air is being used and what that air costs? How many yards have made an engineering evaluation of their system in terms of productive efficiency?

Even if the maintenance costs for a specific system are recorded and accounted with great detail and accuracy, these costs are not meaningful if the efficiency cannot be accurately evaluated. As a result, system improvement may not be planned and engineered.

Scot Foss in a series of three articles in *Maintenance Technology* magazine sets forth an excellent overview for *Managing Compressed Air.* The articles are titled Economics of *Compressed Air, Auditing Compressed Air Costs,* and *Controlling Demand in Compressed Air Systems.*

SUPPLY CONTROLLED SYSTEMS.

If the system under review consists of compressor(s), distribution (piping), and the connected equipment and tools but has no regulation, the system

is as basic as can be found in the smallest of shops. This is a SUPPLY controlled system, in which the user operates his equipment and when that equipment demands more pressure and flow than the system can supply "more capacity is obtained" in order to meet the increased demand. The *supply* is creating the demand. This is a vicious cycle and can victimize the best operated yard.

Another way to look at the problem is Uncontrolled Demand which creates a cycle where system pressure is increased, via the application of greater amounts of energy, until the resulting air flow exceeds the capacity of the distribution piping and the delivery pressure drops. Back to "the need to add compressor capacity".

Additionally, where controls are absent or inadequate the user demand as well as line leaks become a function of supply pressure. As the supply pressure rises the flow rises proportionately.

All of this builds toward the issue of cost.

COST EVALUATION.

For the moment, look at the basic question of the right way to measure cost and return to the system configuration question at a later point. The supply system makes it difficult to measure or calculate costs since the lack of a truly controlled system forces the necessity to evaluate parts, such as the compressors on a stand alone basis. The operating cost of the compressor(s) can be calculated based upon HP rating and therefore (calculated) electric power consumption. These can be metered over a period of time and therefore an even more accurate consumption of power may be determined. The capacity of the compressor(s) can then be related to the consumption of electrical power and the cost / 100 CFM can be derived.

The problem with this method is that even if performed with great skill and accuracy it does not relate to the various demand loads of the system, but at best to the efficiency of the compressor(s).

The proper method and unit of measure should be production demand or cost/hour/1 00 CFM. Scot Foss puts this into the following equation:

$$\text{COST/HOUR/100 CFM} = \frac{\text{TOTAL SYSTEM COST/HOUR}}{\text{DEMAND/100 CFM}}$$

4

The full engineering calculations needed to support the complete working analysis of all the contributing factors is contained in the appendix.

The components of Compressed Air Costs are:
* Power (Electricity/ other)
* Cooling
* Drying
* Maintenance
* Operation
* Depreciation
* Other (i.e.. G&A, Insurance, etc)

The tasks required for any complete evaluation are:
* Identify the complete system.
* Quantify the Air Supply (Demand and Leakage).
* Quantify the operating cost to sustain the supply.

Production Demand is the ideal, true measure of use. However, Total Demand is what is found in most yard systems and is made up of the following:

1 Production Demand (the real requirement).
2 Artificial Demand (caused by having a supply pressure that is higher than is required at point of use, thus delivering more air than the use requires).
3 Line Leaks.

HOW TO PUT THE COST UNDER CONTROL.

The ideal operating system with the optimum cost/hour/100cfm is one in which the "on line" compressor capacity exactly equals the "real" production demand. This is a system with no "artificial" demand and without "leaks", and uses "off line" compressor capacity for standby purposes.

Good Operating Practice uses the rule that----
(1) All compressors that are on line run "flat out", with one additional compressor for "trimming", and
(2)   All other compressors are off line,
                                                ----This is regardless of demand variations.

When determining accurate system costs, both AIR FLOW and POWER CONSUMPTION must be measured.

MANAGEMENT VERSUS ECONOMICS.

All of this leads to the understanding of cost, and hopefully the best cost for a specific system: determining what the cost is, determining what to do to attain improvement, and how to maintain the improvement.

Scot Foss prescribes the MANAGED SYSTEM as the fundamental solution and building block to solving this. Managing a system consists of CONFIGURATION PLANNING, ENGINEERING, and IMPROVING. Since most yard systems change with time, increasing and decreasing work loads, the management practice will be a constant responsibility, the same as system maintenance.

The over view of a Compressed Air System is made up of five functional components:
* DEMAND
* DISTRIBUTION
* STORAGE
* REGULATION
* SUPPLY

Demand was well defined previously. However, detailed evaluation of the production demand by large users with in the yard is necessary in order to determine the maximum compressor capacity. The work schedules for areas of large demand when integrated into the planning and engineering activity will help determine the number, capacity, and power of the compressors.

Distribution at this point in the discussion centers on several concerns: piping sizing must be engineered to the ultimate flow needed to satisfy the true demand; does piping figure into the *Storage* factor?; have the fittings and connections been evaluated for best application?; etc. Most important in large systems, as most yards must have, i<u>s the *continuous loop* of the Header or Pipe Main.</u>

Storage is the *balancing act* of a properly configured system. Without storage, the compressors alone service the extremes of the demand. If the compressors are set to supply the *peak demand* all the machinery (including the ancillary equipment) will run during the less than peak periods. Storage is used to handle the *peak* and thus allow the machinery to be run at the level to supply the *mean demand,* a far more cost effective and efficient operating method.

Regulation is the method for controlling the system and permits the system to remain in balance. Intermediate control(s), placed down stream of the compressor and storage vessel, provides management of the demand (including leaks), controlling of storage, and unloading of the compressor power. Regulating the intermediate pressure and the compressor control pressure dictates the weight flow *of demand** and significantly the way in which the system performs. Intermediate control is the most important control point in a system. With proper, high quality devices the upstream and downstream conditions can be analyzed and controlled.

Supply and the cost of providing it is obviously the beneficiary of the completeness, thoroughness, and quality of the other component parts of the *managed system.*

The best cost of operation cannot be obtained unless the yard commits to managing air as *a Utility.*

WHAT IS THE COST?

When accurate costs are developed and all aspects have been considered (reference page 4), the cost of air will be 1.5 to 3 times that of electricity. The Scot Foss approach is to make a full audit of the system which encompasses engineering configuration and economics.

Again, if the" compressor operation alone is evaluated and costed from a load (electric power usage) point of view, the efficiency of the system and demand control are not addressed and there is no way to identify the ultimate source of cost control and reduction.

It is certainly in the realm of common sense estimating that if 20% loss to leaks, 20% loss in uncontrolled demand, and 10% loss to artificial demand is creditable, 1/2 of every $1,000,000.00 in power consumption for compressed air generation is attributable to system inefficiency.
*
This is explained in detail in the Appendix.

A CASE STUDY

NASSCO: A COMPRESSED AIR SYSTEM EVOLUTION

THE NASSCO EXPERIENCE

Like many yards and plants throughout the country Nassco's compressed air system started out as several systems which grew to meet production growth, a classic response to need. In 1980, faced with the need for a better understanding of the technology of compressed air systems, the commitment to improving the engineering and configuration of the system, and a realization that the problem had a large *dollar impact* the Facilities department engaged Scot Foss.

What happened from that point makes for an interesting case study. However, the best place to start is an overview of the system history: configuration, operations, maintenance, and engineering redevelopment.

1978   Started conversion from sub-system configuration to single system configuration.

1979   First common piping construction projects started.

1980   Scot Foss engaged to review system needs.

1981   Extension of common piping to the building dock and outfitting areas.

1982   Common piping extended to Floating Dock.

1982   Initiation of system controls and monitoring and automatic controlling of the compressors.

1984   Energy Conservation Project adds management focus to compressed air as a *Utility.*

1984   System *Looping* completed.

1988   Installation of *point of use* regulating begun.

1990   Second Foss engagement. Blast area review and experiment.

1992   *Balancing* of the complete system through point of use control and use of 18,000+ Lin Ft of 8" diameter piping distribution as storage.

The decisions, the relationship to the Foss approach, the impact of the improvements, the lessons learned, the advantages, and the disadvantages

will be discussed in order to give a detailed picture of this case study process.

THE EARLY PERIOD

Sometime prior to 1978 NASSCO had five separate and distinct compressed air systems. This condition was due directly to the fact that the National Steel and Shipbuilding Company was actually an amalgamation of several shipyards and other water front facilities. Each of these had its own supporting utilities, including compressed air.

There was probably a second reason for these individual systems to remain after the amalgamation and that was the prevailing view of Compressed Air. This was identified as a secondary facilities requirement to be dealt with after space, buildings, electric power and water, etc. There is little doubt, among the current yard *Informed,* that the planning was *put in a compressor and pipe* and let's get going.

The exact time that NASSCO started to *link* some of the of the systems is not known but was sometime prior to 1978. Therefore, as of the earliest date of this case study the *unification work* had already begun, but for these intents and purposes, 1978 marks the beginning of the *commitment.* That commitment was probably not as clearly defined as a formal statement and plan outline. However, it was a distinct change on the part of facilities engineering influence and the initiation of *a yard wide air supply system.*

If the *classic Scot Foss book approach* had been followed from this point, a complete audit, master plan, and supporting engineering would have been done. This was not the case due to the difference of priorities and most pressing issues. as seen by the production / maintenance departments versus those of facilities engineers.

This case study is classic, in that the prevailing philosophy was to maintain a *Supply System* while unifying and developing the larger nature of the *utility.* There were some pretty smart people who did not see the nature of the problems of the system beyond the fact that it made good sense to have one system rather than several small ones.

* Calculating compressor capacities showed that certain compressors could be working while others were not working.
* This possibility was viewed as an important aid in reducing the maintenance impact on production, since the compressors would be operated in a more efficient manner.

* **The combining of compressors could *increase total capacity of the unified system in order to meet more DEMAND.***

These highly logical reasons go another step in arguing the Scot Foss point for knowing the *cost of AIR* This *hind site* error is in no way unique and it is not intended to embarrass nor to detract from the effective improvement program which followed.

THE GROWTH OF ONE COMPLETE SYSTEM

No sooner had the unification of the system been undertaken, than the need for expansion was recognized. Up until this time portable compressors were utilized to supply production at the building dock and outfitting areas. In 1979, 80, and 81, the new system piping was extended to cover these functions as well as new "on-block" areas that were being utilized.

In 1982, NASSCO had acquired a new floating dry dock and piping extension to this new facility was undertaken. At this same point in time, a very important step was taken. The engineering and maintenance group introduced a *Westinghouse PC 900B* programmable controller with 256 input / output capacity.

This control has evolved along with the system, however, it was utilized from inception for displaying system status and permitting remote control of the compressors. The introduction of this layer of sophistication was not without problems and an associated learning curve. After some experience and study the complete system was reprogrammed in order to make it more effective and efficient.

NASSCO formed an ENERGY CONSERVATION PROJECT in 1984 which looked into all energy use issues. Among these was the compressed air system since it had such a high use of electric power. This caused a Management Awareness never quite like it before. The power consumption of the compressors put new stress on the control system and the advantages of a *looped header* were identified. This helped the project and added emphasis to the completion that year.

During the next few years, the production demand caused the changes in the system to wait for *priority treatment* and it was not until 1988 that a new push was made. *Regulation* for control and balance was the objective of this phase of the project and included:

1. **PRESSURE VALUE WORKING STANDARDS** for each end user.

2. **BALANCING OF THE SYSTEM.**
3. **TEMPERATURE AND VELOCITY CONTROL.**
4. **PROPER DRAINAGE SYSTEMS.**
5. **DELTA PRESSURE FEED BACK AND MONITORING.**

It should be noted that the PC 900B was reprogrammed in order to tighten the pressure band width that would afford closer control for the delta P required in the system *balancing.* The system itself was now a *storage* component that added 6300 CF *(free air)* to the receiver storage already in the system.

The completion of this work was accomplished in 1992 with the installation of the final group of regulators.

THE PREVAILING OBJECTIVES.

Remember, the NASSCO goals were driven by the primary desire to lower energy usage while improving the system effectiveness and maintenance. One very specific objective was to lower energy costs by *shifting loads to off peak hours* through the utilization of high pressure storage, demand control, and compressor control.

The Foss involvement early on had made the key players realize that there were four areas of system configuration improvement that can significantly reduce power cost:
1. **Minimize waste.**
2. **Control demand.**
3. **Control the compressors.**
4. **Utilize storage.**

The efficiency of the system, the ability to shut off the compressors, is far more important than the efficiency of the compressors.   .

The looping of the 8" header, the installation of the PC 900B, and installation of the regulation effected each of these desires. Pressure Value Standards for each production area impacted the waste conditions (primarily leaks and equipment) immediately. The regulation controlled the demand. The automatic control system managed and controlled the compressors *load, unload, and trim* status with *planned parameters.* And, the loop in combination with the regulation provided the *storage.* The waste condition was the least satisfactory of the improved targets, this will be discussed in detail in a later section.

THE DETAILS.

Now that the history of the system has been traced, and it may be very similar in part to other yard system evolutions, a look at the *details* is in order. How well does the NASSCO experience fit the *Foss Program?* What have been the benefits of this effort for production? . . . . maintenance? .... cost effectiveness?

In order to do this, the 1988 effort needs to be looked at more closely. What had happened prior to this point had been largely the necessity for *amalgamation* with an emphasis first upon a single system configuration, then an expansion to meet new production and facilities needs, and finally the *looping* of the header. The latter was the bridge to the Foss based program which set the stage for truly creating a *Managed System.*

A complete Industrial Engineering study was conducted by the Maintenance and Facilities Departments in 1988. This was the main thrust of the system survey advocated by Scot Foss. This included the following work:

1. Setting Pressure Standards with the *users.*

2. Balancing the system with P2 (Compressor discharge) controlled to 117psi, P3 (Entry to header from the ancillary equipment discharge) at 105psi, and P4 (farthest point in the header) at *user standard.*
   Note: This is a greater differential than recommended by Scot Foss and represents a practical decision, through specific system experience.

3. Review of all Drying and Filtering Equipment for best operation.

4. Re-evaluate operating and maintenance procedures.

5. Evaluate Slave Coolers to enhance drying performance.

6. Evaluate drainage and waste disposal.

7. Evaluate Ventilation of each compressor station in order to assure positive ambient pressure, exhaust to the external atmosphere, and ambient clean air.

8. Establish *Delta* pressure and temperature monitoring

9. Evaluate compressor and ancillary equipment lubricants to determine operational and cost effects.

It was necessary for the *users and providers* to agree on the pressures that would be delivered by the system for each production area or *sector.* This is a vital step in any system management program and not always an easy step. Firstly, the providers, in this case the Maintenance Department, had to accept themselves as the *vendors* and Production as the *customers.* Secondly, an education effort had to be made with key players on both sides since the misconceptions concerning costs *and management* of a Compressed Air system were universal. Some of these misconceptions are still alive and well at the yard. The main issue was naturally *pressure.* The prevailing idea that *more is better and the highest is best is* not easy to eradicate from the thinking where the system history had been *Supply Controlfor* so many years.

In spite of the problems, the NASSCO team was able to negotiate *Pressure Standards* which have formed the basis for system operations since.

DEPARTMENT/FUNCTION	PRESSURE (psi)
Paint	85
Portable Blast	100
Stationary Blast	100
Flame Spray	95
Respirable Air	90
Water Front	90
General (Shops)	85
Steel	85
Navy	85

Balancing the system is accomplished by setting the *Sector Regulators (see* the system plan) to the standard delivery pressur. es; utilizing the storage in the 8" piping loop; running the *on line compressors* flat out; and utilizing one compressor for *trim.* The ability to automatically control the compressors to respond to *pressure windows* and *time windows* is also vital to maintaining the balance.

A pressure window consists of settings that tell a compressor control to *turn on* and *turn off,* or to *throttle* up or *throttle back* in the case of a trimming compressor. The time windows control the delay period that might be necessary prior to the control response to any given pressure change. This prevents unnecessary starts and stops, jerks and glitches to the equipment due to momentary pressure readings at the critical *window edges.*

the equipment due to momentary pressure readings at the critical window *edges.*

The operational history of the system is captured in the following chart:

| Year Ins tituted[Control Method] | PRESSURE | | (psi) |
	P2	P3	P4
1978 [Manual]	120*	110*	100
1982 [Automatic/unbalanced] ***115		105	85
1990 [Balanced/Automatic]	117	108	**

*Whatever was needed to maintain 100 psi at the user station. This was a **Supply Controlled System** *dictated by* **Demand.**

** pressure value Standard shown above.

*** **This** system still had to operate as a **Supply** system since the regulation was not completed until later. However, the controls allowed for a greater degree of planning so that compressors could be brought **on line** and taken **off** line as changes in pressure down stream of the compressors were detected.

The maintenance aspects of the program were in most respects a reflection of how the operations were going. If the compressors and ancillary equipment could be run flat *out or shutoff,* and not start and *stop ---- start and stop,* there would be an obvious advantage and improvement in the machinery wear. Preventive maintenance for *filters, lubricants, bearings, and peripherals* has always been a key to the NASSCO practice. The maintenance costs for normal preventive maintenance dropped by 12% simply by the reduced operating time ,which was 33%. However, this did not take in the additional savings in lubrication costs of about 10% reduction.

The overhaul costs for compressors could not be properly analyzed relative to the new operating practice because of age. Several units were due for complete or major overhaul and no history could be established. There are two new Leroi compressors now coming into full service and early maintenance cost returns are positive. While these can not be

There was a negative impact on maintenance costs due to the increase of coverage for new coolers and regulators. However, it is estimated that this is only a fraction compared to the cost reductions.

COSTS.

The Foss formula for true system cost measurement was stated early in this report ..... *cost/hour/100cfm.* A review of the information in the Appendix will show that this is not something arrived at without a certain degree of effort. The CFM out put of the system as well as each compressor is required along with a myriad of engineering and accounting details; however, it appears from the NASSCO experience to be very valuable and worth while, even if some values must be arrived at on *a best estimate basis.* The latter was true in this case. The out put for specific compressors was measured, along with cost calculations for the specific units. System usage was estimated and proofed with several different calculations.

The resulting cost factors were developed and can be applied very usefully to future system projects.

	$/Hour/100CFM		%
	Old Unit	New Units	Reduction
Supply Controlled System	*5.773*	N/A	
Balanced/Managed System	*3.810*	*2.020*	*34.0%*
Without Leaks	*3.193*	*1.693*	*16.2%*

NASSCO
Compressed Air System

Cost Analysis

The older compressor equipment has a higher cost simply because of the out put per KWH and relative maintenance cost (overhaul, etc.). The new unit cost includes amortization of the capital cost, not necessary with the older equipment.

The percent reduction was calculated by taking the difference between the pre-improvement value and improved value, dividing by the pre-

improvement value and correcting to a percent (the more conservative method).

A most important cost consideration is this: if the *yard demand is* 6000 CFM *for* 5000 *Operating Hours per Year, the cost* (applying these experience factors) will be between $1,730,000. *and* $510,000. (using the worst and best costs as an example). THIS CLEARLY SHOWS THAT THE COST OF OPERATION *or THE COST OF AIR* CAN OUT WEIGH THE INVESTMENT COSTS OF NEW COMPRESSORS AND ANCILLARY EQUIPMENT. This is so even if a single unit installation can cost $300,000. or more. Depending upon the improvement potential for a given yard, capital investment justification may clearly point to new equipment installation, as well as system improvement.

CONCLUSIONS.

This case study shows great success, but also has been a source for discovery and definition of future project objectives. In order to summarize the accomplishments and the to be accomplished a score card was made to indicate these conditions.

NASSCO'S FOSS PROGRAM SCORE CARD

FOSS RECOMMENDED ACTION	COMPLETE	PARTIALLY COMPLETE	NOT COMPLETE
System Configuration Revamp/Looping	X		
Regulation		x	
Storage		x	
Balance		X	
Cost/Hour/100CFM			x
Line Leaks			x .

From this, and having developed a better understanding of the costs related to systems operations and maintenance, a plan has been made to accomplish the following objectives:
1. Repair Line Leaks.
2. Replace poorly performing, high maintenance cost compressors.
3. Re-evaluate Blast Area to improve nozzle performance, *peah to peak* problems, and storage assessment.
4. Complete the Lubrication Study now in process.
5. Make a Cost/hour/100cfm evaluation for each compressor, and total system at various levels of demand.
6. Conduct a bearing vibration analysis.
7. Conduct user training in order improve *sector management* of equipment demand, leak correction, shutdown procedures, and *cost awareness.*

Beyond the details of this case study the general rule appears to be "once the effort begins to show real return and promise, the *next areas of improvement should become obvious".*

not
AFTER ALL ------------- IT'sAJUST AIR!!

APPENDIX

MANAGED
COMPRESSED AIR
SYSTEM

OPERATION

REGULATION

MAINTENANCE

STORAGE

ENGINEERING &
PLANNING

CONFIGURATION

EXPERTISE

BALANCE

DEVELOPMENTS

Managing efficient compressed air systems

By Steve Gahbauer
Engineering Editor

WITII MUCH *confusion* abounding about plant air systems. we need to learn how to manage conl-pressed air more efficiently. There are three aspects to learning: Confusion-what's going on? Motivation—a desire to find out. Experience-so that 's how it is done!

When it comes to experience and to "how it's done" in compressed air systems, there is probably no more competent authority than Scot Foss, president of Plant Air Technology, in charlollc North Carolina. Foss does financial and configuration audits of systems to determine their cost and efficiency. He is reducing the overall cost of operations of t hc system in many plants by 35% to 60% and, at the same time. hc improves performance at the production end.

That proves that it can he done. So what can we learn? How much does plant air really cost you? How can you stop blowing money out thc window?

Foss says improving your compressed air systcm starts with rcalizing some fundamental facts. and that there are better ways than throwing energy at it. He is a great proponent of using common sense. Consider this:

l If you forgct thc air. you can forget the results: but you'II never forget the cost!

l Statistical data is fine but coupled with no statistical thinking gives you poor re-sulls.

l An "on". compressor is an indication of cost: but not necessarily an indication of need.

l only half of the demand in - typical uncontrolled system is the result of real production demand.

l Compressors set to supply thc highest demand are wasting energy.

• Low pressure at the point of use does not necessarily mean inadequate power in the systcm.

• You must cont rol the weight flow of the gas despite the varations in pressure. temperat ure and flow. the closer you can do this to the production demand, the more efficiently you will control the results and the energy.

• Every unit of pressure demand generated by systcm components adds energy cost to the system.

For a cost effective compressed plant air systcm. Foss suggests that you:

❑ Use air as cfficiently as possible and make usage decisions based on t he operating cost.

❑ Service demand with potential energy as much as possible.

❑ Meter the recovery for energy savings.

❑ Never satisfy demand at any cost. Compressor controls are to refine the response to a controlled demand interpreted

through storage. The volume of storage and the weight flow of demand will determine the amount of energy which must be applied.

o Maintain a maximum control pressure.

❑ Slow down the rate of decay in pressure.

❑Controrl the expansion of the gas at least twice to the point of use to differentiate betwecn supply and demand.

❑Always operate a demand-controlled rather than a suppIy-controlled system.

Solving Problems: Foss also has some grind advice for problcm solving. Hc says whatever you think the problem is. it's probably not that You are likely looking at the effect. not the cause. And whatever you think the solution to the problem is, there are probably at least three better ways to do it. In other words: don't lank at the situation. look at the system. Always think in terms of pressure. volume. storage. time. and speed of transmission.

It also helps to draw a picture. If you can't. you probably donut understand the problem, Foss says.

What are some of the typical and recurring problcms in compressed air systems?

One is air leaks. They ran come from sources anywhere m your plant -hose teaks and worn disconnect plugs: abandoned cquipment with air left on: mechanical failures on valves and cylinders: pipe connections and stem valve packings m shut-off valves.

A leak is Iittle more than an unregulalrd hole m the compressed air syst em through which you blow air with pipe scale, iron oxide and other contaniuauls. Without any effort on your part. the hole- will get larger. And increasing operating pressures speed I the process.

Costly Leaks: Foss talks alxout industrial and process plants in which he dirt an audit. In 15% of them. leaks wasted more then $500 000 a year. I Half of them would have turned a profit if they had controlled their air leaks.

"Leaks made up 20% to 35% of demand in almost all the plant air systems surveyed." says Foss. "That means that one-third of all compressors, associated costs and electricity expenses served no other purpose than to increase the cost of the product manufactured."

Consultant Peter Stern puts the real cost of air leaks into perspective. He says the average corporation's income is 5% of the gross sales. Thus. when a company loses $200 000 a year from comprcsscd air Ieaks. the organization must increase its sales volume by $4 million to make up fur the loss.

The easiest method for finding individ - ual leaks is with a microsonic or ultrasonic leak detector. Once Ieaks are Iocatcd, they should be marked and fixed. To deal effectively with Ieaks. you need to:

✔Determine the operating cost for your compressed air system.

✔Measure the flow requirements for leaks under various conditions.

✔Establish the total annual cost for leaks.

✔Fix the leaks.

✔Report the reduction in system operating cost.

✔Educate personnel about the importance of leak and pressure management and reporting procedures.

Tricky Nomenclature: Another prob-Iem is the CFM trap. Different rating conventions for compressed air power make it confusing. Do you know what capacity you arc really talking about? CFM ran mean ICFM. ACFM. SCFM or FAD. depending on i the supplier.

There arc at least three different abbreviations for virt ually t he same rat ings for industrial air service to dcscribe intel air *free* air. or ambient cubic feet of air com-pressert. There is an addition meaning when you deal wrth European systems wherer delivery is delined as the actual an delivered by a compressor in t hc system when the performance does not include power losses due to inlet filters. oil filters, cooling systems. or oil separators.

The "safest " term is SCFM-standard cubic feet *per* minute-meaning the vol-

uom of flow of conpressed air m one- mm-ute related hack to a standard set of inle conditions. More and more. FAD—free air delivered-is becomming a tcrnnology standard. It unambiguously means the amount of air avaiIable from the unit bcfore the aftercooler.

What really concerns you as a user of compressed air in your plant when you are trying to match supply and demand effi ciently is how much usable air is available at the discharge end and what the power cost is to deliver that air.

Action Plan: Out of all this comes an action plan to imporve compressed air systems in your plant. Here is what Foss recommends:

❑Control demand by intermediate or sec-I or controls. point of use controls. establishing appropriate operating pressures. and dcvcloping control and overhead storage systems.

q Reduce demand by correcting poor applications. developing a leak management program, and reducing abandonce equipment.

q Reduce *horsepower* by unloading unnecessary compressors, refining part load and trim load, and operating at the best power flow.

❑ *Reduce ancillaries* by cleaning equipment. doing preventive maintenance, and automating where possible to reduce operator expense and improve quality/reliability.

To stay on the winning side of your plant air system requires constant vigilance. You are never a loser until you quit trying. Don't give up: there are rich rewards in maintaining a cost efficient compressed air supply. ♻

MANAGING
COMPRESSED AIR

by R. Scot *FOSS*

Economics of Compressed Air

Auditing Compressed Air Costs

Controlling Demand in Compressed Air Systems

EXECUTIVE BRIEFING:

Economics of Compressed Air

It is time to get compressed air out of the unassigned cost category so rational decisions can be made about maintenance and production costs. An expert examines the problem.

By Scot Foss

T he vast majority of facilities cnginccrs and maintenance managers have no idea how much compressed air they usc or what it costs. They are not sure ifthc systemis efficient or what alternatives they have.

If you were challenged by managemcnt to rcducc energy or cxpcnsc for maintcnancc by 25 pcrcent over the next 2 years. should compressed **air bc on the** priority list of inanimate opportunity cxpcnscs?

Auditing and value cnginccring of compressed air arc difficult when there is an abscncc of operating convention. configuration technology. systems management hardware. or a method of costing this vital utility. Despite this situation,a growing trend for the past 15 years has been to throw energy at all systcm problems. while operating compressors at ever greater pressures.

When dcmand controls in the system arc inadequate. thc demand. as well as loss from leaks. becomes a function of supply pressure. and

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WHO IS AN AUDIT CANDIDATE?

Every plant is a candidate for a compressed air system audit. It is not. however. the plant that feels it has thc most problems that is in greatest need. Facilities that feel they have overcome their problems may have the largest problems. They may have managed only to overpower problems without applying controls, auditing. or other investigation. These plants have learned to tolerate the expense of satisfying the Black Hole of uncontrolled demand.

Each increment of energy increases system pressure and demand. Not until the flow created exceeds the capacity of the piping and the pressure begins to drop geometrically will anyone show an interest in altcrnative solutions. If you have enough capital and your management does not find fault with escalating power and maintenance costs. this is one of the ways of dealing with the system. Despite its popularity, it is without a doubt the least effective approach of the many alternatives.

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volume rises on a straight line. The **question then is, H**ow much of a systcm"s input energy is being wasted?

In largcr facilities it is not uncommon to be able to rcducc waste energy and its attendant costs from $500.000 10 $1,000,000 a year. Typically, input energy can be rcduccd 15 to 25 percent. although in many cases a 50 pcrccnt reduction is possible. But electricity is just one of eight general areas and many subordinate areas in compressed air where there is a tremendous opportunity for cost reduction. efficiency improvements. or both. The real question to ask is, What impact dots this less than efficient system

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have on the quality and landed costs of your manufacturcd goods?

Typically. rotating equipment represents 50 to 60 pcrccnt of a plant"s maintenance budgct. and compressed air represents 30 to 50 pcrccnt of that figure. Mantcnancc on rotating equipment has incrcascd gcomctrically for thc past 10 vcars. The **opcrating** cost for comprcsscd air in the first year alone is 1.5 to 2.5 times the capital investment for the basic equipment. And these figures do not include depreciation expense. Thcrcforc, adding horsepower to solve a poorly defined problem has to be a very difficult decision.

In 1973, energy activists made us take a hard look at automobile fuel efficiency. Since that time wc have doubled and in some cases tripled fuel efficiency while the cost of fuel has only doubled. The net economies have been substantial. Other areas have been targeted in industry. such as quality of manufactured goods. effectiveness of receivables administration, and purchasing and

inventory management We have rcsponded to these areas with statistical process controls. just in time (JIT) manufacturing. materials rcsource planning (MRP) I and II. automacted rc-ccivables. qua!ity assurunce **programs. and** othcr programs.

What is the rclationship of thcsc **management issues 10 mismanaged compressed air?** The purpose of these programs is to make you more competitive in your industry. If you arc doing a job with **JIT** and arc not looking at your less than optimum compressed air system. it is possi-hlc that thcy cancel each othcr out. Both affect thc bottom line geomc-trically.

In the Far East and Europe industrial and process managers know precisely what compressed air costs and how **it** affects thcm. At a recent workshop in Northern California. a Eurocan facilities manager told the group that when you thoroughly investigate the burdened cost of this utility. you can no longer overlook configuration inefficicncics or incf-fectivc management philosophics. In most systcms. morc energy can mean more waste. When a leak costs $5000/year. you cannot afford to make it a $7000 leak by adding compressor capacity to solve another problem in the system. You must consider the alternatives.

It is possible that compressed air falls 27 lcdgcr columns behind cn-tertainmcnt expense in the fiscal plan. Maybe it simply represents 5 to 25 percent of many categories, all lost in the name of burden. With plants moving or being shut down, and utility cost a factor in the decision, perhaps it is time to address this important issue.

In scminars **around** thc country I have asked facilities and mainte-nancc professionals the same question. Would you put in a ncw hoilcr each timc you rccci.vcd pcrsistcnt point-of-usc complains? You know the answer. Is it possible that you deal with compressed air in this manner? Part of the problem is that you know what a pound of steam costs. Altcrnativcs can bc mcasurcd in money and presented to manage-ment along with specific action plans. Without a reasonable method of fiscal measurement. compressed air problems must reach crisis pro-portions before managcmcnt reluc-tantly responds.

It is always the same
The scenario is always the same. Someone complains about low pres-sure somcwhcrc in thc plant. You assumc responsibility whether you should or not. You make sure all compressors arc on. and you may rcnt a compressor. Then you make a haIf hearted attempt to investigate system configuration or technologi-cal alternatives. Sooner or later you wind up with a prc-cnginccrcd, packaged. capital cxpcnditurc to solve the problem until, in the near future, you again step over that neb-ULOUS line. It is not difficult to un-derstand why management is reluc-tant to support this pattern of behavior.

Whenever a problem becomes painful enough, effective ways can bc found to deal with it. However. in the area of compressed air. wc have yet to deal with a num-bcr of factors:
Ž A lack of system standards against which performance can bc measured
l Insufficient configuration technology to define problems or solutions properly
• Poorly detined levels of rcsponsi-bility and authority for comprcsscd air in most facilitics.

We simply have not yet dcvclopcd a thorough method for the costing of this vital utility. The bottom line is that we don't know how painful it might bc. Wc only know that wc don't know.

From time to time, discussions arise concerning various parts of the system. However, the compressed air system is typically not dealt with as a systcm. The first step is to iden-tify how to quantify the gas and its operating costs. All other system-atic methodology will follow.

what unit of measure?
The quantitativc unit of measure for comprcsscd air cost analysis should bc consistent with standard units of compressed air. The unit should be smal cnough that it will accommo-date the largest or smallest facility.

The two most common units cur-rentl y in use are cost/1000 cu ft and bhp/ 100 cfm. Neither accommo-dates the constituents of cost or the variabics of part load that influcncc cost. They are used to evaluate parts of the system, such as compressor efficiency, but not the system at var-ious demand loads.

All the components of cost can easily be broken down to dollars, cents. and roils per hour. Because supply can create demand, and op-

eraling equipment dots not necessarily have any correlation to demand. the unit of measure should be **production demand. The unit of measure** should also be easy to apply as a multiple or fraction at various demand conditions.

On **the basis of this information.** the cost/hour/100 cfm is the most appropriate unit of measure. This unit is **Calculated by** the formula:

$$\text{Cost/hour/100 cfm} = \frac{\text{total system cost/hour}}{\text{demand/100}}$$

When the cost of electricity. depreciation method. and other variables are considered. the cost/hour/ 100 cfm can vary from \$1.10 to over \$5.00. On a 1000 cfm system the cost/shift/year could range from \$32.120 to \$146.000. With a fixed cost of electricity. configuration effectiveness and operational efficiency can cause the cost/hour/ 100 cfm to remain constant or increase inversely to rcduction in demand.

Supply or demand
The **amount of flow and its varia**tions **must be determined before cost can be determined. It is** important not only to differentiate between supply and demand. but also to determine **whether supply creates demand or vice versa. If you attempt to use compressor controls to** control point-of-use pressure. it is **reasonable to assume that supply creates** demand. In that case. you will need to determine not only what the flow is. but also what the demand should be in order to maintain the maximum demand control pressure in the header. at the sectors, or at the point of use. whichcver is most **practical.**

Demand has three components: the real production requirement, artificial demand created by supply pressure that is higher than required at the point of USC. and leaks. Sector management maintains real demand

Low pressure at the point of use does not necessarily mean inadequate power in the system.

while climinating artificial demand and minimizing leaks. If you get flow to a minimum and do nothing about the system. you reduce the volume **but increase the cost/hour/ 100** cfm almost proportionately.

The lowest cost/ 100 cfrn is produced when you can precisely match "on equipment" with demand and minimize "off equipment" for standby. The philosophy that matches this reasoning is that all compressors and ancillary equipment that need to be on run flat out. except one compressor for trimming. and all other equipment is off. regardless of loading or demand variations.

When attempting to determine flow. do not .assume that because a compressor is on that it is using its **capacity** for the system. Capacity varies as a function of inlet conditions. although it may or may not influence input energy. Different types of compressors deal with this rule differently.

Even if you were to measure watts. which is the best measurement of power. it is not likely that you would be able to acquire a performance chart from a manufacturer to show flow against power. You need to measure both flow and power to get an accurate picture of cost. Depending on the systcm's configuration. you need to determinc whether you arc measuring supply or demand. The compressor controls arc there to refine the re-

sponse to a controlled system. not to centrol the system.

When approaching this problem. it is important to be clear on the operating philosophy used for **your system.** The reactive mind set that dominates most situations asks. "How **many compressors and ancillary** pieces of equipment do I need to have on so that no one from production calls about low pressure?" There **are two things wrong with that type of thinking.**

First, it is usually the same person complaining about low pressure, forcing you to establish an operation convention for him. All too many maintenance people begin to think of that person as representing "production." and his needs representing system needs. Perhaps he has a problem rather than the system. Low pressure at the point of usc dots not necessarily mean inadequate power in the system. It may mean a configuration problem or excess demand in that sector.

Second, the low-pressure situation is valid only at peak demand. The balance of the time you are destroying the cost/hour/ 100 cfm. You could have served the peak with useful storage and articulated the "on" power the balance of the time. holding your cost/hour/ 100 cfm rather flat. The more constant the cost/ 100 cfm. the more efficient and cost effective the system.

A subsequent article Will examine cost component individually

Scot Foss. PE. Charlone. NC. has been involved in the design and analysis of compressed air systems for 22 years for several major compressor manufacturers. As an independent consultant, he directs system auditing and balancing studies and presents public and inplant seminars on compressed air system analysis.

EXECUTIVE BRIEF/NG:

Auditing

Compressed Air Costs

*The first step in controlling compressed air costs
is finding out what you have and how much it costs.
Here is a review of the procedures for auditing a system.*

By Scot Foss

Every plant is a candidate for a compressed air system audit — even facilities that seem to have overcome their problems. Often, these facilities have managed only to overpower problems without applying controls.

The basis for audit calculation is cost/hour/100 cfm of compressed air. This unit is calculated by Equation 1. Because supply can create demand, and operating equipment does not necessarily have any correlation to demand, the unit of measure should be *production* demand.*

Eight primary cost components must be investigated:

Electricity or alternative energy
Water or air cooling
Contaminant control equipment
  (dryers, filters)
Preventive maintenance
Breakdown maintenance
Operators
Depreciation
Miscellaneous (interest on inventory, insurance, supervision, general administration, etc.)

Finding the costs may be difficult because these items usually are not identified as compressed air expenses. Although the accounting department may not identify these items as compressed air, they are still real components of the cost of compressed air. Each component is essential to investigating and tuning the system.

*The relationship between supply and demand and other system control factors was discussed in a previous article ("Economics of Compressed Air")

EXAMPLE A: *AIR TREATMENT
COST* SUMMARY

System Air reactivated dryer with 10.000 cfm capacity. 750 cfm system flow, 5850 hr operation annually

Purge air: Assume 12 percent of dry capacity, SO.06/kWh. 0.92 compressor motor efficiency. and 4.55 cfm/bhp compressor efficiency

$$\frac{10.000 > 0.12 \text{ cfm purge}}{4.55} \quad \frac{0.746}{X\,1\,0\,0}$$

$$x\,\frac{0.06}{750/100} = \$0.1711/hr/100\,cfm\ purge\ air$$

Breakdown maintenance:

$$\frac{\$1500\ \text{annual breakdown}}{5850\ \text{hr service annually}} \times \frac{1}{750/100} = \$0.0342/hr/100\,cfm$$ *

Desiccant change: Assume desiccant al $3. 10/lb and 534 lb per tower times two. labor to change at two people for 4 hr at $20/r. one change every 2 years.

$$\frac{\$3.10 \times 1068 + 8 \times 20}{5850 \times 2} \times \frac{1}{750/100} = \$0.0395/hr/100\,cfm$$

Depreciation expense: Assume $13,500 dryer purchase price and a 5 yr straight-line depreciation method.

$$\frac{\$1350015}{5850\ hr} \times \frac{1}{750/100} = \$0.0615/hr/100\,cfm\ depreciation$$

Summary:
Purge air cost ....$0.l77l/hr/l00 cfm
Breakdown maintenance 0.0342
Desiccant change plus labor. 0.0395
Depreciation expense 0.0615
Total . . . .$O.3063/hr/l00 cfm

Hourly cost: $0.3063 x 750/100 = $2.297

Annual cost: $2.297 x 5850 = $13,438.92

Electricity costs
Electricity is the largest component of the cost of compressed air. It represents 45 10 70 percent of the total unit cost. depending on the electricity rate structure. In the United States. the cost ranges from **$0.025 to $0. 16/kWh. The electric-** ity cost for compressed air can range from **$0.50/hr/100 cfm to $3.82/hr/100 cfm. Therefore. cost savings that can cut demand or unload horsepower are important.**

Four areas of configuration improvement significantly reduce electricity cost: 1. minimizing

CALCULATING COMPRESSED AIR COSTS

For most **facilities, finding the costs may be difficult because data entry on the Item does not identify it as a compressed air expense. If the cost factors are not available directly, they can often be estimated from broader cost factors. The physical factors such as flow and electricity usage can be measured directly. The following equations are basic to a system audit.**

Overall cost of compressed air

Equation 1: Basic compressed air cost

$$\text{Cost/hour/100 cfm} = \frac{\textbf{total system cost/hour}}{\textbf{demand/100}}$$

Electrical component

Equation 2: Electrical cost (kWh)

$$\text{Electricity cost} = \frac{\textbf{0.746 compressor } \textit{power} \textbf{ rating x electricity rate}}{\textbf{motor efficiency}}$$

Equation 2a: Electrical cost (kVA)

$$\text{Electricity cost} = \frac{\textbf{0.746 compressor power rating x electricity rate}}{\textbf{motor efficiency x power factor}}$$

Equation 3: Electrical cost of compressed air

$$\text{Electrical cost of compressed air} = \frac{\textbf{electricity cost}}{\textbf{compressed air flow/100}}$$

Cost of compressor cooling

Equation 4: Cooling water flow

$$\text{Cooling water flow} = \frac{\textbf{compressor power rating x 2545 x 60}}{\textbf{(temperature out - temperature m) x 500}}$$

Equation 5: Cooling water cost

$$\text{Cooling water cost} = \frac{\textbf{cooling wafer flow}}{\textbf{1000}} \text{ X } \frac{\textbf{water rate}}{\textbf{actual air demand/100}}$$

Units of measure:

demand = cfm
cost = dollars
overall cost = dollars/hour/100 cfm
motor efficiency = decimal fraction
electricity rate = dollars/kWh
compressor power rating = brake horsepower (bhp)
power factor = ratio
compressed air flow = cfm/hour
electrical cost = dollars/hour/100 cfm
cooling water flow = gph
temp out = deg F
temp in = deg F
water rate = dollars/1000 cu ft
cooling water cost = dollars/hour/100 cfm

waste, 2, controlling demand, 3, controlling compressors, and 4, utilization of storage.

The efficiency of the system (the ability to shut off compressors) is far more important than the efficiency of the compressors.

In measuring electricity, the kilowatt is the only appropriate unit of measure for most applications. The electrical component of compressed air is calculated using Equation 2.

The variables of power consumption, motor efficiency, and power factor are not on a straight line with compressor capacity. Optimum efficiency is near, but not necessarily at, flat out operation of the compressor. All other conditions of part load affect the variables negatively to some degree. Because it is often difficult to get performance data from suppliers, and values vary with the load, it is best to measure and record electric power consumption. Once electric power consumption has been determined, you can calculate the electrical component of compressed air with Equation 3.

Cooling costs

If your facility has air-cooled compressors, the cooling fans may be mounted on the compressor motor shaft or driven by a separate motor. In both cases the horsepower rating and attendant costs must be determined. A cooling fan, however, is not a variable-speed device. It operates flat out regardless of the load condition of the compressors.

Even when unloaded, the compressor generates heat that must be removed. If it is unloaded at the same time that another unit is supplying the system, the air or water cooling media must be added to the operating cost of the system.

For example, a 100 hp compressor capable of 470 cfm is operating in a system with another similar compressor that is running flat out.

The electrical cost is $0.06/kWh. Cooling cost for the compressor running flat out is $0.158/hr, which reduces to $0.0336/hr/100 cfm. When the second unit is running at 50 percent of capacity, its cooling cost is the same as for full output. The cost for the second compressor's cooling increases to $0.0687/hr/100 cfm. When the combined cooling cost for operating both compressors in these modes is divided by system output (470 + 235 cfm), the system cost becomes $0 045/hr/100 cfm.

If your facility has a water cooled machine or system, the cost of water in gal/hr/100 cfm must be obtained. Many plants know the cost of 1000 gal of water for city, well, and tower water. Usually these costs range from $0.55 to $1.80/1000 gal. To calculate the water flow across the compressor when data at various inlet temperatures are not available, use Equation 4: cooling water cost can be calculated with Equation 5.

For a closed loop or tower with glycol, the factor of 500 in Equation 4, which is used for a once-through system, must be reduced to account for the lower heat-transfer rate.
Factors that contribute to the cost of cooling water include makeup water, sewage cost, pumping cost, fan cost, maintenance, electricity for the system, and depreciation.

Furthermore, if the cooling water is allowed to run for a compressor

producing no flow, its cost must be calculated into the cost/hour/100 cfm. An average cost would be $0.30/hr/100 cfm although costs can run as high as $0.75/hr/100 cfm on once-through systems.

Air treatment costs

Cleanup equipment such as dryers and filters are a necessary part of most plant or process air systems. Unfortunately, the selection and installation of this equipment tends to be experiential. Clearly defined problems and well conceived configuration technology seem to become the victim of the common philosophy: "If it's worth doing, it's worth overdoing." Without the audit function of measuring results and costs, perhaps this approach can be justified.

Many types of dryers are available including refrigerated, direct expansion, heatless and heat reactivated, thermal mass, and deliquescent. Most dryers in current use are the refrigerated noncycling or the heatless regenerative types. The effectiveness of these units is a function of inlet temperature, velocity, ambient conditions, part load condition of the system, and drainage design.

For auditing purposes, both types of dryers have the same characteristics; without energy management controls that consider heat load, both operate flat out regardless of input. As the volume of compressed air being processed goes down, drying cost/hour/100 cfm and maintenance costs rise.

When evaluating refrigerated dryers, remember that most are equipped with hermetic and semi-hermetic compressor/motor combinations. Motor efficiency and power factor are much lower than that of the average industrial motor.

With regenerative drying, it takes purge air, electrical heat energy, or a combination of the two

an average of 12 to 14 percent of the input energy to operate

The constituents of drying cost are electricity (if any). purge air (if any). water or air cooling (if any) breakdown maintenance (including labor). desiccant change (including labor). and depreciation

Calculations for drying costs are illustrated in Example A. "Air Treatment Cost Summary."

The ability to match cleanup equipment to the system's load largely influences unit cost efficiency. At $0.06/kWh. refrigerated drying can cost between $0 07 and $0.13/hr/100 cfm. Regenerative drying at the same electricity rate can cost between $0 22 and $0 36 hr/100 cfm. Considering these cost variables. a wise business decision comes from defining the problem and systems technology.

Filtration should be selected on the basis of wet load differential capacity to hold dirt. and applicability to the system. Every unit of pressure demand generated by either wet load clean or the amount of dirt allowed to accumulate adds energy cost to the system.

Filter elements should be changed when the cost of energy to maintain the system's pressure exceeds the value of the replacement element. Initial selection should account for these issues. The constituents of cost for filtering are maintenance (including drainage and element changes) and depreciation. Power costs will show up in electricity. but should not be overlooked for audit purposes.

Maintenance costs
Three distinct categories of maintenance should be audited: preventive maintenance, breakdown maintenance, and outside service You should know the difference between the cost of outside labor and full-burdened inside labor.
There can be a substantial differ

ence between minimum preventive maintenance and quality preventive maintenance programs and their influence on breakdown maintenance (and the consequences thereof) Many facilities have found that records of these expenses are lost in the accounting system. Appropriate data coding can make auditing as well as future decisions much easier regarding the air system, its cost efficiency, its unit efficiencies, and equipment retirement issues. Maintenance cost calculations are outlined in Example B, "Maintenance Cost Summary."

Operator costs

Whether operators are employed depends upon the size and manageability of the system, union agreements, the presence of compressor controls to manage the system efficiently, and scheduled data collection for monitoring maintenance and performance. A number of companies surveyed used an average of 5 percent of an operator's annual cost of $40,000 for monitoring. The operator cost factor can greatly influence the need and selection of automation management and data collection equipment.

Depreciation and installation costs

Although depreciation is not normally assigned specifically to the system operating data for accounting purposes, it is a real cost for auditing purposes. There are as many methods for depreciation scheduling as accounting conventions. Investigate the method used by your company.

The cost of depreciation on a 1000 cfm capacity system operating at 750 cfm, with a capital cost of $72,000 and an installation cost of $15,000, operating 5850 hr/yr is $0.396/hr/100 cu ft using the 5 yr straight line method.

Although many people would

The cost of preventive maintenance, breakdown maintenance, and outside service must be included.

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minimize the depreciation cost factor, auditing should show whether you are receiving full value for the capital investment. Whether the compressors are part loaded, fully loaded, off, or standing by, depreciation expense must be factored simply because they are there. The condition of loading in the system will give you an idea of the value being received.

Miscellaneous costs

Many costs can be used in the miscellaneous cost category or, in most cases, be factored into other categories. These costs include interest on inventory (value x prime interest rate x 1.7); inventory aging to destruction (7 to 9 percent of inventory annually); insurance expense; supervision expense; purchasing expense (a percent of purchase value); and administration (a percent of total cost).

The type of cost accounting system used determines how these costs are handled; however, these items are all real costs that cannot be ignored. Other costs may have been overlooked. However, we are only setting up guidelines for a convention that will realistically assist the user to analyze efficiency and cost value effectiveness.

All of these factors can be called burden or be applied to the individual categories. Once the annual costs have been computed, divide them by the hours of operation and

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then divide that figure by the system's flow divided by 100 to get the cost in dollars/hour/100 cfm.

Summary

When you consider the multitude of variables and the infinite configurations possible, it is no surprise to learn that costs for 100 cfm of compressed air can vary from $1.10 to over $5.00/hr.

Overall costs are outlined in Example C, "Total System Cost Summary." This example provides numerous opportunities to improve efficiency and reduce cost. A combination of demand and supply management controls, with a more articulated trim configuration such as one 100 hp and two or three 50 hp units, could reduce unit costs by 20 to 25 percent and annual costs by 30 to 45 percent.

There are many ways to reduce demand and unit cost while improving production quality. Where should you begin? The first step is a configuration audit with value analysis. The most efficient equipment in a poorly configured system will produce mediocre results.

If improvement in production quality, reduction in downtime, and improved costs are important to you, get compressed air out of the area of unassigned cost. It is doubtful that any other system in a modern facility can offer as many variables of cost or opportunities for expense reduction.

Scot Foss, PE, Charlotte, NC, has been involved in design and analysis of compressed air systems for 22 years for several compressor manufacturers. As an independent consultant, he directs system auditing and balancing studies and presents public and inplant seminars on compressed air system analysis.

Controlling Demand in Compressed Air Systems

Half of the energy used by most systems is wasted by uncontrolled demand. Attention to system control and balance can pay significant dividends–more than $1390 per shift per year in a typical uncontrolled 25 hp system.
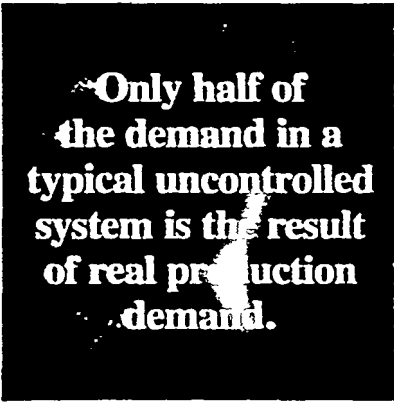
By R. Scot Foss, PE, Plant *Air* Engineering

o ver the past 15 to 20 **years. responsibilily for the end results in compressed air systems has been** shifting to comprcssor room equipment. Driven by the development of **packaged air compressors. thus approach is responsible for considerable waste of energy and a** numher of **Consequetal** problems

The **desired result of a compressed** air system is pneumatic power at the point of use delivered at sufficient **volume and pressure to do the job. When** difficulties occur. most owner operators throw prepackaged engineered solutions at poorly defined **problems with little thought given to configuration technology The prepackaged solutions seldom produce more than marginal improvement for short** periods of time.

Most **perceived system problems can be solved by overwhelming them with energy. However. this solution is certainly the most costly. from both capital and operating viewpoints. Intestingly. it is not the user who believes he has problems (that is pleased by such a "solution." but the one who has "soived" these problems by wasting 30 to 50 percent of his input energy. He feels pleased be-**causc **management** has supported him with capital to **overpower the problems. This approach takes away**

one problem and Ieaves others.

The common requirement of I(K) cfm at 80 psig is an expression of what is desired at the point of use. lf all of the resposibilit for that result is assigned to compressor room

"Only half of the demand in a typical uncontrolled system is the result of real production demand.

equipment. you have joined the multitude of users who have **begun the endless journey of filling the bottom-Iess pit of unconntrollled demand.**

All compressed air systems **have three fundamental elements: demand, distribution and storage. and supply. These three factors must be controlled for the system to work at optimum energy and quality levedls. A properly designed and operated system can be described as "refining the energy response to a controlled**

demand through a controlled storage system."

Only half of the demand in a typical uncontrolled system is the result of real production demand The rest goes for artificial demand. poor applications. and leaks.as illus-trated in the accompanying chart.
• **Artificial demand. which repre-sents at least 15 percent of typical System demand.is generated by an application where the operation has adjusted the pressure to a higher level than ncccwarye (often wide (open) In Iieu of appropriate control pressure maintenance. It is also representative of applications where a regulator was not installed because if was not con-sidered essential to the application** Regulators. however. are **essential** to **system control because demand is a function of supply** pressure. **A de-mand of 100 cfm at 80 psig. if not regulated at 80 psig. will increase to 120) cfm at 100 psig. If a I(K) cfm compressor at 100 psig is installed to handle 100 cfm at 80 psig. it cannot** deliver. The pressure will drop to Iess than 80 psi. and the system will usc **33 percent more energy than neces-sary to do a poor job.**
l **Demand from poor applications is generated by using compressed air for keeping workers cool during the summer. open air Iines for parts below**

TYPICAL SYSTEM DEMAND
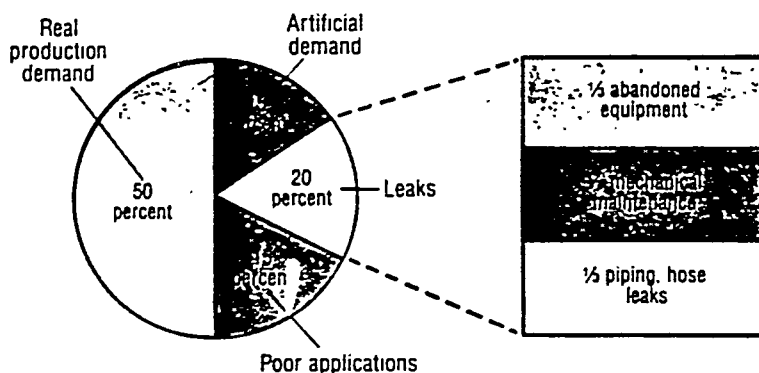
Only half of the demand in most compressed air systems goes for real production work. The rest is lost through mismanagement.

EXAMPLE 1—TYPICAL UNCONTROLLED SYSTEM

Supply capacity		Leaks		Original production demand
100 cfm				
110 psig		20 cfm		
		110 psig		100 cfm
				80 psig

	No demand controls therefore no storage			Less than total demand controls system response		
63.5 lb	No	12.7 lb	50.8 lb		117.7 cfm
110 psig	+ storage =	110 psig	+ 70 psig	or	70 psig
100% load		Leaks	Demand		Drawdown

This typical system only "sees" the 70 psig demand and "thinks" it needs another compressor.

ACTION PLAN TO IMPROVE THE COMPRESSED AIR SYSTEM

1. Control demand (weight flow)
Install intermediate or sector controls
Install point-of-use controls
Consider operating pressure of the compressors
Develop storage systems

2. Reduce demand
Educate hourly workers and system operators
Correct poor applications
Eliminate leaks
Shut off abandoned equipment

3. Reduce horsepower
Unload unnecessary machinery
Refine part load and trim load
Operate at the best power flow

4. Reduce ancillaries
Water and air
Clean up equipment
Preventive and breakdown maintenance with predictive diagnostics
Automate where possible to reduce operator expense

off, cleaning the floor, and other inappropriate applications. Most of these applications require impingement energy, calculated as: Impingement energy = ½ mass × velocity^2. Mass is a function of volume, so impingement energy is a function of half the volume. However, impingement energy is a function of the square of the velocity. Therefore, high-velocity or high-thrust nozzles can reduce the demand for these applications by 60 to 70 percent and improve the end result. These devices, like all air equipment, must be applied rather than "thrown" at the problem.
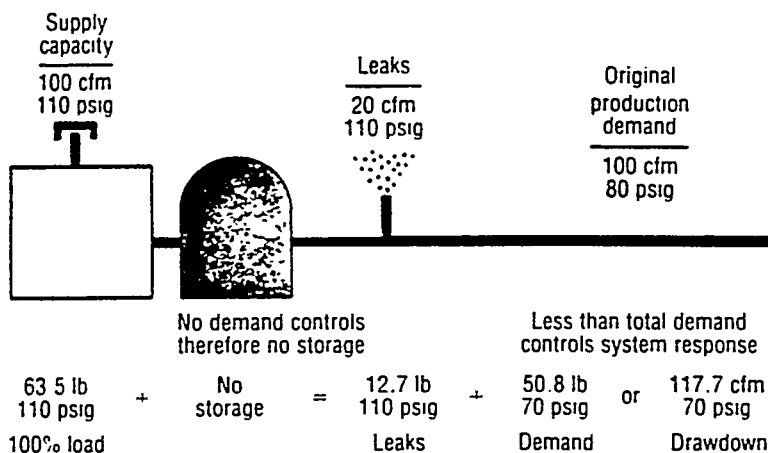
● Leaks are an ever present problem for all users. They are never dealt with because they are not identified by location, quantified by volume and pressure, or expressed in dollar cost. When they are properly identified, management will respond quickly. There are three types of leaks: abandoned equipment leaks, where operators walk away from their work stations, leaving the compressed air on; mechanical operational leaks in valves and controls requiring maintenance; and plumbing leaks in pipe, hose, disconnects, and fittings.

User education is needed in the area of unproductive demand factors. Furthermore, there is equipment available for dealing with these issues, including controls that automatically shut off abandoned equipment and ultrasonic detectors for locating leaks in the system. These devices produce an attractive return on investment considering the real cost of compressed air.

Both ends of the distribution system must be controlled. At the points of use, demand is controlled by automatic filter-regulators. At the other end of the distribution system, the discharge from the compressor room should be controlled with an intermediate mass flow controller or sector control. All capacity to store air between these two locations is a func-

WEIGHT OF AIR AT VARIOUS TEMPERATURES AND PRESSURES

Weight of air, lb per cu ft

	70 psig	80 psig	90 psig	100 psig	110 psig	120 psig	130 psig
60 F	0.4482	0.4927	0.5547	0.596	0.649	0.700	0.752
70 F	0.4316	0.4824	0.5332	0.584	0.635	0.686	0.737
80 F	0.4234	0.4729	0.5224	0.572	0.622	0.673	0.723
90 F	0.4154	0.4639	0.5122	0.561	0.611	0.660	0.709
100 F	0.4897	0.4555	0.5033	0.551	0.599	0.648	0.696
110 F	0.4811	0.4481	0.4950	0.542	0.589	0.637	0.685
120 F	0.3944	0.4403	0.4866	0.533	0.579	0.626	0.673

CONVERSION FORMULAS

Atmospheric volume flow (ACFM) to supply capacity:

Formula:
ACFM × wt at control pressure ÷ wt at use pressure = supply capacity

Example:
100 ACFM × 0.635 lb at 110 psig and 70 F ÷ 0.4824 at 80 psig and 70 F = 131.6 scfm at 80 psig and 70 F, or 63.5 lb

Standard volume flow (SCFM) to demand required:

Formula:
SCFM × wt at use pressure ÷ wt at control pressure = demand required

Example:
100 scfm × 0.4824 lb at 80 psig and 70 F ÷ 0.635 lb at 110 psig and 70 F = 75.96 icfm at 110 psig and 70 F

Inlet volume flow (ICFM) to atmospheric volume flow (ACFM):

Formula:
ICFM × actual psia ÷ 14.69 × 519 F ÷ (ambient temperature + 460 F) = ACFM
Temperature effects on summer and winter flow conditions may be significant.

Summer example:
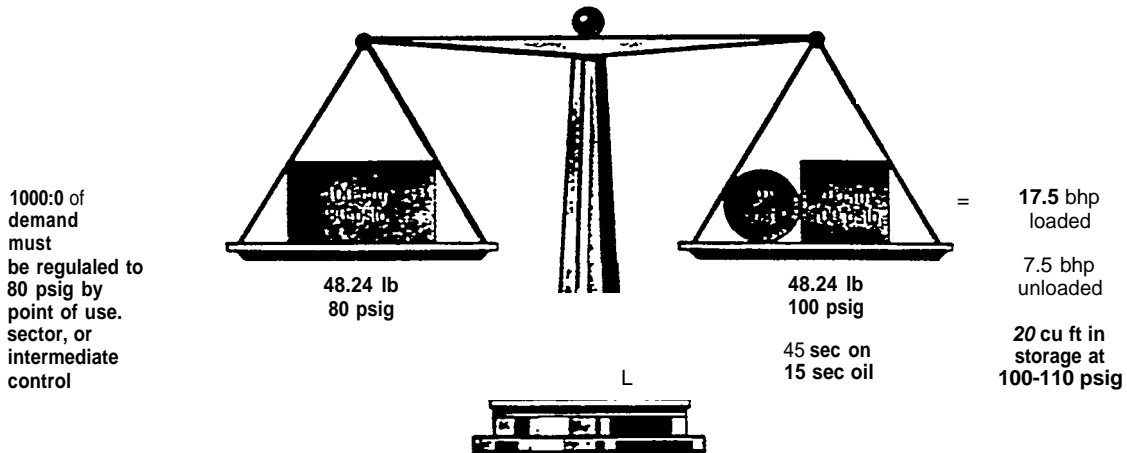100 icfm × 14.2 ÷ 14.69 × 519 F ÷ (95 F + 460 F) = 90.39 acfm

Winter example:
100 icfm × 14.5 ÷ 14.69 × 519 F ÷ (40 F + 460 F) = 102.46 acfm

BALANCE + *STORAGE* = *REDUCED* HORSEPOWER

1000:0 of demand must be regulaled to 80 psig by point of use. sector, or intermediate control

48.24 lb 80 psig

L

48.24 lb 100 psig

45 **sec on** 15 **sec oil**

= **17.5** bhp loaded

7.5 bhp unloaded

20 cu ft in storage at **100-110 psig**

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tion of the controlled differential pressure and the compressor"s operating pressure.

For every barometric pressure ratio (14 5 psia. for example). one capacity of air can be stored. For example. a 400 gal tank has **53.5 cu ft of physical storage capacity. If the difference between the maximum control pressure at the point of use (80 psig) and the intermediate control pressure upstream of the tank (90 psig)** is **10 psid. the controlled differential pressure is 10 psid + 14.5** psia barometric pressure = 0.69 of **physical capacity This ratio represents 0.69 x 53.5 = 38.9 cu ft of storage at 90 psig. In mass units. the storage capacity is 38.9 cu** ft X 0.5332 **lb/cu** ft at 90 **psig ¯19.7 lb of air in storage.**

Typically there is little storage value in piping for meeting (demand peaks. but each system Should be evaluated on its own merit. Dedicated storage should be used for high-surge applications. Check Valves upstream of the dedicated storage isolate the surge load from the rest of the system. Several intermediate controls should be used as sector controllers If there are sectors in the system such as various buildings. different pressure requirements. or arcas where usage must be determined for accounting purposes.

Point of use controls and intermediate controls are essential to controlling storage. which in turn increases **the capacity of the system and reduces the brake horsepower needed to power it. Storage also affects the load/unload cycle of the compressors. The more storage. the**

This application requires at least 25 percent of demand to have a 50 percent duty cycle or less to be sucessful.

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longer the load mode and the longer the unload mode. Rcduced cycling will significantly extend the useful life of the equipment even **if the output is the same.**

Without storage. compressors must serve every peak and valley of demand. If compressors are set to supply the highest peak. the macilines and accessory equipment will run during nonpcak demand and thereby waste energy. Storage could be used to handle the peak and keep the compressor off. With pressure-only controls on the compressor. it is not uncommon to have 30 cfm of added demand drop the pressure below the set point for two 200 hp compressors and load a third.

As can be seen in the second example system diagram. intermediate controls are the first priority for **balancing the system. managing demand (including leaks). controlling storage. and unloading horsepower. Control of the inlermediate pressure and the compressor control pressure can change the storage and the weight flow of demand and significantly change the way the system operates.**

Intermediate control is the most important control point in the system. Because the system can tolerate no hysteresis or failure. the controller should be a proven high-reliability unit (that can analyze upstream and downstream conditions and control both. This control point is an excel-

lent place to evaluate flow. dew point. storage volume. and minimum and maximum pressures. The controller Should have tamperproogf controls and failsafc circuits. Witiout this feature. a control failure would cause a system faiiure.

The third system example shows the effects of intermediate controls plus improved point-of-use demand and leak repair. Intermediate controls will affect all (downstream demand regardless of the presence of demand controls and possible operator tampering to increase the maximum control pressure. The controls must create a pressure differential: The intermediate pressure must be lower than the lowest compressor pressure for the system to work properly.

The fourth system examplc of the series illustratrs a fully balanced system. with automatic demand controls installed at all points of use to control the maximum pressure at which air can be removed. This point-of-use control will create storage in the header. subheader. and branch piping.

The example shows that only 5.25 cu ft of storage will reduce horsepower. Therefore. the reduction in overall storage is not particularly critical. The 2 psid pressure drop between the intermediate control and the demand should be ciiminated. And enough storage should be created in the piping to prevent drawdown from surge at the point of use. To accomplish this. intermediate control pressure must be increased. which will **reduce the tank storage by 31 Cu ft.**

An intermediate control downstream from storage vessel controls leaks and demand of Example 1, boosting demand pressure to 80 psig and unloading 25 percent of compressor horsepower.

EXAMPLE 2—INTERMEDIATE CONTROL ONLY

Supply capacity	Tank 240 gal	Intermediate control 82 psig	Leaks 15 cfm 82 psig	Original production demand
100 cfm 110 psig				100 cfm 80 psig
63.5 lb	64 cu ft			Less than total demand controls system response

Demand controls storage

47.7 lb 110 psig loaded	+	64 cu ft storage	=	7.4 lb 82 psig	+	40.3 lb 80 psig	or	100 cfm 80 psig
15.8 lb unloaded		(12.5 cu ft actual usage) 8 lb 110 psig		Leaks		Demand		Demand

By fixing leaks and improving use applications in Example 2, supply horsepower is reduced to 56 percent of the original load. The additional 58.75 cu ft of storage will extend load/unload to 95.5 percent. The life of the compressor has been increased significantly. Supply pressure could be increased or a compressor of half the size running flat out could be installed.

EXAMPLE 3—INTERMEDIATE CONTROL, NO LEAKS, IMPROVED APPLICATION

Supply capacity	Tank 240 gal	Intermediate control 82 psig	Leaks fixed	Production demand
100 cfm 110 psig				85 cfm 80 psig
63.5 lb	64 cu ft			Original demand reduced 15 cfm by eliminating poor applications

Demand controls storage

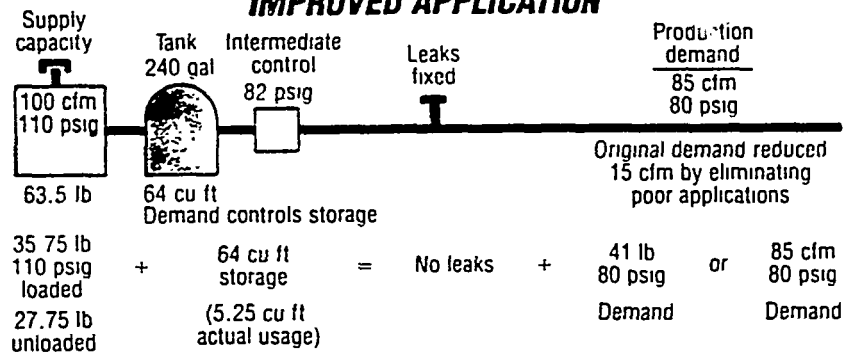| 35.75 lb 110 psig loaded	+	64 cu ft storage	=	No leaks	+	41 lb 80 psig	or	85 cfm 80 psig
27.75 lb unloaded		(5.25 cu ft actual usage)				Demand		Demand

By adding full demand control to 80 psig, the 82 psig intermediate control pressure of Example 3 is increased to 90 psig to further balance the system. Cycling is increased slightly, but surge is eliminated with pipe storage.

EXAMPLE 4—FULL DEMAND CONTROL

Supply capacity	Tank 240 gal	Intermediate control 95 psig	Leaks fixed Storage in piping 10.6 cu ft	Demand control 80 psig	Original demand 100 cfm 80 psig
100 cfm 110 psig					41 lb
63.5 lb	33 cu ft				Current demand 85 cfm 80 psig

Horsepower same as Example 3 · Storage in tank and header · Demand control at 80 psig plus solid applications

35.75 lb 110 psig loaded	+	33 cu ft tank 10.6 cu ft pipe	=	No leaks	+	41 lb 80 psig	or	85 cfm 80 psig
27.75 lb unloaded		Storage (5.25 cu ft used for horsepower)				Demand		Demand

Uncontrolled System A costs more than one third more to operate than controlled System B, a penalty of $820/shift/year for electricity only at $0.07/kWh.

EXAMPLE 5—COMPARISON OF UNCONTROLLED AND CONTROLLED SYSTEMS

100 cfm
63.5 lb
27.5 hp

No storage

A   7 psid without controls

110 psig   0 lb

131 cfm
78.8 psig
capacity
63.5 lb

Original demand	100 cfm 80 psig

100 cfm
63.5 lb
27.5 hp

1.4 bar storage
45 cu ft   Control IC

B   0 psid with controls   Control

110 psig   28.6 lb   90 psig

80 psig   71.41 lb

148 cfm
80 psig
capacity
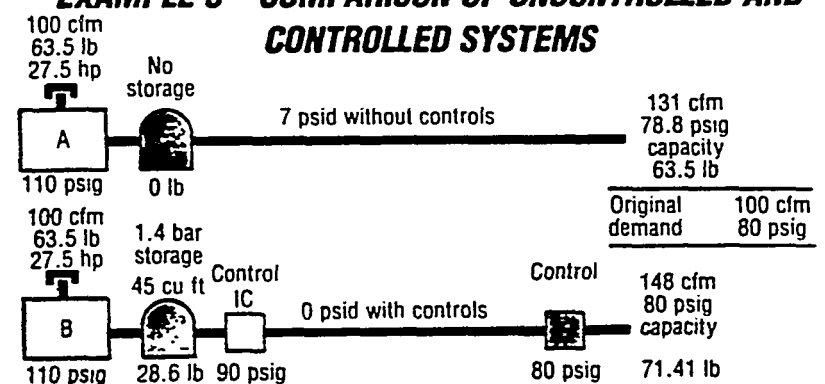
This condition will not improve or reduce horsepower at the compressor, but it will shorten the loading cycles to lengthen the cycles; another storage vessel could be added and the compressor pressure maintained at the current level, or the compressor pressure could be increased (if possible). The final balance of the example system does not seem to be a problem. Obviously, a considerably smaller compressor could be used if it could run flat out.

The advantage of control is demonstrated by the last example, which compares two systems featuring identical equipment, piping, and demand applications, except that one system has intermediate and demand control. System A is a typical uncontrolled system. System B is properly configured with control. Point-of-use regulators alone do not necessarily indicate that demand is being controlled at that point. All points of use must be controlled to a maximum pressure lower than the lowest compressor pressure to have balance. As the demand pressure rises, so also does the demand.

Without controls, demand in System A increased to 131 cfm at 103 psig, exceeding the capacity of the compressor. As a result, the point-of-use pressure will fall as demand exceeds the capacity of the compressor. The compressor will run flat out and create 131 cfm at 78.9 psig at the point of use as a function of the initial supply pressure to a demand, which if controlled at 80 psig would have consumed 100 cfm.

The point of use and intermediate controls in System B will maintain demand at 100 cfm or 48.24 lb. Assuming that at least 25 percent of the demand has a use factor of 50 percent or less, 12.5 cu ft of the useful storage will reduce what the compressor "sees" as demand (12.5 cu ft at 80 psig is 6.03 lb). The compressor will interpret demand as 48.24 lb − 6.03 lb = 42.21 lb, or 87.5 cfm at 80

psig, or 66.47 cfm at 110 psig. The weight flow of demand has now been balanced with the weight flow of supply interpreted through storage.

The next problem is to reduce electric power to match system requirements. System B has a perceived demand equivalent that is about two-thirds of the full load power of the compressor. An equivalent amount of kilowatts should be unloaded. In System B, the 45 cu ft of storage would serve the demand before the compressor operates. The compressor would then have to satisfy the demand and replace the storage before it would unload. Storage is 45 cu ft at 110 psig or 28.6 lb of air. The compressor would cycle 62 sec loaded and 35 sec unloaded for a total of 97 sec. If full load is 22.3 kWh and unload is 6.4 kWh, the overall usage is 16.56 kWh or $1.16/hr for electricity at $0.07/kWh. At 2040 hr/shift/year, the system would cost $2364/shift/year and would hold a steady point-of-use pressure of 80 psig.

System A would fluctuate up to 20 psid and require its 27.5 bhp compressor to run flat out at 22.3 kWh or $1.56/hr for a total of $3184/shift/year or 34.6 percent more than System B in electricity for the compressor alone. That penalty would be at least $1390 of burdened cost per shift per year or more than $6000 on a 24 hour basis.

If the design capacity of the compressor in System B is higher than

110 psig at the same flow, the pressure of supply could be increased, thus increasing the weight flow of supply almost directly proportionate to the rise in pressure. The horsepower would also increase, but at half the rate of the pressure rise by total percentage. There would be a substantial improvement in the mass (weight) flow to input power efficiency. In System B, this increase of efficiency would cause increased unload time and reduced load time. It is always appropriate to run the compressor at its optimum mass flow to power point once the system is balanced and demand is controlled.

The examples have been created with a demand-supply relationship of 100 cfm at 80 to 100 psig so that it is easy to relate to the effect of these issues in existing systems. When a full audit is performed on a system, it will find that the cost of air is 1.7 to 3 times the cost of the electricity when the costs of water or air cooling, dryers and filters, accessories, labor (inside and outside), depreciation, running and breakdown maintenance, inventory, aging to destruction, insurance, administration, etc., are included.

Without auditing the system from an engineering configuration as well as a financial point of view, it is difficult to get the attention of management. You may not get management's support until the next time that you seem to run out of air (or have excess demand) and, in desperation, everyone rushes for a prepackaged engineered power package to throw at the problem.

R. Scot Foss, PE, is the principal of Plant Air Engineering, Charlotte, NC. He directs system auditing and balancing studies and presents public and inplant seminars on compressed air system analysis.
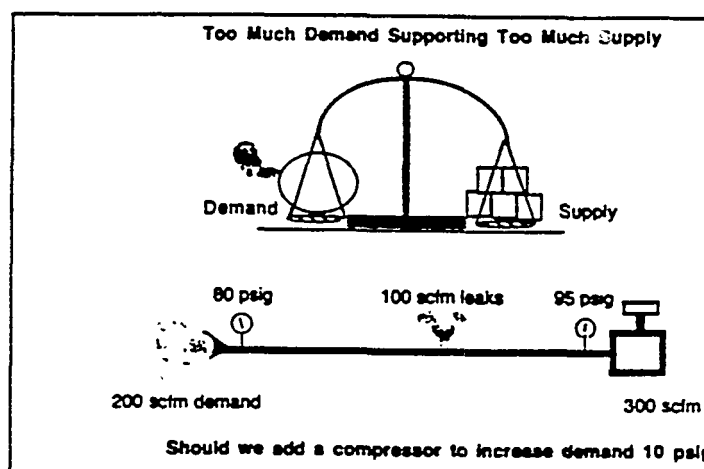
Mr. Foss is an independent consultant who has audited more than 750 compressed air systems in his 27 years in the business.

Compressed Air is Free.....Isn't It?

R. Scot Foss
Plant Air Technology
Charlotte, NC
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It's a tough choice when a maintenance professional has to solve a poorly defined problem with a solution that will cost more to operate in the first year than it costs to buy. This is the dilemma you are faced with when you have to buy another compressor to quiet the typical complaints regarding this misunderstood utility. There are a few things that are true about the vast majority of compressed air systems.

1. We have no idea how much we use or what we really need.
2. We can not make good *business decisions* about compressed air because we don't know what it costs us.
3. No formal or informal education is available about compressed air.
4. Experience is our only teacher and experience is usually what we got when we didn't get what we wanted.
5. The telephone is the instrument of choice in the compressed air system.
6. There are no standards for the use of compressed air at the point of use.
7. Production has the authority to demand more volume or pressure with no responsibility for how they apply or use the utility.
8. Maintenance has responsibility for how well production equipment works at the point of use with no authority except to apply more power to solve all problems no matter how misunderstood.
9. The requirement for compressed air will increase at a faster rate than any other utility regardless of any production increase. Most systems can reduce their on board power by more than 40% with a significant improvement in the quality of the production.
10. As you force the system to work by applying more power, you will get less and less for more and more. The last time you added 25% more supply did you even get 5% more results. Despite these unpleasant facts, more is considered better.
11. Systems that have problems are found to waste enormous amounts of the utility. Systems that don't have problems have been willing to spend an unlimited amount of money to force the system to operate. They waste more than systems who have problems.

Too Much Demand Supporting Too Much Supply

Demand Supply

80 psig   100 scfm leaks   95 psig

200 scfm demand   300 scfm

Should we add a compressor to increase demand 10 psi

As long as items 1, 2, and 6 exist, we have little choice but to live with the other nine items. If we operated any of ou other utilities like we operate compressed air, we would hav continuous problems. Let's take a minute to see what w would have to do in order to operate our electric system base on the same principles that we apply to the operation of th compressed air system.

1. We would have to remove all the nameplates from th motors and electrical devices. We normally have no ide what volume or pressure is required of air using device other than by trial and error.
2. We would buy electrical using equipment with no regar for voltage, amperage, or the effect that it might have on th system assuming that the local utility would compensat for whatever the results were on the system.
3. We would remove all the circuit breakers, transformer; capacitors, and starters from the system and use onl primary power regardless of need. If a particular use required control, we would put reostats on those applica tions and nothing on the balance of applications.
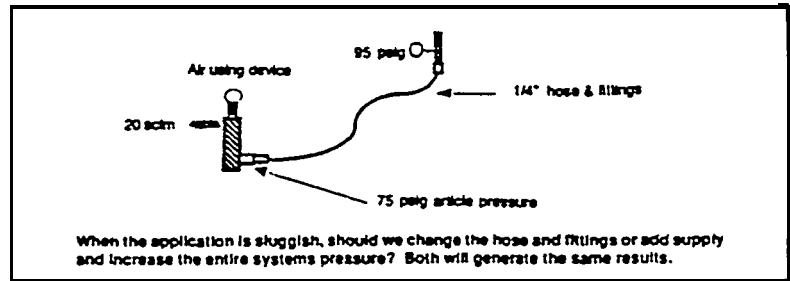
4. We would use one or two sizes of **wire and** connection components on all electrical applications regardless of *voltage or amperage* and expect maintenance and local utility to correct the system to compensate for how the production works. The size and selection of those components would be detemnined by the stores department rind purchasing based on price, availability. and minimizing inventory. Example use 1/4 hose and fitting on all applications regardless of fIow or pressure. Once the connections are made, if the application doesn't work you simply increase the pressure supplying the equipment until it works the way we want it to. Wouldn't thatbe interesting to do with **electricity?**

5. Give every operator and supervisor the phone number of the local utility. If the equipment in production isn't working the way that they want it to regardless of any changes in speeds, feeds, faults or any other problem, they simply call the local utility **who will alter the way they are** supplying electricity to the plant to correct that single problem. If they can not correct the problem with more whatever, they will simply buy more whatever or build another power plant and try again to solve the problem which was reported over the telephone. After all . . . . electricity is free! Well. . . ..certainly compressed air is free....itn't it?

Some of you probably thought that this example was ridiculous. Actually it would be a relatively close parallel to the way that most compressed air systems are operated. The sad part of this is that there are limited resources available to learn more about compressed air.

We have a very interesting way of finding out if problems in the system create a diminishing supply. We find out when the last compressor can no longer hold pressure in the system. The probecm will begin to consume supply at the bottom of the capacity of the last compressor and not be noticed until you have exceeded the full capacity of the entire supply system. Depending on the **relative size** of the last compressor compared to the total supply system. this problem could go unnoticed for years. The bigger the percentage that the **compressor represents, the** longer the problem will go unnoticed.

You would think that you would be able to notice a change in pressure as this occurred. **Based on the** hypothetical way that most people look at compressed air, you should notice sooner. The fact is that the vast majority of systems are supply controlled with 30-70% of all the volume of consumption represented by leaks, users with no regulation,regulated users that arc adjusted wide open. **Since the** volume of demand at these users is a function of supply pressure, as the demand **volume increases and the** compressor preasure drops, the demand volume drops to hold the systems pressure. when the **regulated** demand drops, the compressor pressure rises and the unregulated demand increases to hold the pressure down. It's a self-fulfilling situation. Supply creates demand while unregulated demand supports supply. You have to either significantly increase or reduce demand in order to see any change at all. What is more unfortunate about all of this is that the compressors seem quite happy with nothing much changing in the compressor room while production is experiencing

When the application is sluggish, should we change the hose and fittings or add supply and increase the entire systems pressure? Both will generate the same results.

an almost constant change in volume with fluctuating pressure. The fluctuation at the **point of use is** due to speed of transmission. The pressure flattens out at the compressor room, while fluctuating at a higher rate as **you** get closer to the production user. The farher the production user from the point of supply, the more the fluctuation. If you try to solve the problem with more supply, the problem may get worse. As you elevate the pressure by applying more *volume to the* system, you force more air through the existing piping. Since differential pressure is exponential, you increase the speed of transmission while increasing the differential pressure. The results are less and less for more and more.

Twenty five years ago it was unusual to find **a** plant air compressor which operated at more than 100 psig. Compressors and piping were job engineered to minimize losses in the system. We had no problem holding pressure at 90 psig. Systems were relatively well balanced. In **a** recent workshop I asked 140 maintenance managers and plant engineers "how many of you can hold 90 psig all day, every day without the presure dropping"? Only two hands were raised. I then asked how many people had compressors rated at between 115 psig and 125 psig. Over 110 raised their hands. More than half of the participants had another compressor proposed in some stage of appropriation or proposal. Most of them hoped that the increased supply would solve the problem, yet few if any could define the problem. What's wrong with this picture??? Over the past twenty five years we have been operating at higher and higher supply pressures, while it becomes more difficult to manage pressures which haven't changd at the production end of the system. Perhaps if we put as much effort into problem definition as comparing the redeeming values of pre-packaged solutions, we might be spending less money and resolving more problems.

There are numerous technical areas involved in the air system which arc never discussed or evaluated. Some of them are leak benchmarking, control storage, speed **of transmission.** initial to article pressure diffeenntial. dedicated metered storage for short cycle applications, mass flow control, temperature management for increased capacity, **and Ioad shaping** just to name a few. These are some of the areas that offer more for less . . . . improved production at a lower cost.

At $.06per kwhr compressed air costs arc between $1 .60 to $2.25 per 100 scfm per hour of operation including typical water. dryer/fiIter, maintenance, depreciation, and operator costs. A 300 hp system operating 3 shifts **a day, seven days** a week, will cost over $225,000 per year. The prospect of **a 30-50%** reduction of this opportunity expense is no doubt attractive. Perhaps a more significant question is "how much revenue must the company generate in order to support **this Waste?"**

Some common air system problems

Production uncontrolled use of compressed air is at the root of much waste and expense.

R **Scot** *Foss plant Technology, Charlotte, N.C.*

■ The classic compressed air problems are low pressure and water at the point of use in production. The entire air system winds up being run for the sake of these complaints. Low pressure means insufficient supply--- does it? Water in the system must mean that the air dryer doesn't work-or maybe not.

Every time there is a complaint about quality or pressure, maintenance or plant engineering turn on whatever is perceived to solve that problem. If that doesn't stop the complaints, then more is purchased and added until the complaints stop.

The idea that all problems in production can and must be solved by altering supply is ridiculous. We wouldn't think of this approach with eiectricity, steam, or water. In each of these utilities we would go to the point of use and figure out what the problem is. If the lights flicker, we don't call the local utility. We look at capacitance. When we can't maintain water temperature, we don't double the heater output. We look at demand management. If an application problem arises with steam, we don't rush out and instalI another boiler. We check the problem.

Yet, somehow, over the **years, we have** missed these straightforward paralles with compressed air. We assign all

responsibility for the workability of production equipment and applications to the supply end. Production has authority to demand what it wants, with no responsibility for its actions. Plant engineering and maintenance have responsibility for production's results, but with no authority. From the simplest management principles this makes no sense. Yet virtually every plant is faced with this dilemma.

There is seldom any communications regarding compressed air between the people using it and the people supplying it. In fact, it is not managed as a system. It is a system, however, and should be dealt with accordingly. Despite this there are never any standards for its use, which would assure that it performs as expected. There are no limits to what production can do with compressed air and no costs too high to solve the most poorly defined problem.

It's hard to believe that we would act in such an irresponsible way in light of global competition. On the other hand, 99% of the facilities that use compressed air have no idea how much they use, what it costs, or if it is working efficiently. They only know if it meets an undefined minimum level of acceptability based on the opinion of the users. And generally these users never have received any training in the use of the utility.

In the hierarcheology of all organizations various levels of management are allowed to make certain financial decisions before approval must go to the next level. in most plants a decision involving more than $10,000 is approved at a number of levels. When it comes to compressed air, these rules of prudent management seldom apply. In the average plant with a cost of $.06 per kwh, compressed air costs are more than $1.70 per 100 scfm per hour of operation. A l/4-inch open air line, whether it is in the form of leaks or poor applications is a $10,000+ business decision-and anyone can make the decision with no discussion. In fact, in most plants more than 25% of the total compressed air usage is from leaks, often costing well into six figures. In most of those plants there is a requisition circulating to buy more power, which will elevate the pressure and increase the waste.

The use of compressed air by workers on a prodution line should be an eucated use. 0therwise, the plant's air system can never be efficient

Let's look at some more specific problems that are neither understood nor dealt with.

Leakage

A leak that forms a tube, hose, fitting or disconnect will cause the volume to increase in a particular installation. The result is an increase in differenual and a drop, in the article pressure to the using equipment As the leak gets bigger (that's the nature of a leak) the article pressure continues to drop, reducing the performance of the item using air. If it's part of a control System. the whole system eventually will malfunction.

We will increase the regulator pressure until the arucle pressure rises. As we do this the leak volume increases. As the leak volume will increase linearly and the differenual will increase exponentially the increase in pressure will have to be **substantial to compensate.**

Eventually this application will cause other use points in the same supply line to do the same thing. In time we will add **more power. I am fascinated that the results of this leak can justify a capital expenditure to add more supply which Will** cost more to the first year than what it costs to buy. This could easily be a five or six figure decision. Yet the problem is correctable in 2 minutes with a *$3 part.*

Air leaks are not a part of any management agenda. **Even when they are known to be** substanual, nothing is ever done. In most plants the procedure for assembling point of use air and the components used propagate the eventual leaks. It's bard to **believe that any knowledgeable mange-** ment person would encourage the tool crib to buy the cheapest compressed air components possible if they understood the consequences on the production equipment.

Water in tire lines

Here's a Here's a fascinating anomaly We dry the compressed air to say 45 Fdew point p-sure in the compressor room. We don't want water in the production equipment We all learn in engineering school that vapor seeks the lowest vapor pressure. The vapor pressure is lower in the compressed air lines than at atmosphere. As leaks increase in the system, the remaining vapor in the balance the system causes the dew point to rise.

Evenually, as leaks increase sufficient- ly, the vapor content per cfm will rise to the point where water will form downstream in the system. This Can happen on a plant-wide basis or at a particular point of use. A leak on a critical application that becomes equal to the volume of air in she using de-vice will cause water vapor to coalesce in the air-using device. The common solution is not to fix the leaks. It is to add a drver or change to a lower dew point dryer.

New equipment

Anew piece of production equipment is in-**stalled. No one Knows how much air vol. tune is** required. production engineering never considered whether the required pressure inappropriate or not It is nomral to select equipment based on the highest achievable pressure in the air .ssystem. If we did that with electricity. the light bulbs would be 13,000 Volts.

There are a growing number of industrial companies that have pressure standards for the selection of air-using devices that are well below the lowest compression pressures in the **plant.** This **requires flexibility** on the part of suppliers, but that is what air is all a about.

This standard will always guarantee that the production equipment will function properly. **Despite this obvious fact,** *thousands* of pieces of equipment are specfied every day in production that either will not work, can't be adjusted to higher speeds or feeds. and will have problems when the first leak shows up. lf the cycle rune is increased, the volume of air-increases and the pressure drops.

The common solution is to call maintenance and plant engineering and request that something is done—i.e., the production equipment is not responding properly because of the compressed air. While that phone call is being *made,* someone else is planning for another future problem to be installed in the facility.

We would go on with various exarnples *for* quite some time. Undersized components in the installation of compressed air, insufficient storage at the point of use, and improper metering of surge applications are just a few examples. It is not these specific problems, but education and assignment of responsibility that really needs to be corrected.

Production rnaintenance and engineering needs to assume responsibility for understanding compressed air and its use. Standards need to be developed and conformed to if the quality and reliability of prodcnon~unfmrtam The system needs to be operated as a process, not as parts operated independently.

Ongoing predictive maintenance, such as ultrasonic leak benchmarking, must be established. Education and standards for compressed air must be a regular and normal part of the production and facilities **agenda** Demand must be considered part of this dynamic process with all of the comunications necesary to maintain its integrity, operating cost, and quality.

More information on this subject is aailable on request
To learn more. Circle 260

In most plants more than 259% of the total compressed air usage is from leeks, often costing well into six figures.

Control demand to contain expenses

Engineered responses to demand

will bring compressed air savings.

R. Scot Foss *Plant Air Technology. Charlotte. N.C.*

Compressed air usage should be reviewed. Production may need education about air pressure.

■ Since compressed air is our least understood utility, it should be no surprise that most of the time we throw power at poorly defined problems. Problem solving using brute force is extremely expensive from a capital and an operating cost point of view.

Phone calls from irate users provide the best information about problems. Users demand what they think is lacking on the supply end. A large part of this problem stems from inappropriate assignment of responsibility.

Users in 99% of the systems are not responsible for controlling how they use compressed air or how much they use. Users have no requirement to apply reasonable engineering to any installation. Often, a user has no idea how much air an application needs or even if the application is appropriate. Please remember that it takes at least ¯ horsepower of electricity to generate 1 horsepower of compressed air power.

> **The compressor room is not the demand. It's just another stage of conversion. The user is the demand.**

Employees at the using point are allowed to adjust the regulators to a maximum pressure or not use one if they see fit. Existing leaks can continue to grow at an unmanageable rate. Any worker on the floor can apply an open air line with five-figure consequences. Production can install a piece of equipment with catastrophic consequences for other users. Applications can be installed with critical pressure requirements that can't work. All this can be done without discussion between the user and the compressor room operators.

Sooner or later any one or all the above situations will motivate a representative of production to use the instrument of choice in the compressed air utility system. This instrument of choice is, of course, the telephone. The magical word is spoken that expresses the standard for compressed air. The standard is "more." But more *what?*

point there is no recourse **but to abandon** the confines of the compressor room. We must seek demand-side solutions, despite the lack of interest and the protest of the user.

Think of the last lime you applied power to solve a systems problem. Suppose you had three compressors and you added a fourth. Simple math says that you added 33% more capacity. When you ruined on the unit, did the pressure rise 33%? Did it rise even 10%? It probably did not. Did you try to reduce demand or reengineer installtions with high pressure differentials?

Maybe you could use an air storage unit with metered recovery. Storage and metered rccovery can reduce the horsepower that supports demand surges. The storage and metered recovery combination reduces the rate of flow and spreads the surge demand requiremems over a **longer** period of time.

I

> **Employees at the using point can adjust regulators as they see fit. Any worker on the floor can apply an open air line with five-figure consequences with no discussion.**

The speed of air transmission may be the problem. *A* **demand surge causes a pressure decay** in an under-capacity system. In this case. you can increase the transmission capacity instead of the differenual pressure for improved service.

Increasing the pressure requires a substantial amount of power and increas es leaks and unregulated demand. Careful engineering reduces the impact of demand surges without adding power.

What if your production department increases **its operating rate?** This means that all the installed hose, filters, regulators, etc. will see higher flow. The elevated flow rates result in higher differential pressure. Increased differential pressure reduces specific pressure to the equipment.

Should you increase the flow capability to increase the specific pressure. or

add power to increase the supply pressure for the same result? In most systems that I audit and reconfigure, 20 to 40% of the total demand usage has no value to **production.**

One of the major constituents of waste is leaks Another wasteful constituent is excess air volume consumed at work stations. Wide-open regulators indicale

waste. If another compressor is added increase the system's pressure. it wi increase waste also.

Without standards for compressed a usage. it should not be surprising th these situations are commonplace A utility costs escalate. the effects of dea ing with compressed air waste become major concern..

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KW =  AIR  ────────►  Real Demand
                      (Good and Bad Applications)

              ────────►  Leaks
                        (Volume Inverse with Real Demand)

              ────────►  Artificial Demand
                        (Created by High Supply Pressure)
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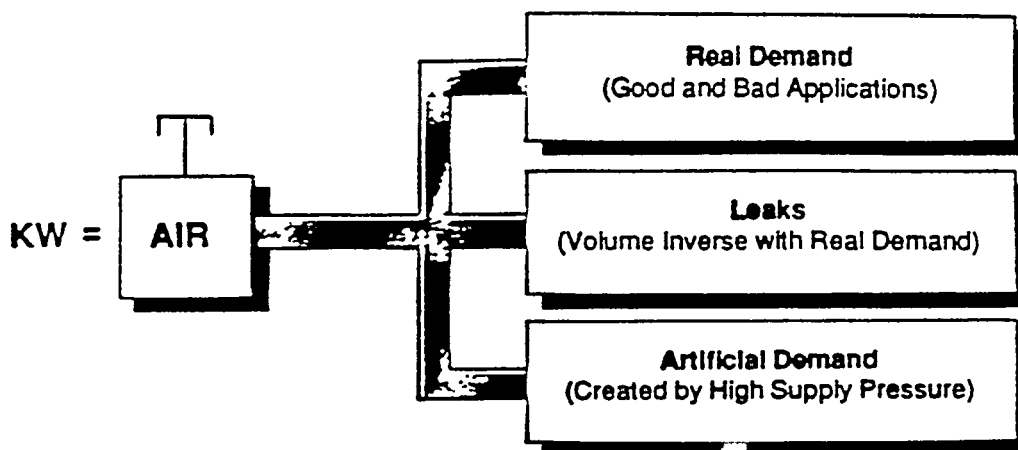
Dealing with Air Leaks

*A single ¼ in. hole in a compressed air system
can waste $3000 to $10,000 per shift per year.
How much are leaks costing your plant?
Here is how to get the figures and approach the problem.*

By R. Scot Foss, Plant Air Technology

One of the most insidious forms of industrial waste in America is compressed air leaks.

About 20 percent of all power used in American industry for compressing air is wasted because of leaks. That waste represents between 6 and 7 million kWh of electricity or about 16 billion Btu/hr of energy—enough energy to heat and air condition approximately 134,000 homes for a year. The energy bill is even greater if support equipment such as water pumps, dryer motors, and fan motors is included. And these figures do not include compressors of 10 hp and less.

Far too many people in American industry view compressed air as a free commodity. Your plant is probably using more compressed air than in the past, and the rate of increase in air use probably was greater than the increase in productivity. Operating pressure and leaks also may have increased during this time.

A leak is a hole through which is blown pipe scale, iron oxide, and

Total demand is made up of real demand from work applications, leaks, and artificial demand caused by too high supply pressure.

other compressed air contaminants. Abrasion from the contaminants will cause the size of the hole to grow as long as the system is pressurized. Adding to the loss from leaks is a growing interest in higher operating pressure. Not too long ago, standard pressures were 90 to 100 psig. Today, they are 125 psig for larger compressors and 150 to 175 psig for smaller industrial models.

Unfortunately, it is generally believed that anything that goes wrong in the compressed air system must be corrected in the compressor room. When production personnel complain about low pressure at the point of use, the operating pressure is jacked up in the compressor room.

Increasing the pressure is not an appropriate diagnosis of the problem or the solution. Demand will increase

as a function of the increase in pressure, and additional energy will be used to overcome the geometric effect of mass flow restriction or differential pressure created by the increased flow in the piping and ancillary equipment.

By increasing the pressure, the amount of air blowing through the leak increases significantly, and the leak hole is enlarged because of the increased velocity of the abrasive

Justifying repair work
Can you ask for funds to fix the system if you are unaware of what compressed air costs in your plant? Perhaps there has never has been an audit. When problems are poorly defined, configuration technology is nonexistent, and database measurements are not expressed in money, management will postpone repairs until situations become desperate.

"Desperate" in an air system means not enough pressure, dirty and wet air, and all compressors continuously loaded. What is the solution

to a desperate situation? Install another compressor? Leaks will increase. Unregulated demand will increase with no real improvement in production after leaks and artificial demand are satisfied. Each additional compressor will serve less and less productive uses. Carried to an extreme, the increase in flow and the resulting pressure drop in the piping will exceed the capacity of the new compressor. As a result, the pressure will fall below the original pressure instead of increasing. When you consider that it costs more to run a compressor in the first year than the original purchase price, such a result could be embarrassing.

When was the last compressor installed in your facility? Compare the percentage of new power the unit represented. If Mr. Bernoulli was right, the increase in system pressure should be linear with the power increase. Most likely, the increased system pressure was not linear with the power increase, and the rate of increased pressure probably was less than half the rate of power increase.

A group of industrial and process plants were audited in 1990, and 20 percent had leaks costing in excess of $500,000. These facilities were paying no more than $0.065/kWh for electricity. Their full burdened cost of compressed air ran between $1.10 and $2.56/100 cfm/hr at operating pressures between 80 and 110 psig. Half of these companies would have turned a profit if leaks had been controlled. One plant manager compared this cost to hiring 35 hourly workers to stay at home on sick leave for a year.

Identifying and fixing leaks and installing demand controls for a system usually produces a payback of a few months. Nevertheless, most maintenance and facilities managers consider leaks an unfortunate cost of business, unworthy of their attention.

One fact remained consistent during the 1990 audits. Leaks were re-

> **Contrary to popular belief, compressed air leaks are not a constant demand on the system.**

sponsible for 20 to 35 percent of demand in most of the plant air systems surveyed. Therefore, one-third of the expenses incurred for all compressors, dryers, lubricant, parts, outside and inside labor, water, depreciation, and electricity served no useful purpose. The plants participating in the survey were aware of the problems. Other plants unaware of such problems, overpower leaks and other deficiencies so the leak rate may be much higher than plants reporting low pressure.

The largest motors in many plants drive compressors. As such, they have a dramatic influence on the demand and time use charges for plant electricity. Therefore, if leaks were identified and fixed and air demand were controlled, the electric bill would be reduced significantly. The plant reduction in total electrical cost could be 10 to 15 percent, depending on the size of the compressors and rate structure.

The full burdened cost of compressed air is 35 to 100 percent more than the cost of the electricity necessary to operate the system. Depending on the rate structure and the efficiency of the system, total cost could run between $1.10 and $3.75/100 cfm/hr. A ¼ in. hole that consumes 94 cfm at 100 psig will cost $3019 to $10,293/shift/year.

Contrary to popular belief, leaks are not a constant demand on the system. Demand from leaks increases and decreases as a function of the supply or operating press of the compressors. Because c pressor operating pressure is versely proportionate to real prod tion demand, loss through le increases as production drops off

When production drops off p sure rises in an effort to unl horsepower. The elevated press causes an increase in leaks and o unregulated demands. The artifi increase in flow causes a reductio pressure, reducing demand wh causes pressure to rise, which cau the demand to increase, etc. T oscillating influence on pressure flow tends to prevent compres: from unloading. If leaks and o unregulated demand are la enough, compressors might never load, regardless of the produc requirement. One maintenance m ager noted that all compressors main loaded during shift breaks was not difficult to track the probl in his system. The accompanying tion "Costs Add Up Fast" illustr how much money such a system c be wasting

Identifying amount of leakage
Obviously, it is important to ider leak locations. Major sources of l are noted in the accompanying tion. To justify corrective act managers must know the opera costs for their compressed air tems, and the total amount of le It would be a shame to take action on the basis of reason: guesswork and then not be abl take credit for the savings that c be applied to other budgetary ne

Determine the total amoun leaks during a period when no duction is on-line and when a minimum of pressure is requi Then put only the necessary pc on-line to support the leaks a production pressure you have t maintaining. Where there are di ent loads at different shifts, load test conditions to each opera

pressure to determine the flow and power required for each shift, pressure would be higher as production flow requirements dropped off.

The most accurate measurement method is to put on just enough power so pressure cannot quite be held and then interpolate the additional required inlet airflow necessary to bring the pressure up to the desired test pressure. This "not quite enough" condition is called "drawdown", it is a dynamic condition in the system where the flow of the compressors will be accurate for machines that are in service. The interpolated volume is added to the base load information to produce the volume of leaks minus the known minimum other load that may be on, such as agitators or HVAC.

It may be necessary to eliminate various demands one by one, while identifying the required power during the process of elimination. If the compressors are too large to unload and put the system into drawdown, the machines that must be operational must be timed in the load–no load operating condition.*

The cycling of the last machine put into a load/no-load condition must be monitored to establish the volume of trim to add to the base load. This "positive displacement" condition, unlike drawdown where a firm pressure is held, will not give hard information when demand is not controlled with intermediate controls, and pressure is rising and falling. The demand would rise and fall as a function of supply pressure. An intermediate control pressure lower than the lowest compressor operating pressure in the throttling band would produce constant demand pressure

*In most systems, compressor and ancillary equipment sizes are selected on the basis of peak demand only. The consequences are that less than full load always puts you in the middle of a "too large machine." The machine may have good part-load power characteristics, but the system part load is terrible.
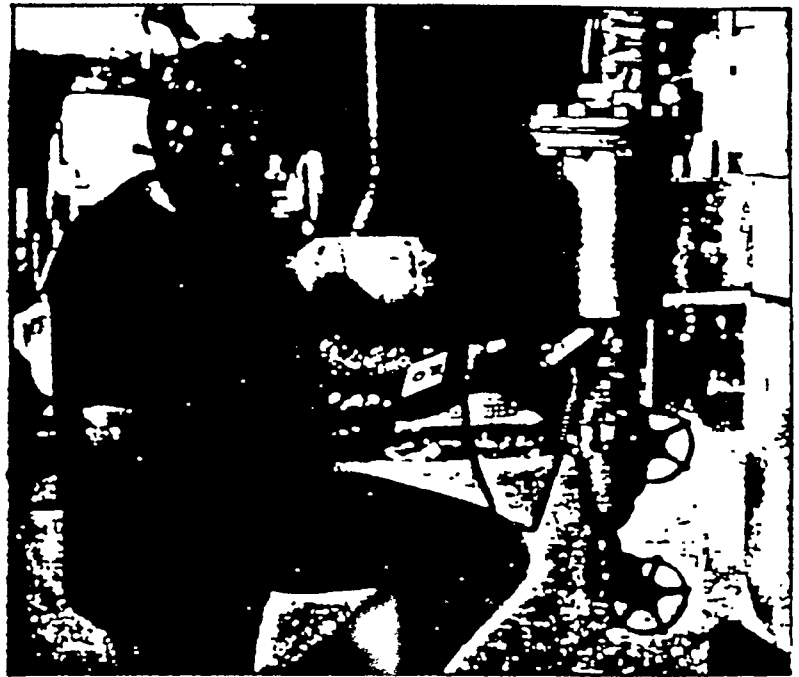
An ultrasonic leak detector can locate leaks in all types of piping systems. (Courtesy SDT USA)

MAJOR SOURCES OF LEAKS

Hose leaks and worn disconnect plugs.

Abandoned equipment with air left on.

Mechanical failures on valves, cylinders, and controls such as seals, seats, gaskets, and O rings.

Leaky traps and motorized drains that blow more air than effluent.

Pipe connections and stem valve packing in shut-off valves.

ACTION PLAN FOR DEALING WITH LEAKS

1. Determine the operating cost for the compressed air system.

2. Measure the flow requirements for leaks at various production and nonproduction conditions.

3. Establish the total annual cost for leaks.

4. Identify the locations of the leaks and label with paint.

5. Fix the leaks.

6. Install automatic shutoff devices for automatic machinery that is frequently abandoned.

7. Install intermediate controls and point of use controls at all locations to control a "maximum" pressure that is lower than the compressor operating pressures.

8. Report the reduction in system operating cost.

9. Minimize the possible points of potential leaks such as disconnects or excessive hose lengths.

10. Educate hourly workers and maintenance personnel to the importance of leak and pressure management, as well as reporting procedures. Incentive programs with T shirts, etc., have proved effective in developing awareness.

11. Test the system for leaks on a regularly scheduled basis as part of a good preventive maintenance program. Set an achievable benchmark for maintenance to manage on a weekly basis, such as 100 cfm. Once you get to the goal, it is easy to manage.

COSTS ADD UP FAST

Examine the costs associated with a plant that has 750 cfm of leaks during normal production with an average operating pressure of 90 psig, only 15 to 17 leaks at ¾₆ in. on the average. The plant operates three shifts, five days a week, from 7 a.m. Monday to 11 p.m. Friday. The system then maintains pressure over the weekend.

Compressors are operated at a conservative 110 psig in order to have 90 psig at peak production. Demand is not managed except for equipment where the manufacturer specifies a minimum pressure be held. That includes leaks.

Intermediate controls between the compression equipment and the distribution piping will control all demand to a maximum control pressure. Without a maximum control pressure, you cannot maintain a minimum pressure at the point of use.

To keep the example simple, assume that leaks are at 90 psig on production and 110 psig off production. That represents 750 cfm at 90 psig (0.5332 lb/cu ft) and 893 cfm at 110 psig (0.635 lb/cu ft). Assume a cost of $1.11 per 100 cfm/hr based on $0.06 per kWh plus 50 percent burden (labor, water, depreciation, ancillary power, etc.) for an additional $0.57 per 100 cfm/hr. Normally, when the total air requirement goes down, the inefficiency of part load for the system causes the cost per 100 cfm per hour to rise inversely proportional to the reduction in flow. Again, to keep the example simple, the cost per 100 cfm per hour will be assumed constant, although off production should be much higher.

Where 1 unit of compressed air equals 100 cfm/hr and costs $1.67, and production time is 112 hr/wk (5824 hr/yr) and off production time is 56 hr/wk (2912 hr/yr), 7.5

units of air x $1.67 per unit x 5824 hours = $72,945.60/yr and 8.93 units of air x $1.67 per unit x 2912 hours = $43,426.95/yr, for a total cost of leaks per year = $116,372.55.

This figure does not include the influence that the 150 kWh has on demand charges to support the leaks, or the power factor penalties. This example represents a real plant that was recently audited with a total production load of 3000 cfm.

Noise reduction is an additional benefit derived from controlling leaks. When air demand is reduced, noise is significantly reduced. A plant engineer in the Northeast fixed the leaks in his facility and controlled all other air-users so pressure would not exceed 85 psig. He reduced air systems operating costs $379,271/yr and reduced plant noise level 4.5 dBA.

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regardless of the effort of the compressors to unload horsepower.

Flowmeters would be the obvious method to test volume. However, if the system is not balanced, where the compressor controls refine the response to a "100 percent controlled demand" interpreted through storage, the flowmeter would not deliver accurate data. In an unbalanced system (99 percent of all air systems) the temperature, velocity, mass flow, demand, and pressure are changing continually. It is only in a balanced system that demand can be accurately matched with the minimum required power. The many variables have an effect on each other. When demand, distribution and storage, and compression equipment are not controlled, the results are less than desirable, leaks included. Once the total amount of the leaks has been determined, you must identify the operating cost of the leaks.

The easiest method for finding in-

dividual leaks is with a microsonic or ultrasonic leak detector. These directional hearing devices can even locate leaks in overhead piping from a floor location. They are good devices for checking new or corrective installations. Most leaks begin at an inaudible level and accelerate to audibility.

Managers may have to identify the total amount of leaks first to justify acquisition of leak detection equipment. Once leaks have been located, mark the spot with fluorescent paint. A memo should be sent indicating the average cost per painted spot. When corrective action is accomplished, the spot can be painted black or the original color.

If leaks are not fixed immediately, workers will jack up the point-of-use pressure in response. Volume of air at the point-of-use station will increase and cause a reduction in pressure in adjacent workstations. Adjacent workstations will respond by increasing the pressure, and the horse

race is on. In a few weeks, when you have run out of compressor capacity, you may attribute the problems to "insufficient power," and start shopping for another compressor. However, most systems problems are not caused by insufficient power, but excessive, uncontrolled demand, and leaks are at the top of the list

Further information on managing compressed air systems can be found in the author's previous articles "Economics of Compressed Air" (MT 11/89), "Auditing Compressed Air Costs" (MT 12/89), and "Controlling Demand in Compressed Air Systems" (MT 4/90).

Scot Foss, senior consultant, Plant Air Technology, Charlotte, NC, direct system auditing and balancing studies, and presents public and inplant seminars on compressed air management

MAINTENANCE LOG

Helpful maintenance information and problem solving case studies from suppliers of plant equipment and services.

Stopping Air Leaks Saves $150,000

Pat Lyons, maintenance manager of Conley Frog and Switch Co., Memphis, TN, is a careful magazine reader. Always alert for new technology to use in his plant, Lyons was influenced by Scot Foss's articles in MAINTENANCE TECHNOLOGY magazine on the benefits of auditing air leaks ["Economics of Compressed Air," MT 11/89, pg 41; "Auditing Compressed Air Costs," MT 12/89, pg 39; "Controlling Demand in Compressed Air Systems," MT 4/90, pg 24; "Dealing with Air Leaks," MT 5/91, pg 35].

By applying the information he gained from the Foss articles, Lyons has saved his company more than $150,000. Approximately 10 percent of these savings can be attributed to products supplied by Loctite Corp. through Motion Industries in Memphis.

Conley Frog and Switch is a trackwork assembly supplier for U.S. railroads and a commercial forging supplier specializing in automotive forging. The plant has 300 employees, 22 of whom are in the maintenance department.

How he did it

Lyons read the articles in July 1991 and was "astonished at how much air costs."

He started monthly air audits to determine the plant's air leakage rate. The plant's capacity of 19,000 cfm at 100 psi requires 3175 hp to produce. Electricity for the air system costs

Packing glands on an 8000 lb Chambersburg power drop hammer are checked for leaks by Pat Lyons and a member of the maintenance staff.
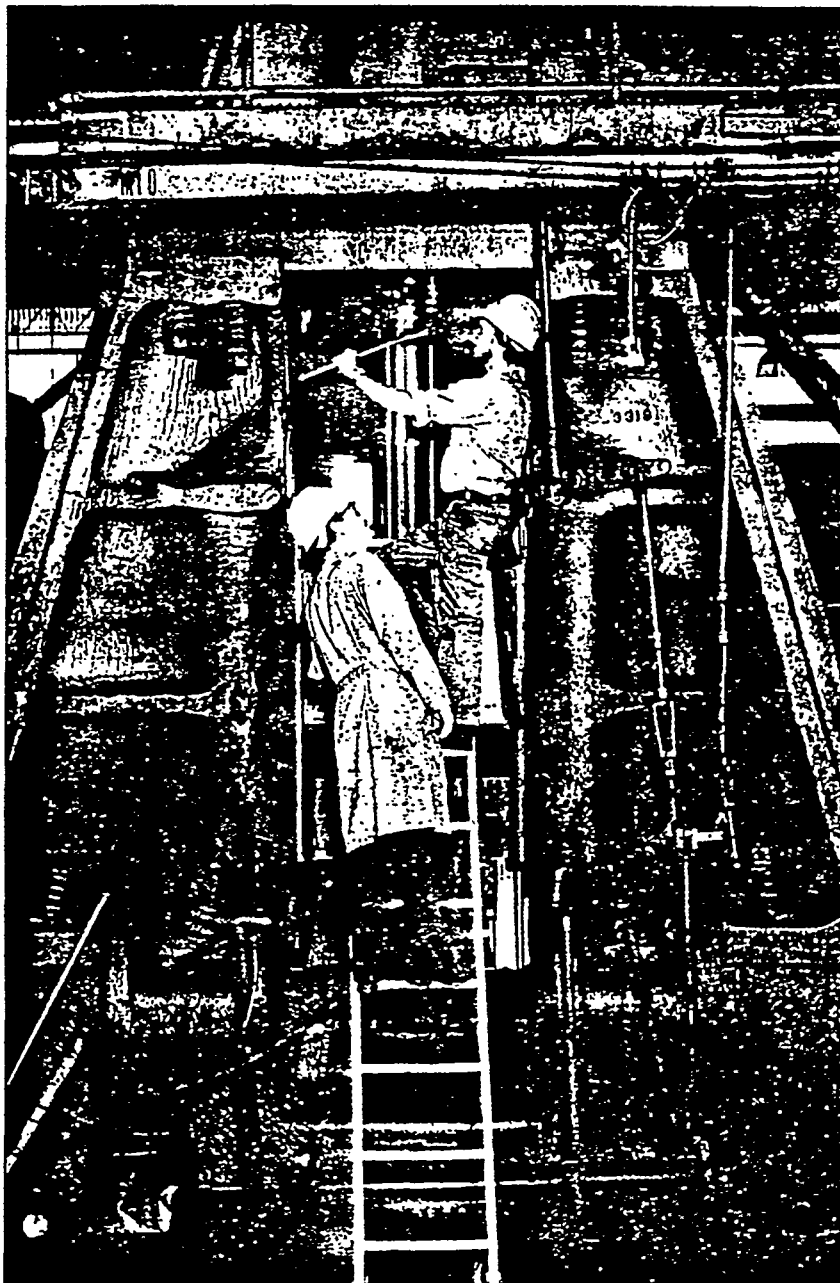
Primer is applied to clean threads to speed cure of sealant.

Sealant is applied to pipe threads of air inlet to actuator cylinder.

Treated fitting is assembled.

COMPARISON OF AIR COSTS
August 1991 and June 1992

Condition	Year	Amount of leakage, cfm	Electrical demand, kW	Annual electrical consumption, kWh	Annual electrical consumption cost, dollars	Annual electrical demand cost, dollars	Total annual electrical cost, dollars	Cost per day, dollars
All valves open	1991	3745	584	2,455,000	74,632	66,576	141,208	606
	1992	925	144	665,000	20,216	16,416	36,632	157
One hammer isolated	1991	3285	512	2,165,000	65,816	58,368	124,184	533
	1992	750	109	500,000	15,170	12,426	27,596	118
Two hammers isolated	1991	2365	369	1,505,000	45,661	42,066	87,727	377
	1992	675	100	400,000	12,160	11,960	24,130	104
Three hammers isolated	1991	1656	258	1,100,000	33,370	29,412	62,786	269
	1992	525	89	334,000	10,254	10,146	20,300	87
Four hammers isolated	1991	1196	187	830,000	25,182	21,318	46,500	199
	1992	430	67	250,000	7,600	7,630	15,230	65
Five hammers isolated	1991	1104	172	770,000	23,361	19,608	42,969	184
	1992	200	31	130,000	3,952	3,534	7,486	32
All hammers isolated	1991	920	143	660,000	20,024	16,302	36,326	156
	1992	90	14	55,000	1,676	1,596	3,268	14

Air costs August 1991	$202,208
June 1992	$46,632
Total reduction	$155,576

about $750,000/year; when operating costs are added, power costs total $900,000.

Lyons' first air audit, conducted in August 1991, revealed leaks of 3745 cfm, nearly 20 percent of the plant's capacity. It required one 200 hp and two 250 hp compressors just to satisfy the leaks—at a cost of $157,130 for electricity and $60,000 in operating costs (including labor, parts, and lubricant).

The next step was isolating the leaks. Lyons found six major leaks, plus many small leaks, and set out to correct them.

A month later, three major leaks had been eliminated, along with many minor leaks; however, three new major leaks had been detected. "We are moving in the right direction, but we still have a long way to go," he told his staff.

Lyons says the most difficult part of controlling the leaks was getting associates to report them. "They thought the leaks were normal and did not report them," he says.

A series of weekly plant meetings was started to enlighten everyone as to

the **extremely** high cost **of air leaks. These meetings were very successful." Lyons** reports.

In the first **6 months,** air leaakage was reduced from 3745 cfm to 1050 cfm. representing savings of $107.820 in *electricity and $40.000* **in operating costs..**

Leaks go back Up
Soon. however. air losses from leaks began to rise again. Lyons attributed the increase to a combination of recurring leaks and failure to stress the importance of the numbers. In January **1992. Conley began implementation of a total quality** management **program that** inciuded total **quality maintenance.**

As part of the program Lyons asked **Duncan** Campbell of Motion Industries to set up training sessions fur the maintenance department and other staff. Several sessions were held on beaarings, chains, and couplings. and then a series of four sessions on leaks.

In the first 6 months, air leakage was reduced from 3745 cfm to 1050 cfm.
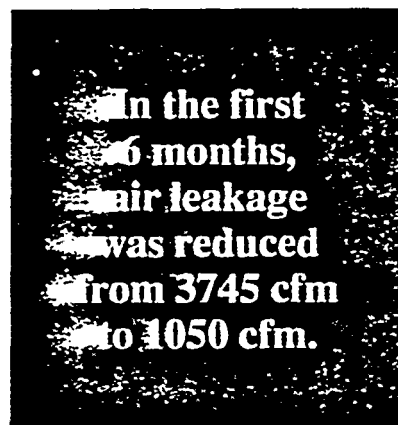
Loctite's PST Pipe Sealant 565 and Lxcquic *Primer* N were used to seal pipe joints and other plumbing in the plant. "Before using these products. we had recurring leaks. Lyons says. "We. d fix a leak on Monday and it **would be** back on Thursday due to the vibration caused by our big air hammers. Since we started **using these products. no leaks have recurred."**

Major leaks were attributed to parts with mechanical seals. Minor leaks occurred in threaded parts such as pipe fittings that were easily sealed with the pipe sealant. About 10 percent of the savings were attributed to use of the Loctite products.

As of June 1992. Lyons reports that his plant had reduced major compressed air leaks to 925 cfm and minor leaks to 100 cfm. In less than a year. he and his staff have brought costs down $155.576.

The development of the air audit/ leak prevention program is just one example of how Lyons has changed his maintenance department from an overhead cost (or necessary evil) to a valuable profit center.

Information supplied by Steve Tenhundfeld of Loctite Corp., Newington, CT.

Evaluating, Sizing and Selecting Air Compressors

By R. Scot Foss

Nine rules of thumb when adding a new air compressor to the plant's compressed air system.

The fact that compressed air is a utility does not make it as easy to obtain as electricity, water, gas, etc. It is not practical to transport the energy of compressed air over long distances; otherwise, it could be purchased from a central station. Yet it is vital to every plant engineer. With very few exceptions, plants must operate their own compressors, which are the heart and the supply of a rather complex system.

The use of compressed air in the U.S. is increasing rapidly. This is important to every plant because the increasing use of compressed air devices goes to a company's bottomline as increased operating cost. Most production personnel have no idea how much air they use or what it costs, so its application has no known business consequences. Consequently, many plants are playing catch-up in regards to this technology. With little knowledge about demand management, most plant engineers feel the resulting low production pressure must be corrected by adding compressors. There should be a relationship between productivity and compressor power, so plant per-

sonnel find themselves in a dilemma when the next compressor is requested and there has been no increase in production to warrant it.

When it comes time to select the type and brand of compressor for a compressed air system, whether for a new system or to correct a problem in an existing one, the decision can be confusing at best. Sizes and types of plant air compressors (90-15 psig) cover a wide spectrum. Size selection and numerous opinions regarding product features can make the choice a confusing exercise in many plants, where machines of different sizes and types may be operating together. All compressor types can be driven by prime movers other than electric motors with more or less ease. Turbine, steam, oil or gas are the primary alternatives.

NARROWING COMPRESSOR OPTIONS

At this point in the discussion, one would expect a biased suggestion as to which of these compressor types is best. Let's examine this issue from a variety of points of view. In general, a number of issues must be examined first in order to hone in on this difficult subject:

Energy Cost: The cost of energy to operate a compressor, depending on the number of shifts and cost per kilowatt, is so significant that in almost every case it is the most important selection criteria.

Equipment Interface: Despite Item "A," the characteristics of the system and the way the compressors will work together in all shifts, loads and conditions will easily outweigh individual machine performance or unique feature offered in any one type of machine. Inappropriately applied, the most efficient compressor will be a costly mistake. Too little consid-

Compressor Options: Locating the best type and brand of air compressor for an application will depend on key criteria such as energy cost, operating time and system compatability.

Types of Air Compressors	
RECIPROCATING	
Single Acting	1- and 2-stage, lubricated or non-lube (no contact cooling)
Double Acting	1- and 2-stage, lubricated or non-lube: 2-, 3- and 5-step controls (no contact cooling)
ROTATING	
Dynamic Type:	
Centrifugal	2-, 3- and 4-stage, non-lube (no contact cooling)
Axial	1-, 2- and 3-stage, non-lube (no contact cooling)
Positive Displacement Type:	
Sliding Vane	2-stage, lubricated (no contact cooling)
Flooded Vane	1-stage (no contact cooling)
Dry Screw	2-stage (no contact cooling)
Flooded Screw	1-stage (with contact cooling)

eration is given to the interface of existing machines and the application. Generally, emphasis is placed on test cell data, peak load only, and hypothetical performance. Recently, the president of a major compressor manufacturer said that to buy the most efficient compressor and put it in a poorly-configured and managed system would be like buying a Corvette and driving it with the handbrake on.

Operating Time: The best way to operate a compressor, from every point of view, is off. If load variations can justify it, especially across shifts, you are better off with smaller, more efficient machines capable of shutting off and turning on rather than larger machines which are more efficient either at full load, part load or both. Entirely too many jobs are evaluated only on peak and first shift – consequently, most compressors are oversized, inefficient (regardless of hypothetical efficiency) and prone to maintenance problems. Many people oversize the compressor based on projected demand in the future, feeling they will avoid the need to get another machine in a year or two. Despite these good intentions, the added cost for energy and maintenance for one year will outweigh the intended savings in capital and significantly reduce the useful life of the machine.

Demand Event: The volumetric size of the demand events that occur in the system should be examined carefully as a criteria for size and type selection. If you have a 2000 scfm peak, and the demand ramps up to that point with the largest single demand event being 200 scfm, two 1000 cfm compressors will be a problem. You will waste a great deal of energy and will probably have a difficult time controlling pressure swings in the system. With centrifugal compressors, you may have problems with surge because of the size of the initial response to the small size of the demand events – resulting in the need to run both compressors all the time, using either controls or overboarding to reduce problems caused by the dissimilar size of supply and event size.

Compatibility: Although virtually all air systems have two or more compressors, installation and operations manuals assume the unit will operate independently. Always consider what you have, how it will interface and what needs to be done to the new and old equipment to achieve the best systems performance for all conditions.

Base Load, Trim Load: All base load machines should be the same type. All trim

machines should be the same type. All base load machines should not necessarily be the same as all trim machines. In selecting base load, energy is the most important issue. In trim load flexibility, control speed, maintenance, sizing and the ability to start and stop automatically are more critical. Although it is not normally the case to mix types of compressors in larger systems, it is practical in order to get the best of all worlds in terms of energy and maintenance. Only where you have a relatively predictable load, such as a process application or where much planning has gone into "balancing" the system, is this not necessarily true.

Engineering: All or part of every perceived systems problem can be solved through an engineering effort and patience. The same problem can usually also be solved by compensating with additional compressors. Corrective action in the system always yields the best return on investment and it usually requires less or no additional compressor horsepower.

System Design: When the compressed air system is designed from the compressor out to the using devices, unless a significant factor is assumed for either volume or pressure, the results will be less than desired.

Application: In virtually every case where an individual or company has biased themselves against a type of compressor, the compressor or compressors have been inappropriately applied. The most common mistakes, in order of priority, are:

- Incorrect sizing – primarily too large and occasionally too small.
- A significant absence of "point of use" regulation or intermediate pressure control and the inability to maintain an adequate control differential between supply and demand. This should be a controlled delta, not one created by flow restriction pressure drop in the piping.
- Operating all compressors on their independent controls where all units are producing less than full capacity. Just because they are running does not mean they are fully loaded.
- Poor compressor room ventilation.

COMPRESSOR LIMITATIONS
In all of the above instances, numerous problems will show up six to 12 months after start-up. Despite good maintenance practices and periodic troubleshooting, problems will persist – and not always the same way. In addition, the compressor(s)

will be inefficient. Although not di related to the compressor(s), it shou noted that because of velocity and perature variations inherent with above conditions, it would be diffic provide clean, dry compressed air cc tently. When the above issues ar considered, frequently you will find self adding new compressor horsep in unreasonably short periods of Please note: this does not suggest th of "fudge factors." Proper design req understanding demand at the poi use, design losses, control energy co erations such as rate of decay, spe transmission and control speed from s to response. Also, everything shou examined in terms of pressure, vol storage and real time – not compr time. Once these issues have been n down and you have selected piping, trols and contaminant removal e ment, then you may select the ty types of compressor(s), size accordi the energy issues already mentione determine how you intend to use (either base load, trim or both).

Most salesmen don't want to talk a the downside of their equipment, how all compressors have limitations. S are extremely flexible and low in r tenance, but inefficient. Other type hypothetically very efficient but ar pensive in terms of maintenance run flat out. When oversized to unlo part load a reasonable part of the these very efficient compressors lose attractiveness with larger motor achieve the unloading. Some are exce in terms of a balance of efficiency an part load only in a limited portion c uppermost range of the machine. S types have such slow control speed do not fit well in many systems for service, regardless of other benefits.

Since limitations are not discusse most manufacturers, it is hard to ide what's what. In most cases, knowled these limitations will prove to be important than benefits.

PRODUCT/ SERVICE REVIEW

Guide to Air Compressors

A compact look at klustrial air compressors, their ratings and features.

Today's compressed air systems play a central role In facilities operations, accounting for up to *30* percent of total energy usage in American industry. Virtually every plant and facilities engineer is Involved in the purchase, design and/or maintenance of this critical equipment. Frequently, decisions about sizing and selecting air compressors can be difficult. For that reason, *AIPE FACILITIES* has compiled this guide.

As with past Product/Service Reviews, this "comparison study" is based on surveys completed by air compressor manufacturers and OEMs. In developing the initial survey, AIPE FACILITIES polled plant engineers as well as manufacturers and distributors about the basic criteria required to make a purchase decisioin for air compressors. In particular, plant engineers responded that they needed comparison data to help evaluate the factors affecting life cycle costs and the features and benefits of each product line.

COMPARING EQUIPMENT PARAMETERS

Both buyers and suppliers noted three distinct difficulties in comparing equipment:

l The air **compressor industry has not established universally-accepted standards to compare air compressors. This can create problems** for buyers in making valid comparisons between air compressors from a range of manufacturers. In our **survey, we attempted to avoid ambiguity in responses to some questions** by carefully defining the most important equipment parameters. However. many distributors and manufacturers **warned that extreme care is needed to ensure the buyer is "comparing apples to apples** when selecting a compressor.

Ž • The number of key parameters to be evaluated, in fact, is vast, so *AIPE FACILITIES* requested information based on limited scenarios, e.g. BHP/ 100 scfm under **full load conditions.** When evaluating compressors, **facilities engineers need** to compare equipment parameters within the range of full- and part-load operating conditions anticipated.

● Most product lines consist of a wide range of units varying in pressures, capacities and motor horsepower. To keep this review compact, *AIPE FA-*

CILITIES covers only broad product lines with numerical ranges of values across these lines.

Although many product features and equipment parameters were considered, the final list was narrowed to only a few key areas. The review itself is divided into four major compressor categories "Reciprocating" (Single and Double Acting). "Rotary Screw." "Centrifugal" and "Other." This last category includes Rotary Lobe and Rotary Scrol compressors. Also included is sub-category information, such as whether the air compressor is "oil free," the horsepower range and the number o stages. The range for maximum scfm at 100 psig i reported for the product line.

BEYOND THE RATINGS

To provide a rough estimate of several lifecycl factors, suppliers were asked to report parameter such as: the BHP/100 scfm range for the product line the expected overall longevity in operating hours the approximate cost of spare parts to be stocked and requirements for special lubricants. Particula care should be exercised in using these figures fo purposes of comparison. For example, the longevity of equipment can vary significantly, depending o assumptions made about parameters such as pressure speed and operating environment. Also, it should b noted the cost of maintenance to attain longevit was not requested.

Another important factor in determining lifecycl cost is the maintenance cost to keep the air compresso running at peak operating conditions. Because ther are so many aspects of maintenance, we chose not t report this data. When comparing compresso maintenance, remember to consider the expecte time required for regular maintenance and repairs the cost of major parts needing regular replacemen and the complexity of maintenance relative to you staff's capabilities.

Our first product review of air compress featuring 54 different product lines available fr 14 manufacturers and OEMs, begins on the ne page. For additional data on product lines, regiona offices and distributors, and the availability of fac tory engineering support, contact the suppliers liste in the "Company Index" on page 41.

RECIPROCATING

Company	Atlas Copco Industrial Compressors	Atlas Copco Industrial Compressors	Atlas Copco Industrial Compressors	Blackmer, A Dover Resources Co.
Product Line	D-Series	L-Series	LEH-Series	HD 162, HD 362, HD 602
Subtype	Double Acting	Single Acting	Single Acting	Single Acting, Oil-Free
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 6-125	E 3-20	E 5-10	E 2-15
Number of Stages	2	1 and 2	1	1
Max. SCFM at 100 psig* (Range)	312-635	8-61	26-13	10-28
BHP/100SCFM** (Range)	18.3-19.0	25.3-28.6	28.9-29.7	
Special Lubricants Needed	No	No	No	No
Approx. Cost of Spare Parts Owner Must Stock	0	0	0	
Expected Overall Longevity in Operating Hours	100,000+	30,000+	30,000+	
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Air- and Water-Cooled	Cool Running V-Belt or Direct Drive	Oil-Less Air Cooled V-Belt or Direct Drive	Oil-Free, Air-Cooled

RECIPROCATING

Company	Blackmer, A Dover Resources Co	Blackmer, A Dover Resources Co	Fluid Energy	Kaeser Compressors Inc
Product Line	HD 372, HD 612	HDL 372, HDL 612	OHT Series	Americomp
Subtype	Single Acting, Air-Cooled	Single Acting, Water-Cooled	Oil-Less	Single Acting
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 3-15	E 3-15	E 1-30	E 5
Number of Stages	2	2	1	1
Max. SCFM at 100 psig* (Range)	19-39	19-39	88.2	18
BHP/100SCFM** (Range)			28.3	Varies
Special Lubricants Needed	No	No	No	No
Approx. Cost of Spare Parts Owner Must Stock			$250	
Expected Overall Longevity in Operating Hours			Indefinite with scheduled maintenance	10,000
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	No, Hitachi	Yes
Special Features	Oil-Free, Air-Cooled	Oil-Free, Air-Cooled	Air-Cooled, Oil-Less	

*Standard conditions defined as 14.7 psia, 36% humidity, 68°F   **Complete Package Performance under full load at 100 psig at standard conditions.

RECIPROCATING

Company	Quincy Compressor	Quincy Compressor	Quincy Compressor	Saylor-Beall Mfg Co.
Product Line	QR-25	QRD Oil-Less	QT	700 Series
Subtype	Single Acting	Single Acting	Single Acting	
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 1/3-25	E 5-15	E 3-30	E 1-10
Number of Stages	1 and 2	1	2	2
Max. SCFM at 100 psig* (Range)	95	60	120	35
BHP/100SCFM** (Range)	Varies	Varies	Varies	24.4
Special Lubricants Needed	No	Oil-Less	No	No
Approx. Cost of Spare Parts Owner Must Stock	S20	S15	S10	S100
Expected Overall Longevity in Operating Hours	80,000	50,000	50,000	10,000
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Pressure Lubricated Spin-On Oil Filter, Cast Iron	Oil-Less, Single Stage, 2 and 3 Cylinder	Cast Iron, Splash Lubricated, Two-Stage	

RECIPROCATING

Company	Saylor-Beall Mfg Co	Saylor-Beall Mfg Co.	Scales Air Compressor	Scales Air Compressor
Product Line	9000 Series	CD Series	SQR	SQRR
Subtype			Single Acting	Double Acting Oil-Free
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 15-30	E 1-15	E 1/3-25	E 20-500
Number of Stages	2	2	1 and 2	1-5
Max. SCFM at 100 psig* (Range)	102	51	95	2700
BHP/100SCFM** (Range)	24.4	24.4	23.1	19.0
Special Lubricants Needed	No	No	No	No
Approx. Cost of Spare Parts Owner Must Stock	S250	S175	N/A	N/A
Expected Overall Longevity in Operating Hours	10,000	10,000	20,000	100,000+
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	No, Various Manufacturers	No, Various Manufacturers
Special Features		Complete Air System with Dryer, Filters, Compressors	Pressure Lubricated, Cast Iron, Slow Speed	Large Cylinders, Slow Speed, Oil-Free

*Standard conditions defined as 14.7 psia, 36% humidity, 68°F   **Complete Package Performance under full load at 100 psig at standard conditions

Company	Quincy Compressor	Quincy Compressor	Quincy Compressor	Saylor-Beall Mfg. Co.
Product Line	QR-25	QRD Oil-Less	QT	700 Series
Subtype	Single Acting	Single Acting	Single Acting	
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 1/3-25	E 5-15	E 3-30	E 1-10
Number of Stages	1 and 2	1	2	2
Max. SCFM at 100 psig* (Range)	95	60	120	35
BHP/100SCFM** (Range)	Varies	Varies	Varies	24.4
Special Lubricants Needed	No	Oil-Less	No	No
Approx. Cost of Spare Parts Owner Must Stock	S20	S15	S10	S100
Expected Overall Longevity in Operating Hours	80,000	50,000	50,000	10,000
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Pressure Lubricated Spin-On Oil Filter, Cast Iron	Oil-Less, Single Stage, 2 and 3 Cylinder	Cast Iron, Splash Lubricated, Two-Stage	

Company	Saylor-Beall Mfg. Co.	Saylor-Beall Mfg. Co.	Scales Air Compressor	Scales Air Compressor
Product Line	9000 Series	CD Series	SQR	SQRR
Subtype			Single Acting	Double Acting Oil-Free
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 15-30	E 1-15	E 1/3-25	E 20-500
Number of Stages	2	2	1 and 2	1-5
Max. SCFM at 100 psig* (Range)	102	51	95	2700
BHP/100SCFM** (Range)	24.4	24.4	23.1	19.0
Special Lubricants Needed	No	No	No	No
Approx. Cost of Spare Parts Owner Must Stock	S250	S175	N/A	N/A
Expected Overall Longevity in Operating Hours	10,000	10,000	20,000	100,000+
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	No, Various Manufacturers	No, Various Manufacturers
Special Features		Complete Air System with Dryer, Filters, Compressors	Pressure Lubricated, Cast Iron, Slow Speed	Large Cylinders, Slow Speed, Oil-Free

*Standard conditions defined as 14.7 psia, 36% humidity, 68°F **Complete Package Performance under full load at 100 psig at standard conditions

Company	Atlas Copco Industrial Compressors	Atlas Copco Industrial Compressors	Atlas Copco Industrial Compressors	Gardner-Denver IMD
Product Line	GA-Series	GR-Series	ZR-Series	Electro-Saver
Subtype	Flooded	Flooded	Oil-Free	
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 15-200	E 175-300	E 100-1000	E 100-500
Number of Stages	1	2	2	1
Max. SCFM at 100 psig* (Range)	46-1000	500-850 at 290 psig	400-4100	470-2,580
BHP/100SCFM** (Range)	21.4-23.6	36.8-37.6 at 290 psig	19.9-21.5	19.4-22.6
Special Lubricants Needed	No	No	No	N/A
Approx. Cost of Spare Parts Owner Must Stock	0	0	0	S50
Expected Overall Longevity in Operating Hours	60,000+	60,000+	100,000+	40,000+
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Water- and Air-Cooled, Low Sound Enclosure	Water- and Air-Cooled, High Pressure	Water- and Air-Cooled, Oil-Free, Low Sound Enclosure	Micro-Processor (100-150 hp) Constant Speed Control (200-500 hp), Turn Valve, Capacity Control

Company	Gardner-Denver IMD	Gardner-Denver IMD	Gardner-Denver IMD	Hitachi America Ltd
Product Line	Electro-Saver II	Electro-Screw	Twistair	Hitachi-DSP
Subtype			Oil-Free	Oil-Free
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 40-150	E 15-200	E 50-75	E 20-400
Number of Stages	1	1	1	1 and 2
Max. SCFM at 100 psig* (Range)	186-760	60-950	225-340	1700
BHP/100SCFM** (Range)	20.4-22.5	22.5-27.5	22-24.1	20-32
Special Lubricants Needed	N/A	N/A	N/A	No
Approx. Cost of Spare Parts Owner Must Stock	S50	S50	S50	S200
Expected Overall Longevity in Operating Hours	40,000+	40,000+	40,000+	50,000+
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Intensive Injection Lubrication System, Micro-Processor Touch Pad Control	Belt-Driven (15-50 hp) Direct-Drive (60-200 hp) Micro-Processor, Touch Pad Control	Oil-Free, Direct Drive, Micro-Processor, Touch Pad Control	Series Provides Oil-Free Air

*Standard conditions defined as 14.7 psia, 36% humidity, 68 F   **Complete Package Performance under full load at 100 psig at standard conditions

Company	Ingersoll-Rand	Ingersoll-Rand	Kaeser Compressors Inc.	LeROI International, Inc.
Product Line	SSR	SSR	Sigma Profile	WSS
Subtype				
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 10-450	N 400	E 3-600	E 20-500
Number of Stages	1	1	1	1 and 2
Max. SCFM at 100 psig* (Range)	34-2086	1600	3220	85-2600
BHP/100SCFM** (Range)	21.9-23.7	24.0		22
Special Lubricants Needed	SSR Ultracoolant	SSR Ultracoolant	No	No
Approx. Cost of Spare Parts Owner Must Stock	$100-1500	$1500		
Expected Overall Longevity in Operating Hours	40,000-50,000	40,000-50,000	45,000	30,000
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Water-and Air-Cooled. 460V ODP Motor, Intellisys Control, Star Delta Starter	Jack Shaft Drive, Variable Speed Control, Unloaded Start		Air-and Water-Cooled

Company	Quincy Compressor	Quincy Compressor	Quincy Compressor	Quincy Compressor
Product Line	QMA	QMB	QSI	QST
Subtype				
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 50-150	E 10-25	E 50-350	E 15-40
Number of Stages	1	1	1	1
Max. SCFM at 100 psig* (Range)	752	112	1515	182
BHP/100SCFM** (Range)	Varies	Varies	Varies	Varies
Special Lubricants Needed	Yes	Yes	Yes	Yes
Approx. Cost of Spare Parts Owner Must Stock	$75	$50	$100	$50
Expected Overall Longevity in Operating Hours	100,000	100,000	150,000	100,000
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Slow Speeds, Direct Drive, Modular Design	Modular Design, Base or Tank Mount	Large Rotors, Slow Speeds, Direct Drive	Belt Drive, Large Rotors, Base or Tank Mount

*Standard conditions defined as 14.7 psia, 36% humidity, 68°F.   **Complete Package Performance under full load at 100 psig at standard conditions.

Company	Sullair	Sullair	Sullair	Sullair
Product Line	High Pressure Two-Stage	Series 6E Encapsulated Single Stage	Series 10-32 Single Stage	Tandem Compressors Two-S
Subtype				
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 100-400	E 5-10	E 25-600	E 100-600
Number of Stages	2	1	1	2
Max. SCFM at 100 psig* (Range)	250-965	13-38	185-2000	515-3100
BHP/100SCFM** (Range)	N/A	26.0-27.6	21.5-25.0	19.0-20.0
Special Lubricants Needed	No	No	Required for extended warranty	No
Approx. Cost of Spare Parts Owner Must Stock	Varies	Varies	Varies	Varies
Expected Overall Longevity In Operating Hours	100,000+	100,000+	100,000+	100,000+
Do You Manufacture Basic Compressor/Airend?	Yes	Yes	Yes	Yes
Special Features	Pressures to 350 psig	Encapsulated Pressures to 175 psig	2-Year Standard Warranty, 10-Year Optional Extended Warranty	Two-Stage Efficiency Plus Valve Efficiency

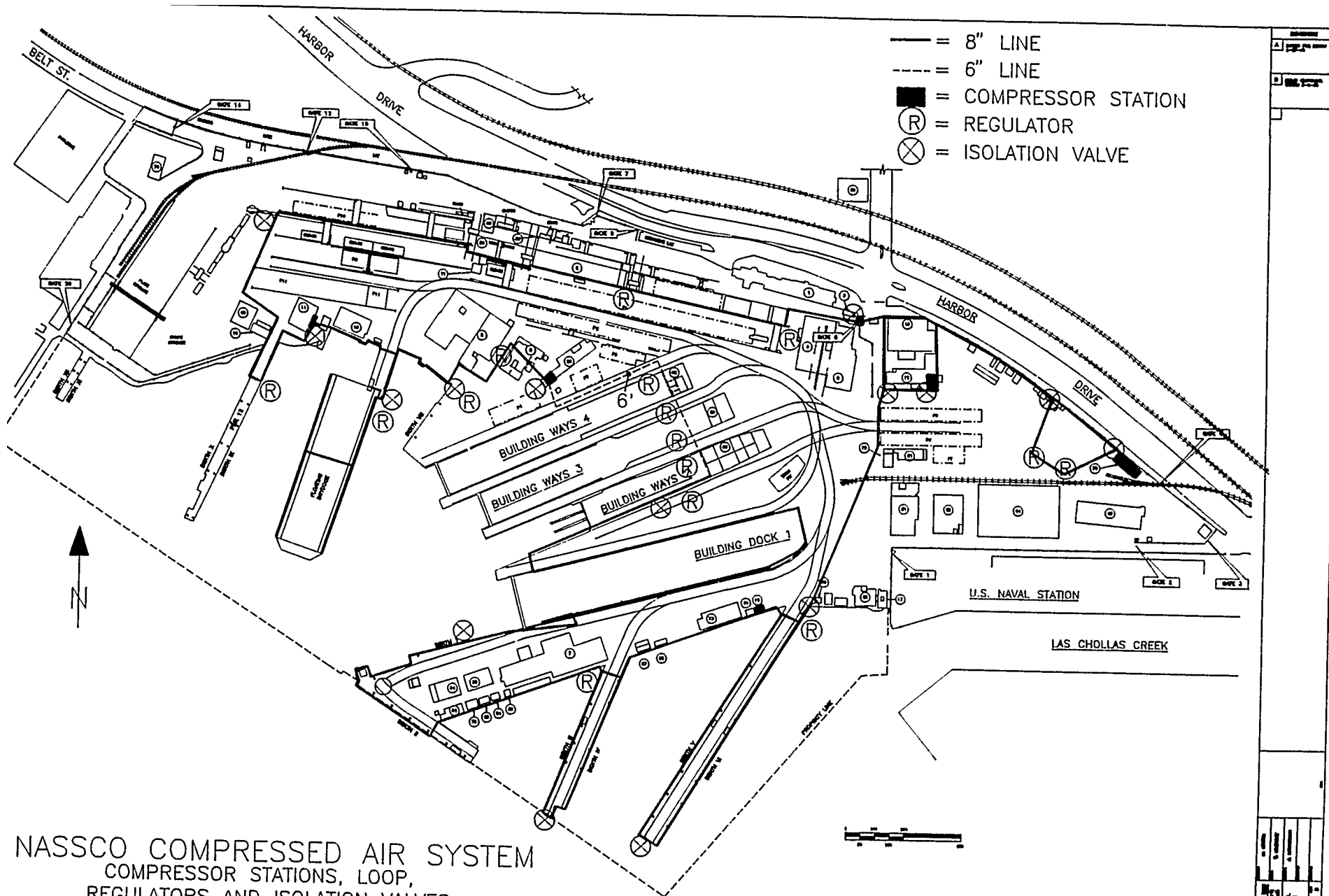*Standard conditions defined as 14.7 psia, 36% humidity, 68°F   **Complete Package Performance under full load at 100 psig at standard conditions.

Company	Atlas Copco Industrial Compressors	Powerex		
Product Line	ZT-Series	SL-Series		
Type	Oil-Free Rotary Lobe	Rotary Scroll		
Motor Horsepower Range E=Electric Motor Driven N=Natural Gas Driven T=Steam Turbine Driven	E 25-100	E 3-10		
Number of Stages	2	1		
Max. SCFM at 100 psig* (Range)	180-400	30		
BHP/100SCFM** (Range)	25-28	30-35		
Special Lubricants Needed	No	No		
Approx. Cost of Spare Parts Owner Must Stock	0	0		
Expected Overall Longevity In Operating Hours	80,000+	50,000		
Do You Manufacture Basic Compressor/Airend?	Yes	Yes		
Special Features	Cool Running Compact, Oil-Free Low Sound Enclosure	Oil-Less, Rotary, Low Noise		

*Standard conditions defined as 14.7 psia, 36% humidity, 68°F.   **Complete Package Performance under full load at 100 psig at standard conditions.

Legend:

- ——— = 8" LINE
- - - - - = 6" LINE
- ■ = COMPRESSOR STATION
- Ⓡ = REGULATOR
- ⊗ = ISOLATION VALVE

BELT ST.

HARBOR DRIVE

HARBOR DRIVE

BUILDING WAYS 4

BUILDING WAYS 3

BUILDING WAYS

BUILDING DOCK 1

U.S. NAVAL STATION

LAS CHOLLAS CREEK

N

NASSCO COMPRESSED AIR SYSTEM
COMPRESSOR STATIONS, LOOP,
REGULATORS AND ISOLATION VALVES

Legend:
- —— = 8" LINE
- ---- = 6" LINE
- ■ = COMPRESSOR STATION
- (DV) = DEMCO AUTOMATIC VALVES

CONTROL STATION

HARBOR DRIVE

BELT ST.

BUILDING WAYS 4
BUILDING WAYS 3
BUILDING WAYS 2
BUILDING DOCK 1

U.S. NAVAL STATION

LAS CHOLLAS CREEK

N

NASSCO COMPRESSED AIR SYSTEM

SP-1

NASSCO AIR COMPRESSORS

PORT.	B. 10	B. 11	BUILDING 12	BUILDING 70	BUILDING 26

PORT.

INGERSOLL RAND #194 1300 CFM

B. 10

SULLIVAN #644 2100 CFM

AIR DRYER #172

AIR RECEIVER

B. 11

GARDNER DENVER #186 1600 CFM

AIR DRYER #187

BUILDING 12

CLARK #183 4800 CFM

JOY #185 1200 CFM

JOY #184 1200 CFM

AIR DRYER #165

AIR DRYER #164

AIR RECEIVER

BUILDING 70

JOY #182 1200 CFM

JOY #181 1200 CFM

JOY #179 1200 CFM

JOY #178 1200 CFM

JOY #177 1200 CFM

AIR DRYER #176

AIR DRYER #175

AIR DRYER #173

AIR RECEIVER

BUILDING 26

LEROI #189 1700 CFM

LEROI #190 1700 CFM

AIR DRYER #196

AIR RECEIVER

COMPRESSED AIR SYSTEM
COST ANALYSIS

Chart with vertical axis labeled "$ / H r / 1 0 0 c f m" ranging from 0 to 6. Categories: Supply Syst, Bal'd Syst, W/O Leaks. Legend: Old Units, New Units.

Additional copies of this report can be obtained from the National Shipbuilding Research Program Coordinator of the Bibliography of Publications and Microfiche Index you can call or write to the address or phone number listed *below.*

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