STEAM VALVES:

Commissioning Tips

Overcoming common field problems related to steam-piping systems

By **DAVID A. SELLERS, PE**
Portland Energy Conservation Inc.
Portland, Ore.

Over the past 20 to 30 years, as improved building envelopes and other technological advances have eliminated the need for steam radiators as a method of handling perimeter heating loads, steam-piping systems have become less and less common in buildings, replaced with forced hot water and other approaches.

With the decline in steam heating has come a decline in the number of practitioners familiar with the science behind it, especially ones with hands-on experience in the design and application of this type of system. This can become a serious issue when an existing steam-piping network must be modified or extended to serve new loads. Even though many of the materials and methods associated with steam systems are similar to those associated with hot-water systems, there are fundamental differences between the two that make some techniques and approaches used for one totally inappropriate for use with the other. If these differences are not addressed by the designer or installer, they will become commissioning and operational problems that can plague a system throughout its life.

A steam-control valve with reducers.

This article discusses some of the more common commissioning and operational problems encountered with steam-piping systems, including the theories behind them and techniques that can be used to overcome them.

VALVE-SIZING PROBLEMS

From an operational standpoint, few things are more frustrating than an oversized steam valve and the pressure and temperature swings it can cause. Often, this instability cascades into other portions of the system, compounding the headaches and energy waste (Figure 1).

Sizing a steam valve involves determining the proper flow coefficient (C_v) for the application. This involves selecting a valve so that at design flow, it has a pressure drop that is significant relative to the system it is serving.[1]

The flow through a steam valve can become supersonic under some conditions. When this happens, the downstream pressure no longer has any impact on the flow through the valve, and the valve's capacity becomes a function of the entering pressure. One can determine the potential for critical or non-critical flow based on the difference between the absolute[2]

David A. Sellers, PE, is a senior engineer specializing in commissioning and energy efficiency. Over the course of his career, he has worked in the design, mechanical- and controls-contracting, and facilities-engineering fields in the commercial-, institutional-, and industrial-buildings industries.

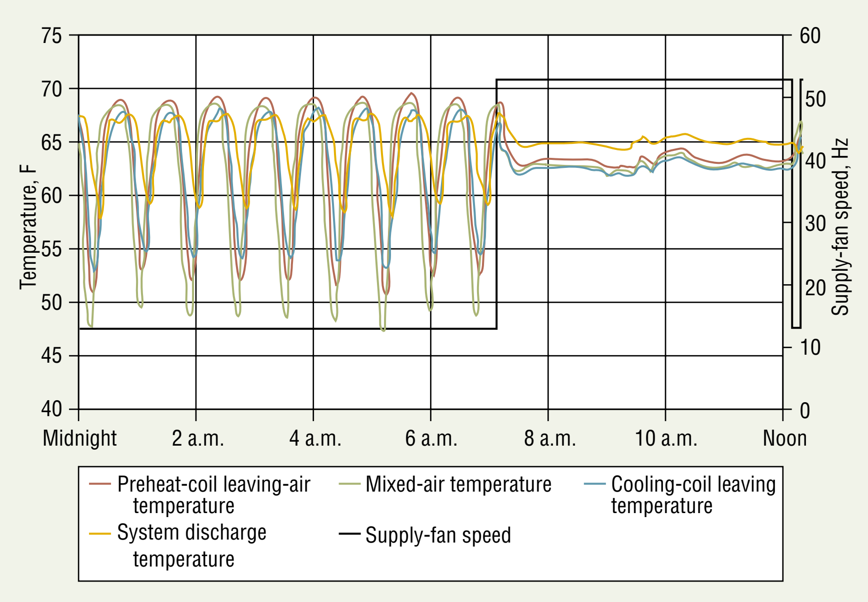

FIGURE 1. A low-flow condition associated with a new unoccupied mode creates a pseudo-oversized condition with the preheat-coil control valve and mixed-air dampers, resulting in instability that "disappears" when the occupied cycle resumes.

entering and leaving pressures anticipated at the valve. If the absolute leaving pressure is greater than 58 percent of the absolute entering pressure, the flow through the valve is deemed non-critical, and the valve's flow capacity becomes a function of both the entering and leaving pressures. Under these conditions, the following equation would be used to size the valve:[3]

$$C_v = \frac{w_s \times K}{2.1 \times \sqrt{\Delta P(P_1 + P_2)}} \qquad (1)$$

where:
C_v = Flow coefficient
w_s = Steam flow in pounds per hour
K = 1 + (0.0007 × superheat in F)
P_1 = Absolute entering steam pressure in psia
P_2 = Absolute leaving steam pressure in psia

For critical flow (the absolute leaving pressure is less than 58 percent of the absolute entering pressure), the sizing equation is much simpler:

$$C_V = \frac{W_S}{1.61 \times P_1} \qquad (2)$$

Another important consideration in selecting steam valves is flow characteristic. Ideally, a valve's flow characteristic complements the flow-related performance curves of the load served and provides a linear relationship between valve stroke and load performance.[4]

Even when a steam valve is properly sized for the design load, the large system turndown ratios associated with some steam loads can cause oversizing-like problems under low-load conditions. Approaches that employ two control valves piped in parallel often are used to address this problem (Figure 2). The load split between the two valves usually is between 50/50 and 30/70. A variety of control strategies are used with this configuration, including:

• *Modulating both valves with the same signal.* Although this approach is simple and usually an improvement over having one large valve, it does not take full advantage of the potential for improved control.

• *Sequencing the valves so that one must be fully open before the other starts to open.* This usually is an improvement over the first approach, but still can show some instability as the load transitions between valves, especially if the second valve is large relative to the first valve.

• *Using the smaller valve at low-load conditions, then switching valves.* This approach uses the smaller valve until it no longer can meet the load, then switches to the larger valve, which is used until it is

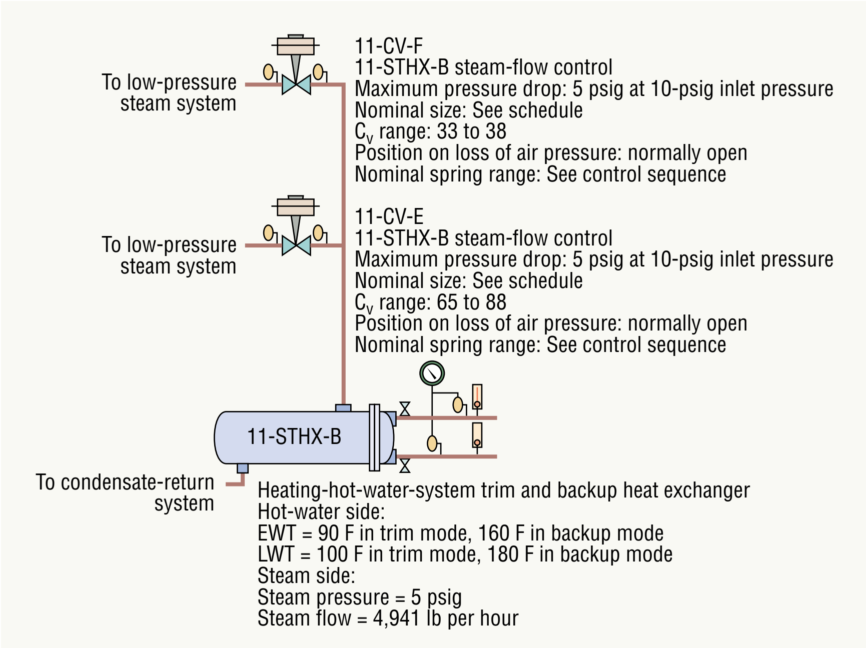

FIGURE 2. A typical multiple-steam-valve arrangement serving a steam heat exchanger (STHX). Note the different valve sizes, as can be seen from the different flow-coefficient and flow ratings.

at maximum capacity. The smaller valve then is used in sequence with the larger valve to handle peak-load conditions. This approach works well and is easier to implement with direct-digital-control (DDC) systems than it is with discrete control components.

• *Adjusting the larger valve as required to keep the smaller valve at mid-stroke*. This is an unusual but innovative approach that has its roots in the process-control industry. It commonly is called "course/fine control." It uses the smaller valve to maintain the set point and the larger valve to take up the offset that occurs when the smaller valve no longer can maintain the set point. One way to achieve this involves the use of a proportional-integral-derivative (PID) loop for the smaller valve and an integral-only loop for the larger valve.[5] This approach also lends itself to DDC systems.

For smaller loads, self-contained valves provide individualized control of steam radiators and convectors at less cost than electrically or pneumatically actuated valves. And because the valves are intended to serve small heat exchangers, the C_v selection often is better.

HEAT PROBLEMS

A steam system operates at high temperatures. This, in turn, elevates the temperatures of:

• Metals in direct contact with the piping (conductive heat transfer).

• Objects in a line-of-sight path with the uninsulated portion of the system (radiant heat transfer).

• Objects located above the pipe (convective heat transfer).

These elevated temperatures can have an adverse effect on some of the flexible materials used in pneumatic valves and the electronics and electrical equipment used in electrically actuated valves. To minimize the potential for damage and/or premature failure, consider:

• *Providing radiation shields between the valve actuator and valve body*. Usually, this simply is a piece of reflective metal installed between the actuator and valve.

• *Installing the valve so that the actuator is at an angle to the pipe instead of directly above it*. This removes the valve from the primary convective path.[6]

• *Making an effort to have the control-valve bodies and the piping in the immediate vicinity of the actuators insulated prior to start-up, if the system is going to be placed on line prior to completion of the insulation process*.

• *Insulating control valves with removable insulation jackets* (Photo A). This will allow mechanics to open and service the valves without damaging the insulation.

START-UP PROBLEMS

Closing the service valves to portions

of a large steam-distribution system during periods of inactivity eliminates parasitic energy losses that can rival the thermal requirements of the loads actually being served. Reopening these valves, however, is no casual undertaking. The reasons are varied:

• Thermal expansion places significant loads on the anchor and guide systems and their associated expansion-control systems.

• Warm-up requirements can place significant loads on drip traps. These loads can be far greater than those seen in normal service.[7]

• Condensate trapped in a cold piping system by failed traps or improperly pitched and drained piping and/or a large warm-up condensate burden can cause flow- and condensation-induced waterhammer.[8]


Photo courtesy of Insultech

PHOTO A. A removable valve-insulation jacket.

For these reasons, the start-up of a steam-piping system should be a carefully planned event, one coordinated and performed by experienced engineers and operators. Automating the start-up of anything but a relatively small, low-pressure network is a task probably best not undertaken. If you find yourself commissioning a project involving an automated start-up of portions of a steam-distribution system, consider:

• Performing an automated start-up only on a low-pressure steam header and only if the facility has a good maintenance program, one that will ensure that all drip traps are fully functional.

• Making sure that the piping system is well-designed and arranged to ensure good drainage and to handle the condensate loads associated with warming it.

• Providing equipment and programming that will allow the automation system to perform the same procedure that would be used by operators to bring the piping system on line. Typical considerations include:

a) Providing a modulating signal to the control valve, even though the valve is line size and providing an on/off control function. This allows the system to crack open the valve and hold it at that position to warm the main and then gradually

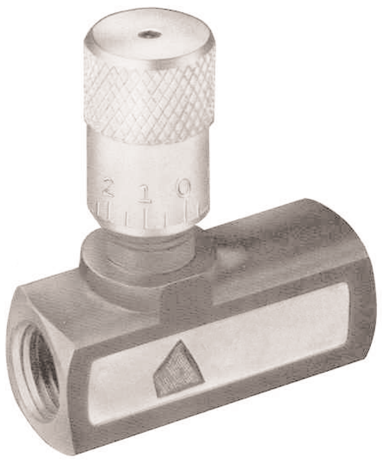

Photo courtesy of Alkon Corp.

PHOTO B. A micrometer-style needle valve that can be used to control the rate of movement of a pneumatic valve.

ramp open the valve.

b) Ensuring that there are no software problems or operating triggers that will rapidly cycle the valve.

c) Taking steps to physically limit the speed at which the valve can open. With electrically driven valves, this can be done by using a slow actuator. With pneumatically actuated valves, it can be done by restricting the pneumatic air supply. Photo B shows a typical micrometer-style needle valve that can be employed for this purpose.

d) Installing interlocks to prevent the modulating valve from moving beyond the cracked position until the downstream main is proven to be free of condensate and starting to warm up.

CONDENSATE-RETURN PROBLEMS

Condensate-return problems often are the result of problems concerning the application of modulating control valves to steam loads. Most steam loads are equipped with a control valve because their capacity requirements vary. When a steam-control valve throttles, it reduces the pressure at which steam condenses. In a saturated system, reducing pressure reduces temperature and, thus, heat transfer. In steam systems, some of the temperatures required to serve HVAC loads result in subatmospheric pressures in the heat-transfer elements, especially at part-load conditions. If a heat-transfer element is connected to a vented return system,[9] no pressure difference is available to force condensed steam out of the heat-transfer element until enough condensate accumulates to create the necessary gravity head.[10] As a result, numerous problems can occur, including:

• The loss of heat-transfer capacity because the backed-up condensate required to produce the necessary gravity head reduces the heat-transfer surface available to the steam. This can lead to extreme temperature oscillation leaving the load, as the flooding of the heat exchanger fights with the heat-transfer-surface area and temperature-difference requirement necessary to serve the load.

• Waterhammer, difficulty predicting

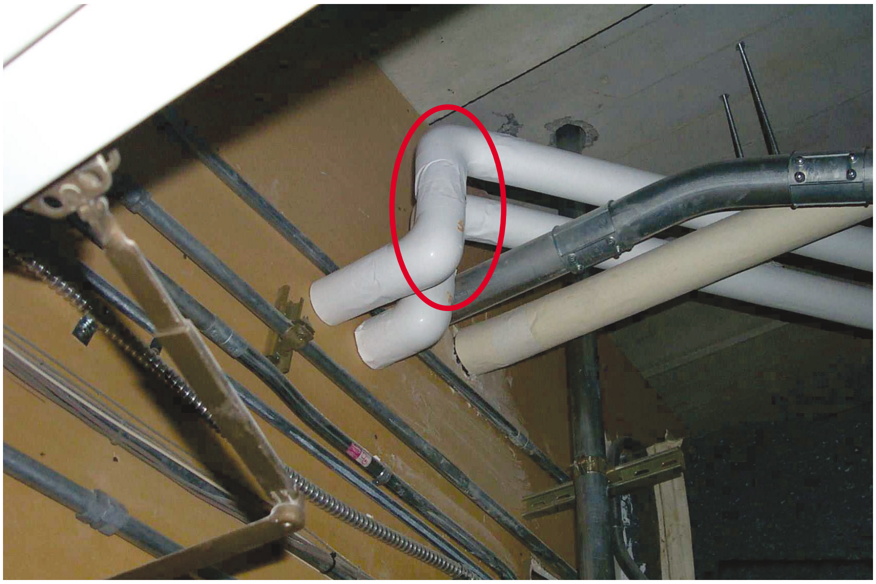

PHOTO C. This 10-in. change in the elevation of return piping trapped a large slug of water upstream, flooding the load. The untrapped elevation change in the parallel steam line (behind the return line) caused condensation associated with achieving and maintaining the supply-main temperature, creating waterhammer in the system.

system performance, and difficulty sizing valves—all because of the cyclical nature of the process described above.

• The condensate backed up into the tubes freezing quickly when subjected to air at subfreezing conditions—if the heat exchanger is a steam coil in a preheat position.[11]

Condensate-return problems also can be associated with improper pitching and trapping of steam-supply piping. Even when insulated, steam-supply piping will lose heat to its surroundings. This loss causes minor condensation whenever the piping system is active. The condensation that occurs when the piping is started can be several orders of magnitude greater than the condensation associated with parasitic losses during operation. If this condensation is not removed, it will impede the flow of steam through the system and eventually cause waterhammer. This can be avoided by pitching the piping (ideally, in the direction of flow) so that the condensate can drain toward a load or to a trap installed on a drip leg at a low point in the system.[12]

If these issues are not addressed during the design and fabrication of the piping system, they will show up as commissioning and operational problems. In some cases, they can lead to costly—and even catastrophic—equipment failures. By reviewing the design and installation of the steam- and condensate-system piping and the associated load connections during the design phase of a project, a commissioning agent can mitigate and avoid condensate-return problems. It is important to keep in mind that:

• Unless a vacuum condensate-return system is scrupulously installed and maintained, it is best to assume that it will operate as a vented gravity return system because of leaks in the piping circuit and/or trap failures.

• All vented gravity return piping should depend solely on gravity to move condensate from the load to the condensate receiver and pump. Even a relatively modest elevation change cannot be tolerated because the vented return system provides no motivation for the condensate to flow uphill against the force of gravity (Photo C).

• Applying vacuum breakers to all loads served by modulating valves can help ensure good gravity drainage. Basically, these devices are check valves that allow air to enter a heat exchanger when the pressure inside becomes subatmospheric. It is important to understand, however, that the return system still has to be designed to drain condensate away from the steam reheat coil (Photo D). Also, vacuum breakers are not without faults. Allowing air to enter a steam system can create heat-transfer problems of its own, as the heat exchanger is filled with a mix of air and steam.[6] This air can cause corrosion in the return system. These issues, however, usually can be dealt with via the proper location and piping of the vacuum breaker[6] and a good water-treatment program. In short, the vacuum breaker generally solves more problems than it creates.

Some additional advice:

• On the outlet of the load, include a piping drop that is long enough to ensure that gravity drainage from the load will create a fluid head above the steam trap under all load conditions. Size the trap conservatively based on that head.

• Always pitch heat-transfer elements toward the drain connection to ensure gravity drainage.

• Do not modulate a control valve for a preheat coil when the entering temperature is below freezing. Instead, keep the valve wide open, and use some other means, such as face and bypass dampers, to achieve temperature control.[13]

• Make sure the supply system is properly pitched and provided with drip legs and traps wherever there is a rise in the piping.

Various trap designs are available, with some better than others for a given application. Generally, a trap that continuously drains condensate, such as a float-and-thermostatic trap, best serves modulating loads. Applications that must lift condensate with the available inlet pressure often are best served with two position traps, such as bucket traps. Traps used on vacuum return systems must be designed specifically for that service.

CONCLUSION

Considering the integrated operating requirements of systems in which steam valves are installed is essential if full functionality is to be realized. A steam valve will fail to perform as intended if sizing and installation issues are not fully considered, even if the material and application specifications are correct. By paying attention to the details of valve installation and taking time to understand the physical principles behind steam-system design, commissioning and operating personnel can mitigate and readily correct a host of problems.

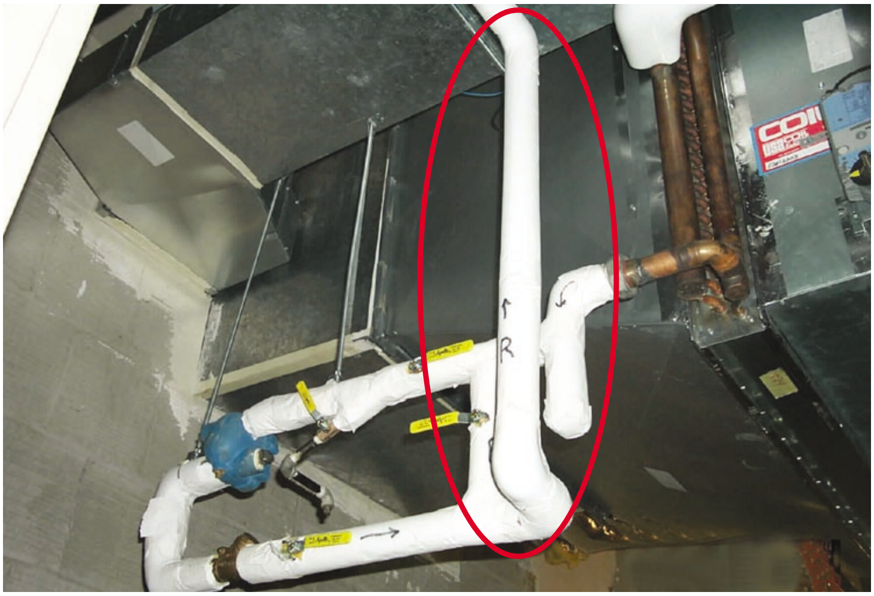

PHOTO D. This modest (less than 2 ft) change in the elevation of return piping from a steam reheat coil creates a condition that sees the coil flood until the reduced heat-transfer surface causes the steam valve to open and introduce steam at a pressure high enough to blow the condensate up into the elevated return main. This sudden change in available heat-transfer surface causes an excessive supply temperature, which results in cycling and instability. This coil was equipped with a vacuum breaker. However, that only guarantees that the coil always will be at or above atmospheric pressure and that it will drain somewhat predictably to a gravity return system. It cannot cause the condensate to flow uphill.

FOOTNOTES

1) This pressure drop often can be based on the difference between the steam entering pressure and the condensing pressure in the load served. Typically, the entering pressure will be set based on the pressure settings of the boiler-firing controller minus any losses caused by flow between the boiler location and the valve location.

2) It is important to use absolute pressure, not gauge pressure, when sizing steam valves. This can be accomplished by adding 14.7 psi (atmospheric pressure) to the gauge pressures.

3) The valve-sizing equations presented in this article can be found in Chapter 42 of the ASHRAE 2000 Systems and Equipment Handbook. They also may be found in other sources, including control-system textbooks and literature from manufacturers. In reviewing these other sources, you may discover slight differences in the constants and the point defined as the transition from critical to non-critical flow.

4) For example, an equal-percentage valve often is a good choice for application with a heat exchanger because the non-linearity of one will cancel out the non-linearity of the other, resulting in a linear or near-linear relationship between valve position and energy transfer. See Page 42.8 of the ASHRAE 2000 Systems and Equipment Handbook for a graphical depiction of this. Additional information can be found in the article "Control Valve Selections for Hydronic Systems" by Mark C. Hegberg in the November 2000 issue of *ASHRAE Journal*.

5) To learn more about this approach, see Moore Products Co. Application Data Sheet AD352-106, which can be downloaded at *www.sea.siemens.com/instrbu/docs/pdf/Ad352-106.PDF*.

6) This approach needs to be used with caution with electrically driven actuators because the lubrication of the gear train can be sensitive to position.

7) The loads can be in excess of the drip-trap capacity if the line is warmed up too rapidly, insulation is missing from a portion of the circuit, or traps serving the circuit failed during shutdown.

8) This can damage the piping circuit and lead to injury or loss of life. To learn more, read "Condensation-Induced Waterhammer" and "What Caused the Steam System Accident That Killed Jack Smith?", both by Wayne Kirsner, PE, in the January 1999 and July 1995 issues of *Heating/Piping/Air Conditioning*, respectively.

9) Although this is not the only possible arrangement, it, by far, is the most common—either by design or because of the failure of a component in a vacuum return system.

10) For more on this phenomenon, see "Fundamentals of Steam Heating Systems" by William J. Coad, PE, in the November 1995 issue of *Heating/Piping/Air Conditioning*.

11) Not all heating coils can function as preheat coils. Even a steam coil will freeze if it is not selected, piped, and controlled in a manner that allows it to safely handle subfreezing air.

12) For a discussion of drip legs and other piping issues, see "Troubleshooting Steam-System Problems" by Walter T. Deacon in the November 2001 issue of *HPAC Engineering*.

13) When conditions are above freezing, valve modulation can be sequenced with face and bypass dampers to achieve energy savings. Do not forget to fully close the valve when preheat no longer is needed because the active elements in the preheat coil represent a parasitic load on the steam and air-handling system, even with no airflow.

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