There is no one-size-fits-all control strategy in variable speed pumping

Sensored and sensorless control are among the options to satisfy ASHRAE 90.1

An increasing emphasis on variable speed pumping as a means to save energy in commercial buildings has provided engineers with many paths to efficient hydronic system design. However, a lack of understanding regarding proper control strategies is resulting in poor-performing systems that gobble up energy.

ASHRAE 90.1 addresses efficiency for chilled water pumping systems with guidelines for controls that result in pump motor demand of no more than 30% of design wattage at 50% of design flow. The concept of differential pressure control is an essential part of variable speed pump control to maximize efficiency, highlighted in ASHRAE 90.1.

Hydronic systems typically operate at various capacities based on the heating or cooling load in a building, which creates a fluctuation in demand. The pump adjusts to maintain the constant differential pressure. In periods of high demand, the pump will speed up; in periods of low demand it will slow down. Controlling a system based on differential pressure maximizes energy savings in diverse systems by reducing pump output at periods of low system demand. Measuring differential pressure to ensure the pump slows down at lower flow is the key to meeting the ASHRAE 90.1 standard.

This white paper outlines different system control strategies using differential pressure control, and details advantages, drawbacks and considerations for each in order to assist system designers in satisfying ASHRAE and achieving optimal space comfort for building occupants, while also maximizing system performance and energy savings for building owners.

Selecting a control strategy for a hydronic system depends on a number of factors, beginning with the design of the system itself. A balanced hydronic system is one in which each zone and each terminal unit in the zone has the proper flow to satisfy the heating and cooling loads of the building. Indoor and outdoor conditions – from building siting and solar gain to the activities that take place inside the building that vary heating and cooling loads – also must be considered in determining the control strategy, along with a weighting of following factors:

- **Simplicity** – What are the complexity of the control logic and the decision-making involved in determining the system parameters?
- **Flexibility** – Will the control strategy be adaptable to changes in hardware, motors, capacity requirements or retrofit scenarios?
- **First costs** – What is the required investment in the control hardware, including sensors?
- **Energy savings** – Will the control logic meet system comfort expectations with the minimum pressure/energy required?
- **Critical zone coverage** – Will the control logic ensure zones within a multizone system are not underserved as demand requirements shift from one zone to another?

Control Logic Options

It's important to keep in mind that the terms "variable speed" and "variable flow" are not interchangeable. Variable flow is changing demand; variable speed is the changing operation of the pump. Variable speed pumps with two-way valves achieve variable flow. The ASHRAE Handbook singles out two categories of variable speed pump control logic – control curve and control area.

Curve control is based on the calculated friction loss in a system and uses the control curve of the system and pump. This control strategy relies on pump-specific algorithms programmed into the variable speed drive to accurately predict the differential pressure across the pump and make adjustments to follow the control curve. The drive can slow the pump according to the data to use less energy while staying on the preprogrammed curve. Systems with low diversity operate successfully because they follow control curve closely.

Area control is a more flexible variable speed control strategy because it can adjust pump speed in real time based on actual system load. It isn't tied to a theoretical control curve, which means the pump can operate at a multitude of points above and below the control curve. In systems with diverse load conditions, area control is more energy efficient than curve control when curve control has been corrected for misses. (It's worth noting here that Bell & Gossett introduced the concept of control area in 2003.)

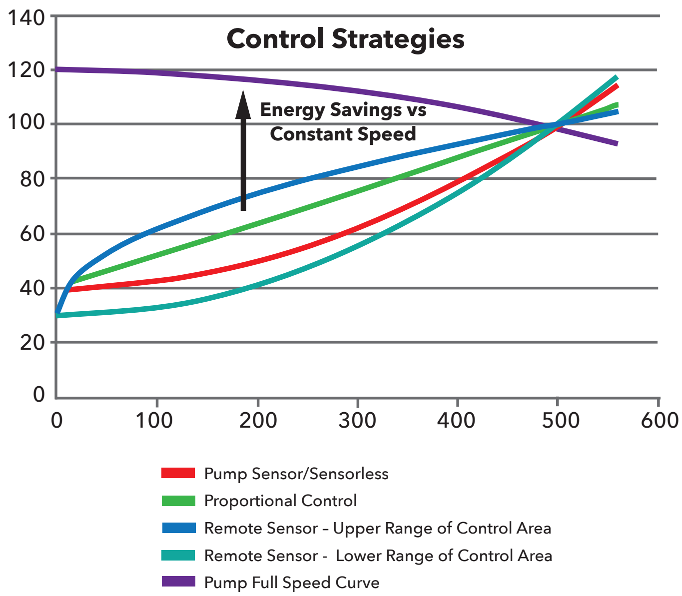

Figure 1
Control Strategy Options

Figure 1 shows an example of the curves that each of these different control strategies might utilize given the same maximum duty point.

Sensored and Sensorless

Curve control strategy can be done with sensored or sensorless pump control. Sensorless pump control uses data on speed, torque and power programmed into the drive to compute differential pressure across the pump and adjust speed to match the predetermined quadratic curve. Sensored curve control is achieved with locally installed (DP) transmitters wired directly into the drive, allowing the variable speed pump controller to adjust pump speed based on direct pressure measurement.

If the load in a hydronic system rises and drops uniformly in all zones, the required pump head is very close to the control curve, making sensorless control a good option. Additionally, with sensorless control, there's no need for external feedback signals or sensors, saving time in setup and commissioning.

Compared to a constant speed pumping system, sensorless curve control is a more efficient method, however, it isn't always the most efficient option in variable speed systems. Systems with a large amount of diversity and a large control area don't follow a single curve, so they generally are not good candidates for sensorless control.

When there is a fair amount of diversity, the required flow and head points will vary significantly from the control curve. Without sensors in the system, frequent and significant misses can occur resulting in over- or under-pumping. This ultimately results in a less-than-optimal comfort level for building occupants.

Furthermore, not every pump is suitable for sensorless curve control. There must be a unique power value for each flow and speed combination across the expected operating range that can then be programmed into the control logic. Some pumps will have curves that make it impossible to accurately estimate flow because the exact operational horsepower and pump curve lines do not intersect at a finely defined point. If the horsepower line follows the same slope as the pump curve, then the pump flow is indeterminable where the pump curve and horsepower lines overlap.

Remote DP Sensors

In systems with a lot of diversity, a remote DP sensor allows the pump and drive to operate within the control feedback to the pump controller to speed up or slow down the pump to maintain the control head, which is the minimum amount of head that must be present in the system at all times to establish full flow through the coils. Proper location of the DP sensor is critical to controlling operating costs and maximizing efficiency.

In direct return systems the DP sensor is typically located near the farthest zone. The DP sensor setpoint will be the required head to ensure sufficient flow through the coil, control valve and balancing valve. If differential pressure setpoint is maintained in the farthest zone throughout the pump's duty cycle, all the other coils will have sufficient pressure to ensure proper flow. As more valves open and there is more friction loss, the pump will speed up to maintain that pressure differential at the last circuit. By maintaining differential pressure across the farthest, or critical, zone, the system will ensure all zones are satisfied over varying demand if properly balanced.

Sensored area control greatly increases energy efficiency in diverse systems at part load conditions because the pump can slow down significantly and still keep occupants comfortable and equipment operating properly. The sensor ensures that the pump is running at the lowest speed possible while still satisfying demand in the system. The direct pressure measurement by the DP sensor eliminates a common problem with estimating this pressure using curve control. Curve control is often increased above the

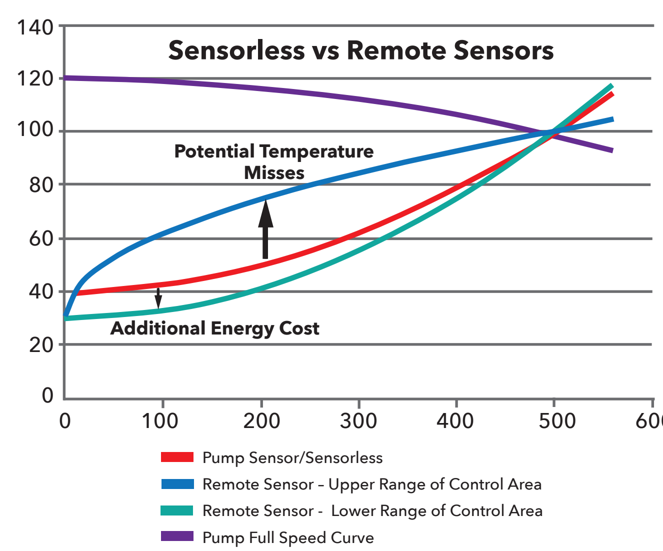

Figure 2
Curve Control vs Area Control

minimum threshold to account for diversity and ensure demand is satisfied. This higher curve robs energy efficiency from the system that could be achieved with accurate measurement and area control.

If, for example, the difference between the system losses for different zones is 15 feet at 500 gallons per minute, that results in an additional 2.3 horsepower any time that demand is in the lower loss area. However, the system has been adjusted to ensure that it meets the higher pressure — a typical scenario when curve control has been employed. Depending upon how frequently that situation occurs, the additional energy costs could be $300 per year. For systems with higher flows or even larger control areas, the annual operating penalties could be even higher. Understanding the loads and the potential demand patterns during the design phase can aid in the decision of selecting the proper control strategy. A hydronic heating/cooling expert can assist you with this analysis.

Placing remote sensors in critical zones has increased up-front costs, but provides the most consistent zone performance at the lowest operating cost. However, it is not a good option in retrofit situations if remote sensors cannot be installed.

Linear and Quadratic Considerations
When remote sensing is not an option, variable proportional pressure control and variable quadratic pressure control, subsets of curve control, are strategies to consider.

Per ASHRAE 90.1-2016, in the absence of remote sensors, variable proportional pressure control using local sensors at the pump is a good option to control performance, especially if pressure losses in the system are significant. Proportional pressure control compensates for pressure loss in the system with a linear approximation, with the result that differential pressure across the control valves is nearly constant, and good control performance is obtained at both full- and part-load operation.

Variable quadratic pressure control is also recommended if pressure losses in the distribution and or supply system are well known and it is ensured that the system is correctly balanced, as outlined in ASHRAE 90.1. Differential pressure across the pump increases exponentially as ow increases. Quadratic pressure control compensates for pressure loss with a quadratic approximation to the control curve, enabling increased energy savings over proportional pressure control at part loads.

In designing the system, different settings of constant and variable pressure control can be selected to fit the pump to the actual system resistance — as noted by ASHRAE — and control curves can be selected manually or by an external signal.

Proportional control, due to its linear flow/pressure curve, provides more pressure and fewer under-pumping situations than some other solutions. It is a simple and flexible solution that can be applied to any pump in a retrofit scenario. Even though there are increased energy savings over constant pressure control, proportional pressure control isn't always the most energy-efficient solution compared to other options.

Sensorless pressure control with quadratic flow loss compensation lowers cost by eliminating the need for sensors and wiring. The pump control point is based on minimum and maximum head, and second order emulation of flow loss compensation. The controller interpolates data stored in the drive to estimate flow and head based on speed and power.

However, quadratic control is not always possible to achieve with variable quadratic pressure control. If the initial calculation value is off, the drive will not adjust the pump speed to unanticipated changes in demand — it can only follow the quadratic curve programmed into the pump. This can be overcome if a DP sensor is installed at a critical zone within the system. If a critical location can be identified and remote control is an option, this strategy can yield significant pump energy savings. **Figure 2** compares a quadratic curve control vs. a remote sensor area control while **Figure 3** compares a linear proportional control vs. a remote sensor area control.

Systems with large control areas depending upon loading might require increases in the control head to raise the quadratic curve or proportional curve to ensure that there are not underflow situations that lead to unsatisfactory environmental control. However, increased control head will lead to reductions in overall energy efficiency. If, for example, with each complaint about temperature, the facility manager increases the control head until the problem goes away, energy savings will, too, because the system will be operating at close to full speed. The snowball effect of this cycle is that the system will exceed efficiency parameters set by ASHRAE. Larger control areas will tend to cause iterative system adjustments to eliminate potential misses, thereby increasing energy costs.

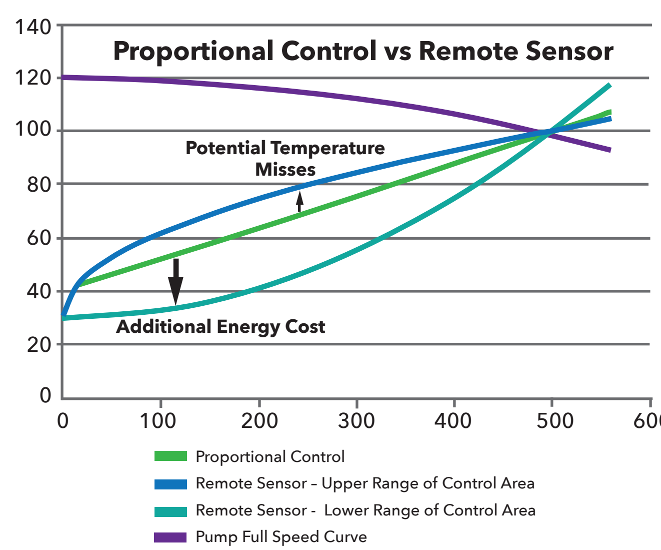

Figure 3
Linear Control Vs. Area Control

Figure 4 Summarizes the different controls that have been covered relative to the decision factors that were laid out at the beginning of this paper.

Options	Simplicity	Flexibility	Install Cost	Energy Savings	Critical Zone Coverage
Proportional Linear Control - Pump Sensors	Best	Best	Better	Good	Better
Quadratic Curve Control - Sensorless	Better	Better	Best	Better	Good
Quadratic Curve Control - Pump Sensors	Better	Best	Better	Better	Good
Area Control - Remote Sensors	Good	Good	Good	Best	Best

Figure 4
Decision Matrix for Control Strategy

To make a good strategy decision, you need to understand the complexity and requirements of the zones in your building along with your priorities for balancing near term cost, long term cost, performance, and system flexibility. No single solution is optimal for all conditions. By weighting the importance of the above factors against the rankings, you can determine which solution is best for you.

Meeting ASHRAE

In order to meet the ASHRAE guideline of design head of no more than 30% of design wattage at 50% of design flow, manufacturers generally default to a control head setpoint of 40%. Most systems won't satisfy ASHRAE with a control head setpoint greater than 40% of design head.

The control head setpoint with sensorless control is generally recommended to be at 40% of design head to protect against under pumping. In a sensored DP scenario, the control head setpoint is typically defaulted to 30% of design head and adjusted at commissioning and offering greater pump turndown. Commissioning will ensure the system meets the ASHRAE guidelines, operates efficiently and provides comfort to building inhabitants.

In systems that have a Building Management System (BMS), keep in mind that ASHRAE 90.1-2010/13 requires that the control head be continuously reset based on the valve position so that under the least loaded conditions, there is just enough head available to keep the most critical valve nearly wide open. In other words, ASHRAE requires monitoring the position of each valve in the system and reduce the speed of the pump until only one valve remains nearly wide open.

In determining the best control strategy for a system, the design engineer must understand the complexity and requirements of the zones in a building. No single solution is optimal for all conditions. Weighing costs, energy savings, flexibility and other factors will aid the design engineer in determining which solution is best.

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Jordan Ruff is product line manager, monitoring and controls, Xylem Applied Water Systems. He manages a line of HVAC and industrial pump controllers in the U.S. Ruff also launched a software tool to simplify closed loop system configuring to cover a wider range of HVAC applications an is running and Internet of Things (IoT) pilot program to link pump controllers to a platform.

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