White Paper

Pump Efficiency: A Single Strategy for Saving Energy, Boosting Reliability and Improving Process Control

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Executive Summary
Pumps consume more energy than any other industrial operations or equipment. What's more, according to a recent study by the FiveTwelve Group, the average money spent annually on pumps maintenance and operations is approximately 50 percent greater than for any other rotating machine. Companies that operate large numbers of pumps also need to worry about energy costs. But too many organizations focus on these costs separately, when in fact they are closely linked. Every watt of wasted energy converts to heat or energy that creates excess wear on a pump or the rotating machine. Focusing on pump efficiency can deliver three benefits at once, and a comprehensive program for managing pump operating costs, maintenance and optimization identifies and eliminates inefficiencies in pump reliability, energy and maintenance.

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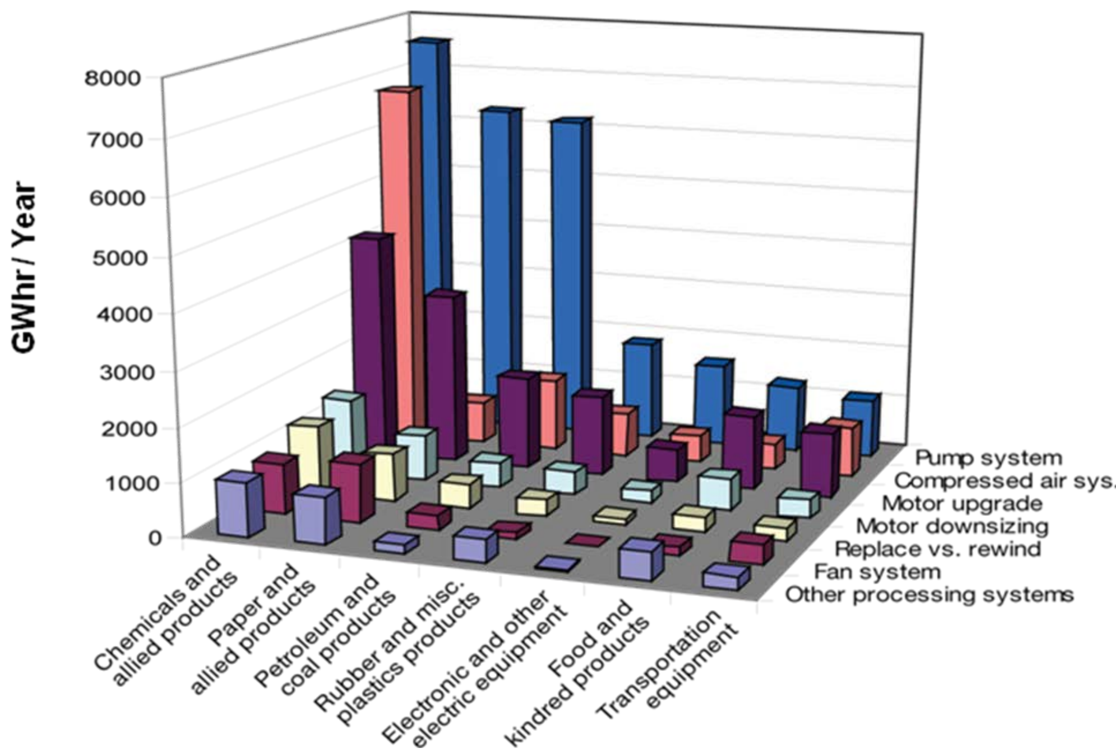
Size of the energy savings opportunity

A recent report by the U.S. Department of Energy's Office of Industrial Technology on the use of motor efficiency technologies entitled, *U.S. Industrial Motor Systems Market Opportunity Assessment* contained an in-depth analysis of energy use and savings potential by market segment and industry. In most industries, the report identified centrifugal pumps, collectively, as the largest consumers of motor energy. Also, among all rotating assets in the plant, process pumps had the highest overall potential for electrical energy savings.



Source: U.S. Industrial Motor Systems, Market Opportunities Assessment U.S. Department of Energy

A separate Finnish Research Center study of centrifugal pump performance found that the average pumping efficiency was less than 40 percent for the 1,690 pumps reviewed across 20 different plants, including all market segments.

Number of pumps evaluated	Number of process plants evaluated	Average pumping efficiency	Percent of pumps running at less than 10% efficiency	Factors affecting pump performance
1,690 pumps	20	> 40%	10%	Oversized pumps, throttled valves, seal leakage

Source: Expert Systems for Diagnosis & Performance of Centrifugal Pumps, 1996

The study also revealed that 10 percent of the pumps were less than 10 percent efficient. Considering this sizable efficiency loss, you can expect that 10 percent of the pumps in any continuous process plant are candidates for optimization. Quite likely, the real number is probably higher (possibly 20 to 25 percent of pump systems can be cost justified for some type of mechanical and control modification).

If pump optimization could become part of an ongoing improvement process, similar to Six Sigma, this would have an enormous impact on a facility's pump and process reliability over time. In the largest continuously operating process plants, these costs and savings opportunities—when all aspects of the system are taken into consideration—can easily represent millions of dollars. Obviously this varies by industry type and plant size, but the impact on profit margins can be large enough to make or break the bottom line.

Energy and reliability nexus

Due to rising costs and regulations, most plants are working to become more energy efficient. Companies are implementing energy management software and installing occupancy sensors throughout their plants to lower electricity bills and even changing times of operation to use less power at peak rate times. Improving the efficiency of the biggest energy users, however, will have the greatest impact on facilities lowering costs, plus it will improve equipment reliability and process performance.

The best way to save energy is to focus on equipment efficiency, which improves reliability. When trying to improve reliability and achieve optimization of pumping systems, one quickly discovers what is called the "energy and reliability nexus." In general, where there is excess mechanical energy not required for moving process fluid through the pipes, it manifests as vibration, heat and noise. This excess energy becomes a destructive force that contributes to pump and process unreliability.

As a result, pump systems routinely have the highest overall maintenance cost compared to other motor systems, including control valves, instrumentation and other types of process control equipment. In addition, pumps and valves are the primary process leak paths for fugitive emissions.

Proper sizing of pumps

Improperly sized pumps often are the major culprit when it comes to pump inefficiency. For a variety of reasons, process pumps frequently are oversized to meet process needs. One reason is that process parameters are often not fully defined as pumps are being specified—and because no one was ever fired for having too much horsepower, engineers tend to err on the side of overestimating pump

needs. It’s also possible for a pump that is perfectly suited to its first installation to become oversized (or undersized) as the demands of the process change.
It’s ideal to have every pump operating at its Best Efficiency Point (BEP) at all times. But that’s not a likely scenario—and to maximize the return on an efficiency program, it’s important to know which pumps are the most in need of attention and whether they are at a significantly faster or slower flow rate than optimum.

In the example below, the Brake Horsepower Formula (head x flow) equates the amount of wasted energy from an inefficient pump system that is over-sized and throttled.

BHP = Flow rate (gpm) • Head (ft) • specific gravity
3960 x Pump Efficiency (%)
A pump delivering 5000 gpm of water at 100 ft requires
(5000) (100) (1.0)/3960) (0.70) = 180 HP
(5000) (100) (1.0)/3960) (0.40) = 315 HP

The difference between a 70-percent and 40-percent efficient pump system is 135 horsepower (75 percent excess energy), which is, in effect, “beating up your pump system,” and contributing to unreliability and poor control performance that continuously degrades over time. In the underbelly of a process plant, tell-tale symptoms of excess energy moving through the system often can be seen—including a highly throttled control valve in combination with pronounced pipe movement, or even a vibrating cat-walk in connection with the infrastructure used to brace the throttled pump. Cavitation that is noted inside the pump, control valve or piping itself is a clear indication that hydraulic turbulence or instability exist.

If the system’s flow is too high coming out of the pump, some users choose to simply throttle the flow back using a valve on the discharge side. This arrangement is a very inefficient and costly way to configure a system, however. It increases energy costs for operating the pump, reducing the operating life of the equipment and increasing downtime.

Pumps are designed for specific flow ranges. When a pump is operating optimally at its BEP, liquid flow is constant and radial forces acting on the impeller are balanced. This allows the pump to experience its highest efficiencies and lowest vibration. But if the pump runs off-BEP it creates an imbalance of pressure inside the pump. Any of these problems can cause shaft deflection, which increases stress on the pump’s bearings and mechanical seals—and the likelihood of pump failures.

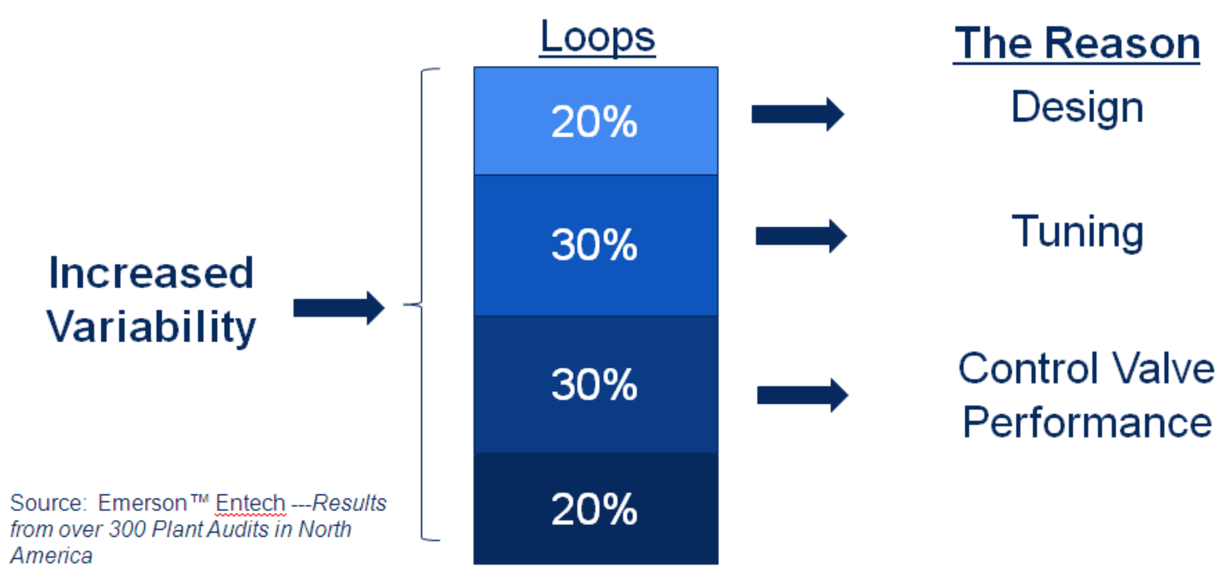
When evaluating proper sizing, it's important to look at the system holistically. You're not just buying a pump—you're designing a process control system and the pump is an integral component.

Process control

According to the results of a study from 300 plant energy audits by Emerson Entech, the majority of basic control loops involving pumps actually increase process variability. The primary reason is mis-sizing of the pump, valve and piping, which makes it difficult to "tune" the control loop.

A control loop system is a set of devices designed to manage, command, direct or regulate the behavior of other devices in a system. The system is designed to try to regulate a variable at a set point or reference value. Control loop systems include some sensing of the results they are trying to achieve by making use of feedback so they can, to some extent, adapt to varying circumstances. They are central to making sure the process is efficient and reliable.

Due to mis-dimensioning issues, including over- and under-sized pumps plus control valves and the associated piping, industrial process control performance is degraded over time. It is not uncommon for the majority of control loops to actually increase process variability when in automatic control mode, and as a result, these control loops are often switched into manual mode to stabilize the process.



As a result, other studies show a high percentage of control loops actually operate in manual mode. A benchmarking report by Honeywell LoopScout of 115 facilities throughout all market segments revealed that the worst performers experienced up to 60 percent of control loops categorized as "bad actors," with many of those systems operating in manual mode.

Fixed-speed pump systems are more subject to reliability incidents during "upset" issues than those operating under variable speed control. By varying the speed, the pump can adapt to process changes, including start-up/shutdown and upsets.

Mechanical options for optimization

Once you've picked a pump to optimize, there is a range of mechanical and digital options to consider.

According to the Department of Energy's Office of Industrial Technology, a number of optimization and efficiency methods can be used to achieve energy savings and help justify reliability projects.

Action	Energy Savings
Replace throttling valves with speed controls	**10-60%**
Reduce speed for fixed load	**5-40%**
Install parallel system for highly variable loads	**10-30%**
Equalize flow over product cycle using surge vessels	**10-20%**
Replace motor with more efficient model	**1-3%**
Replace pump with more efficient model	**1-2%**

Digital options

In addition to mechanical controls, there are digital technologies that vary the speed of the pump motor to improve efficiency. The simplest of these is the soft starter, a solid-state motor starter that is used to start or stop a motor by reducing the voltage to each phase of a motor and gradually increasing the voltage until the motor gets up to full voltage/speed, all at a fixed frequency. Many electronic devices will consume a large initial current when first turned on that can cause voltage fluctuations and affect the performance of other circuits. To counteract this issue, components can be added in series to throttle back the current initially as the device comes online. It's also crucial today to have a climate-controlled environment, which is becoming more common as plants integrate more digital systems.

More advanced digital controls vary the speed of the pump to match the need of the application. These are called variable frequency drives (VFDs) or variable speed drives (VSDs). VFDs offer tremendous benefits (smaller pumps, lower energy costs, efficiency). The U.S. Department of Energy estimates that up to 25 percent of equipment would benefit from VFD technology.

Despite the known benefits of VFD technology, adoption has been relatively slow, primarily due to perceived electrical and safety issues. Though these used to be significant issues, they have largely been eliminated with today's more mature VFD technology.

A VFD is an electrical system (i.e. inverter) used to control AC motor speed and torque. It provides a continuous range of process speeds compared to a discrete speed control device such as multiple-speed motors or gearboxes.

A VFD controls motor speed by varying the frequency supplied to the motor. The drive also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio of voltage to frequency (V/Hz), as required by the characteristics of the AC motor to produce torque. In closed-loop control, a change in process demand is compensated by a change in power and frequency supplied to the motor, and thus a change in motor speed.

Traditionally, a fixed-speed pump and control valve have been used to regulate process flow. Even though VFD technology has grown rapidly in acceptance, the technology and benefits are often poorly understood. As such, there is uncertainty surrounding its use for pump control.

There are a number of reasons for this confusion, including:

- Lack of knowledge about the hydraulic performance between fixed and variable speed pump control

- Lack of knowledge concerning control and failure modes, especially for mission critical applications
- Perception that a VFD is always more expensive than a control valve
- Concerns about the reliability of the electronics platform

Many of these concerns stem from bad experiences before VFD technology became fully mature. These legacy issues can be put into perspective by relating them to the evolution of PC technology. The cost of low voltage VFDs continues to drop while reliability and functionality increases. As a result, VFD technology has become a highly reliable, cost-effective alternative to using fixed-speed pumping systems.

There also are compound benefits through implementation. These include energy and maintenance savings, pump and process reliability improvements, better process control and less fugitive emissions. In addition, on new projects, the application of VFD technology can reduce overall capital cost by eliminating the need for valves and starters, plus the associated wiring and pneumatic lines. In many cases, smaller pumps with lower horsepower motors can be used. In terms of piping, smaller diameters often suffice and bypass lines can be eliminated.

In addition, pump optimization will increase the level of condition monitoring through the broader use of VFDs and wireless vibration monitoring, among other digital tools that offer real-time information on pump system performance.

Hysteresis and harmonics

New problems have arisen today that can have a dramatic impact on pump efficiency. Hysteresis refers to systems that may exhibit path dependence or "rate-independent memory." In a deterministic system with no dynamics or hysteresis, it is possible to predict the system's output at an instant in time given only its input at that instant in time.

This is not possible in a system with hysteresis. The output depends in part on the internal state of the system and not only on its input. There is no way to predict the system's output without looking at the history of the input (to determine the path that the input followed before it reached its current value) or inspecting the internal state of the system.

Another issue is harmonics, which is defined as voltages or currents at frequencies that are a multiple of the fundamental frequency. In most systems, the fundamental frequency is 60 Hz. Therefore, harmonic order is 120 Hz, 180 Hz, 240 Hz and so on. (For European countries with 50 Hz systems, the harmonic order is 100 Hz, 150 Hz, 200 Hz, etc.)

Most utilization equipment today creates harmonics. In all likelihood, if a device converts AC power to DC power (or vice versa) as part of its steady-state operation, it's considered a harmonic current-generating device. These include uninterruptible power supplies, copiers and computers.

Harmonics can cause overloading of conductors and transformers and overheating of utilization equipment, including pumps and motors. This additional loading creates more heat, which breaks down the insulation of the neutral conductor. In some cases, it can break down the insulation between windings of a transformer. In both cases, the result is a fire hazard. But, you can diminish this potential damage by using sound wiring practices.

Case study 1: Failed pump plagues pulp mill beach plant
A vat dilution pump in a pulp mill bleach plant had an 1180 rpm, 250 Hp medium voltage motor driving a double suction pump. The pump had a 14-inch discharge line that branched into three separate 10-inch lines feeding 200-degree Fahrenheit liquor to the end-user systems. Each of the three branches had its own eight-inch control valves that were usually operating in the range of 20 percent to 40 percent open. The gaskets between the pump discharge flange and pipe frequently failed.

Looking downstream and up to the top of the bleaching towers each branch line was “rocking and rolling” and, as a result, experienced an inordinate number of cracks. Pipe cracks lead to chemical losses in the sewers and unplanned downtime. Taken altogether, each layer of cost associated with the over-sized pump system had the cumulative effect of 36 hours of downtime each month to repair some component or multiple components of the system. In this scenario, the detrimental financial impact to the bottom line was substantial—in the range of high seven figures annually.

The primary solution for this application was the implementation of variable speed pressure control. The pump system normally consumed around 200 horsepower, with the end-user valves highly throttled (20 to 40 percent open). In addition, the vibration levels were about 0.6 inches per second. After VFD implementation, the pump normally consumes 75 horsepower. In effect, the excess 125 horsepower, above that required to move the fluid, was “beating up” the pump, contributing to unreliability.

Case study 2: Performance audit helps paper mill cut energy costs
Appleton Coated, a large paper manufacturer headquartered in Kimberly, Wis., offers high-quality products and services, including coated paper for both traditional and digital printing, specialty products, publishing paper, and different text and cover options.

At the company's large manufacturing facility in Combined Locks, Wis., over 1,000 centrifugal pumps aid in the production of more than 1,100 tons of paper each day. Ninety-five percent of these pumps are manufactured by ITT Goulds Pumps.

The mill operates 24 hours day, seven days a week, with brief shutdowns twice a year for major maintenance reviews. With a booming business and a talented engineering staff focused on maintaining production, the company has limited time to research potential energy saving projects.

All of the paper machines are new or have been upgraded within the past 15 years, but many of the pumps used in processing wood pulp into coated paper stock are older. As energy prices have risen rapidly in recent years, and utilities provide price incentives to reduce demand, improving the energy efficiency of pump systems has become a priority.

A pump assessment and efficiency study for Appleton Coated recommended potential efficiency improvement for 23 pumps. To date, the mill has implemented variable frequency drive on five applications that have a 2.5 year payback, amounting to $102,000 savings per year. Other pump optimization projects are scheduled for the future. The mill also was able to take advantage of utility incentive programs for additional savings.

Case study 3: Analysis enables Calif. refining company to trim repair costs 75 percent
Pasadena Refining Systems, Inc., refines up to 120,000 barrels of oil per day. After ITT Performance Services conducted a Cause, Cost and Correction analysis and assessment on 30 "bad-actor" pumps, repair costs have been reduced by 75 percent over two years, and emissions have been cut by 95 percent.

Getting your organization on board
Today, pumps are not considered by most organizations to be an integral component of the process automation architecture. As a result, plant information systems typically lack continuously monitored data for trends and diagnostics.

For all practical purposes, almost all of the work orders and asset information is manually entered. The underlying assets, including compressors, blowers, fans and control valves seldom or rarely are connected to the Computerized Maintenance Management System (CMMS); therefore, this situation becomes a "missing link" in an e-manufacturing strategy and large potential cost savings are unrealized. According to the ARC Advisory Group, nearly 40 percent of manufacturing revenues are devoted to maintenance and approximately 60 percent of scheduled maintenance checks and motor systems are unnecessary.

Companies need to understand that there's a strong link between operational process control data and equipment performance data. In an ideal world, organizations should have a comprehensive integrated system to operate the plant at maximum efficiency. Even before that, however, efficiency projects on high-priority pumps can deliver significant savings. Cross-functional teams need to recognize that energy conservation, equipment reliability and process control are closely linked, and improving pump efficiency is one of the best ways to achieve all three.

Conclusion

Process control can help solve many of the issues inhibiting the "plant of today," both in terms of reducing raw material variability and life-cycle cost savings, which can be estimated based on current costs versus optimized costs.

Making decisions that are based solely on long-term operating costs versus having a large "safety margin," to make sure operations can always produce more flow than will ever be needed, will open a window to the "plant of tomorrow"—one that is adaptable and sustainable. Presumably that is what is meant when someone says the future must be lean and green. It is no easy task to get there, but the benefits are too compelling not to shake off the inertia and move ahead.

About ITT

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