The DeltaPValve® System – Instability First Order Losses – Fan Hunting

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ABSTRACT: *In "The DeltaPValve® System – Standard Control Gets Substandard Performance" the reader was introduced to the overall effects of standard control – wide coil LAT tolerance and instability - and how they can be mitigated using the precision control afforded by the use of the DeltaPValve ® System. In this paper, a portion of the topics raised in the previous paper will be explored in greater depth. Specifically, the first order ramifications of unstable coil LAT will be detailed.*

INTRODUCTION

Unstable coil leaving air temperature (LAT) is not simply an inconvenience to system operators and building occupants. It is *the* fundamental shortcoming of a typical hydronic system in terms of wasted energy, wasted time, and wasted effort. Unfortunately, the negative results of this operational instability are often misunderstood, ignored, or falsely attributed to other causes.

The full effects of LAT instability extend all the way back to plant operation and its subsequent efficiency. Instability is not only the first of many compounding deficiencies, it is the initial domino. The first order of these deficiencies occur at the air handler itself. Unstable LAT inhibits the transfer of thermal energy from the airstream into the water as well as increases electrical energy consumption through decreased fan efficiency.

FAN HUNTING

Often, when inspecting the supply fan variable frequency drive (VFD) on an air handler serving a variable air volume (VAV) system during operation, one of two things will be apparent. First is that, despite being capable of variable speed, the fan will be running full out at 60 Hz. This can have multiple causes from a fully loaded system (unlikely), improperly programmed controls, improper duct static pressure sensor placement or even the VFD being left in Hand mode to mitigate comfort complaints.

The second phenomenon, and the one that is of interest to this topic, is a fan that is found to be 'hunting'. This is defined as a cyclical behavior wherein the fan speed oscillates from high to low. A minor oscillation can be found by watching the display on the fan VFD over a period of a few minutes. A major oscillation is audible and the fan will be heard ramping up and down in speed. The most common cause is unstable LAT control but may also be caused by an improperly tuned PID loop, poor damper control in addition to other maladies.

With regards to unstable LAT and fan hunting, a slow oscillation that can typically only be seen displayed as VFD speed either directly or on the BAS controls is the typical manifestation. The cycle is initiated by either a drop or rise in LAT due to pressure fluctuations on the water side. Over the course of a few minutes, the temperature will reach an extreme and cycle back again. Within that time, the VAV boxes will respond to the new air temperature and modulate in order to maintain their setpoint. This in turn causes the static pressure in the supply duct to change and the fan responds by slowing down or speeding up. As the BAS attempts to correct, the cycle repeats. Ref Figure 1 below.

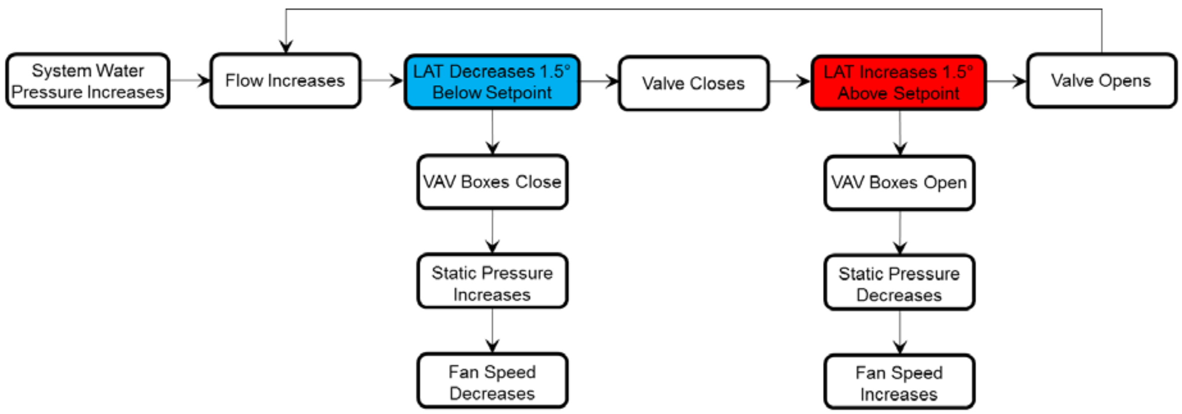

Figure 1 – Fan Hunting Cycle Due to LAT Instability

In the first paper of this series "*The DeltaPValve® System – Standard Control Gets Substandard Performance"*, the effect of this behavior on the water side was investigated. Here on the airside, the focus is on the fan energy lost due to the constant acceleration and deceleration incurred by the fluctuating temperature. If it is assumed that a fan acts as a flywheel then the kinetic energy at a given rpm is:

$$K = Kinetic\ Energy\ at\ RPM\ A$$

If the fan is accelerated from RPM A to 1.1A, then the difference is calculated as:

$$\frac{K \times 1.1A^2}{1A^2} = 1.21K$$

So, if the fan is at 100 RPM and it is accelerated to 110 RPM, the amount of energy that is required to reach the new speed is an additional 21% of the original energy. However, this calculation neglects the effect of the additional drag put onto the fan by the air. This can be calculated using the fan affinity laws that state:

$$P1 \;/\; P2 \;=\; (n1 \;/\; n2)^3$$

Where: P = Power

n = Speed

This means that in addition to the 21% of the original energy it took to accelerate the fan, it will take the cube of the speed difference in power to keep it running at the new speed. As an example, assume a fan running at 500 RPM using 15.6 kJ is accelerated to 550 RPM where it will use 18.9 kJ. The amount of energy to accelerate it would be:

$$18.8\ kJ - 15.6\ kJ = 3.289\ kJ$$

Assuming that this acceleration occurs every 5 minutes or 6 full cycles per hour, the total amount of energy used on acceleration would be:

$$3.289\ kJ\ \times 6 = 19.7\ kJ/hr = 48\ kW \cdot hr/yr$$

The amount of power to keep it running at 550 RPM is:

$$15.6\ /\ P2\ =\ (500\ /\ 550)^3$$

$$15.6\ /\ P2\ =\ 0.7513$$

$$P2\ =\ 15.6/\ 0.7513$$

$$P2\ =\ 20.76\ kJ$$

While the above numbers may not come as a surprise as it is understood that increasing fan speed requires additional energy, the full effect is only realized when it is understood what happens during deceleration. Conventional VFD's are not outfitted with regenerative power circuitry. Some are equipped with *braking resistors* to provide a method of quickly stopping the motor but most simply absorb the energy returned by the motor. Therefore, the energy required to accelerate the fan is not recaptured as electricity by the VFD. Rather, it is expelled as heat from the VFD. With this in mind, it becomes apparent that *any* unnecessary acceleration of the fan should be avoided as the cost will be energy that will only be expelled as useless waste heat.

Another factor to consider is the fan efficiency itself. As the fan speed and static pressure change, the point of operation on the fan curve is shifted. Good practice dictates that the fan chosen for a particular application should operate at or near peak efficiency at the typical operating point. However, like most components in a system, fans are selected for peak airflow and the efficiency at part load ignored. As a result, the increase in fan speed may theoretically equate to an increase in fan efficiency but the fact that the new point of operation is temporary means that the increased efficiency may not be realized.

Simply removing the temperature fluctuation will prevent the cycle from ever beginning. As discussed in *"The DeltaPValve® System – Standard Control Gets Substandard Performance",* system stability begins and ends at the control valve. Therefore, the installation and proper control of the DeltaPValve® will allow the system to stabilize and eliminate fan hunting.

SUBCOOLING

The topic of subcooling in relation to HVAC is usually limited to the discussion of direct expansion refrigerant systems. However, in this context subcooling relates only to the performance of chilled water coils and LAT's below the original coil design.

There are several criteria to keep in mind when sizing chilled water coils. Among them are entering and leaving water temperatures, airflow and velocity, and entering and leaving air temperatures and humidity. If any one of these criteria are changed, the performance of the coil will be effected.

Often, such changes are expected and part of the operating performance of the coil. For example, since the coil will not operate at full load most of the time and the entering air will be cooler than the selection point, the leaving water temperature can be expected to be increased, and the water flow rate to be reduced at part load.

There is however, a parameter that the operator must recognize in relation to coil performance - coil leaving air temperature. Depending on the moisture content of the entering air, there may be a stiff penalty to pay for pushing the LAT below design. Because air is a mixture of several different gasses including water vapor, it exhibits different behaviors as pressure and temperature change. As air is cooled, the partial pressures of the air and the water vapor change. When the partial pressure of the water vapor increases to the point that the saturation pressure of water at the temperature of the mixture, the water will condense out from gas to liquid.

The air cannot be cooled past the point of condensation until enough energy is removed from it to accomplish the phase change of the water from gas to liquid. This is due to the fact that the energy required for latent phase change is greater than that for a sensible temperature change. The further the air is cooled, the more energy is required to condense the moisture. This comes at a high cost in terms of water flow as the coils ability to cool the air beyond the design point decreases rapidly and therefore flow will increase dramatically. Whenever possible, cooling below the saturation curve should be avoided if not necessary.

LATENT COOLING DEGRADATION

While cooling below design is penalized by energy usage, allowing the LAT to drift too far above setpoint can have detrimental effects as well. As stated above, warmer LAT increases fan energy due to the VAV boxes opening to compensate. In addition to that, warmer air has the ability to carry more moisture and as a result, the desired relative humidity of the space may not be able to be met. This phenomenon is known as *latent cooling degradation* or, the inability of the system to maintain the desired relative humidity of the space due to insufficient cooling.

Depending on the ratio of outside air to return air and the conditions of each, latent cooling degradation will be more or less pronounced as the LAT fluctuates. If the fluctuations favor a lower LAT, humidity may not be an issue. If, however, higher LAT's are favored, space humidity can become an issue. These circumstances lead to the next issue to be discussed.

Comfort Complaints

If a system operator finds themselves in a situation where an air handler is experiencing fluctuating LAT accompanied by latent cooling degradation, they will undoubtedly be on the receiving end of occupant comfort complaints. Without a firm understanding of the underlying cause of the increased space humidity, the operator has really only one solution in their arsenal and that is to reduce the LAT.

While this will 'solve' the problem in that the humidity will be reduced, as explained earlier, a host of other problem will result. It is a safe assumption that the control valve will continue to cycle and since the setpoint has been reduced, the minimum LAT has been pushed lower. This, of course, results is higher water flow and reduced ΔT. Which, in turn, runs all the way back to the plant – higher flows, lower ΔT, more pumping, more chillers, etc. etc.

Reduced Setpoints

While dropping the LAT temporarily will rectify the humidity situation, and since cooling comfort complaints typically arise during high load days, any 'temporary' fix is liable to become permanent. VAV systems are perfectly capable of dealing with primary air that is too cold. It is simply re-heated at the VAV boxes to maintain the desired setpoint.

The fact that most 'temporary' setpoint reductions occur during high load situations means that the coil is most likely operating at capacity. The result is that, since the coil curve flattens out at the top end, reducing the LAT simply requires the control valve to go 100% open. Multiply this by several units in the system (not uncommon) and the pumping requirements exceed the capabilities of the plant. This is the leading cause of a system 'going flat'.

While the cold calls will cease, again, the problem has been simply pushed further down the line. Now, the system is called upon to produce colder air and subsequently reduced the system ΔT and thereby the efficiency of the plant as additional flow requires additional chillers leading to condenser water pumps and tower fans. Back at the air handler, fan energy is wasted trying to satisfy VAV boxes that are receiving air that is warmer than what is required to make the reduced setpoint. Further, more energy will now be consumed via re-heat to satisfy the occupant comfort requirements. The energy expenditure has, at best, been doubled.

Conclusion

While LAT instability may not always be the first thought when comfort complaints are logged, if the answer is to reduce the setpoint, the possibility should be considered. Often, the design parameters of the coil are neglected when considering operational issues. But maintaining efficient chilled water system performance requires a thorough understanding of the operation expectations and limitations of the primary energy transfer component of the system; the chilled water coil. Optimizing the energy transfer at the coil can only be accomplished by installing and commissioning the DeltaPValve®.