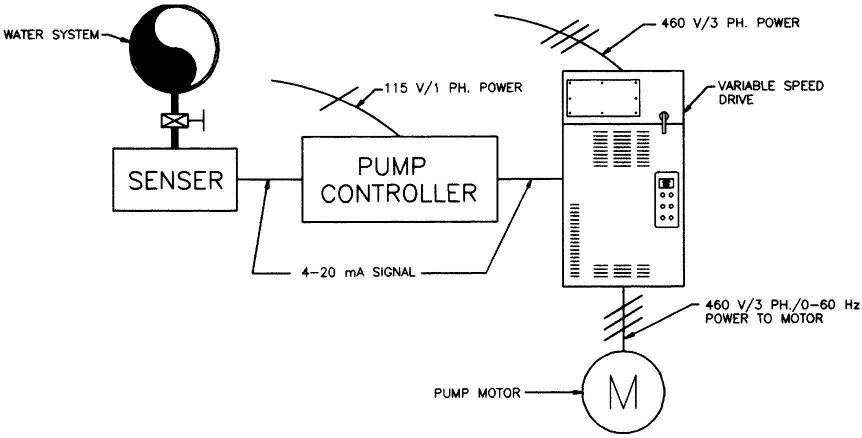
10.11.4 Pump speed control

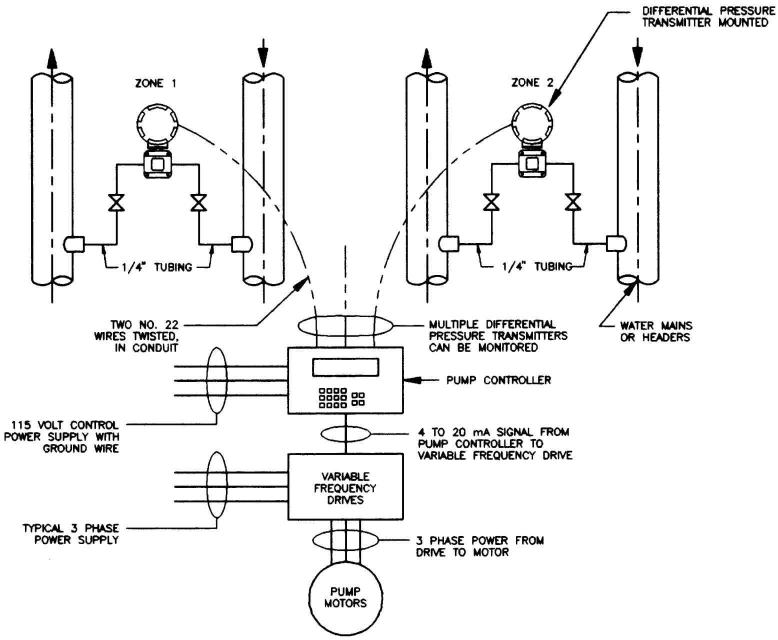
All the preceding discussion has been on programming the pumps efficiently. The second part of operating variable-speed pumps is control of the pump speed itself. Development of the variable-frequency drive has greatly changed the design, selection, and operation of pumps. The resulting variable-speed pump offers many benefits such as reduced power consumption and lower radial thrusts on the pump shafts. The variable-speed drives themselves have been reviewed in Chap. 7. Contemporary speed control of a pumping system has evolved over the past 25 years.

The basic control arrangement for these variable-speed pumps consists of a water system sensor, a pump controller, and a variable-speed drive (Fig. 10.20*a*). In most cases, the water system sensor can be for (1) temperature, (2) differential temperature, (3) pressure, (4) differential pressure, (5) water level, (6) flow, and (7) kilowatts. Special systems may use other physical or calculated values for varying the speed of the pumps.

The pump controller can be of many different configurations depending on the response time required to adequately control the pump speed without continual speed changes or hunting. With initial use of variable-speed drives on HVAC systems, it was assumed that since the loads did not change rapidly on these water systems, there was no need for rapid speed regulation of the pumps. It was learned during actual operation of these pumps on HVAC systems that rapid speed regulation was required, particularly on systems where pressure or differential pressure sensors were used to regulate the speed of the pumps. Although the load on these systems was not changing rapidly, pressure waves within the water systems created changes at the sensors that caused speed changes. Also, with digital control, after computation of the Propotional-Integral-Derivative error, an output signal is given the variable-speed drive to increase or decrease the speed of the pump. PID error for proportional-integral-derivative control is the difference between the setpoint and the process value. This increase or decrease continues until the next signal change. Attempts to reduce the sensitivity of the pump control only caused increased variation in the actual pressure or differential pressure at the point where the sensor was installed. Currently, 500 ms has proved to be an adequate response time for most HVAC variable-speed pumping systems. *If HVAC variable-speed pumps continuously change their speed, the response time is inadequate, or another control problem exists!* Properly controlled variable-speed pumps in this industry should not change their speed so that the changes are either visible or audible.



a. Basic speed control for variable speed pump.



b. Piping and wiring for multiple differential pressure transmitters.

Figure 10.20 Basic speed control for variable-speed pumps.

Most pump controllers are now based on digital electronics and are of the proportional-integral-derivative or digital type, which sense a signal, compute the error, and output the speed signal to the variable-speed drive. Since the speed of the pump is held at a discrete point by such a controller until it is updated, there can be continuous speed fluctuation when rapid control response is not provided. Standard commercial PID computer chips are available with a rate of response as fast as 10 to 500 ms. Rate of response should not be a problem on variable-speed HVAC pumps due to the digital technology that is now available for the control of such pumps. Any variable-speed pump that has continuous speed change is not being controlled properly. It may have too slow a speed response from the transmitters that are controlling the pump speed.

Although standard commercial computer chips are designed for proportional-integral-derivative control, most HVAC applications do not require any derivative value inserted in the actual control algorithm. Also, proportional-integral controllers of the analog type are seldom used in this industry.

10.11.5 Sensors for pump speed control

The preceding description of basic variable-speed control listed the types of sensors used for pump operation. Some HVAC systems require more than one sensor to maintain the proper speed of the pumps. This is due to shifting heating or cooling loads on the water system. The standard signal-selection technique is utilized to accommodate more than one transmitter (Fig. 10.20*b*). The controller selects the transmitter at which the signal has deviated the farthest from its set point. Following is information on the selection and location of sensors or transmitters.

The location of the sensors is important to ensure that the pumps can be operated at the lowest possible speed from minimum to maximum system load. See Chap. 10 for proper sensor location for specific types of water systems.

When pressure or differential pressure is used to control pumps, these transmitters must be located so that the distribution friction pressure loss of the system is eliminated from the signal. For example, assume that a distribution system for a hot or chilled water system consists of differential pressure with direct return piping and has a 20-ft loss across the largest coil, its control valve, and piping. Also assume that the distribution friction loss out to and back from the farthest coil is 80 ft. The total pump head is therefore 100 ft. If the pressure transmitter is located at the pump, it must be set at 100 ft to accommodate the system when it is operating at 100 percent load. If the transmitter is located at the far end of the loop, the distribution loss of 80 ft is eliminated from the control signal. The transmitter can be set at just 20 ft, the loss across the largest coil and its piping. The pump speed can be varied to match the load on the system, thus saving appreciable energy by operating the pump at lower speeds. The pump will operate with less radial thrust and have less repair.

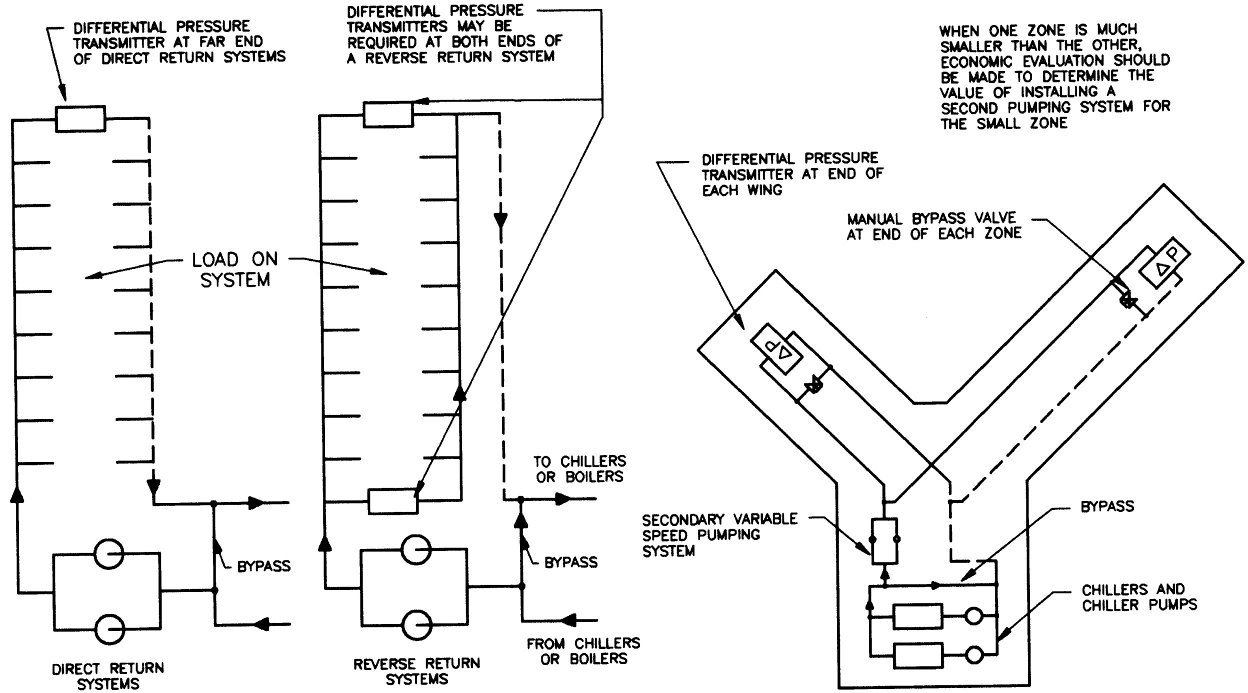
The water system just described is of the direct return type; if it were of the reverse return type, differential pressure transmitters would be required at both ends of the distribution loop. Both the direct and reverse return systems and their transmitter locations are shown in Fig. 10.21*a*. With variable loads in a reverse return loop, if all the loads are located at one end of the loop, the differential pressure transmitter located at the other end will not provide adequate control. One transmitter can be located at the center of the loop, but one-half the distribution loss must be set into the control signal, thus forcing the pump to run at a higher and less efficient speed. This may be acceptable on small systems without much distribution friction, but it would be totally unacceptable on the preceding system with 80 ft of distribution friction. In this case, the differential pressure transmitter would be required to be set at 60 ft, causing the pumps to run at a much higher speed than when set at 20 ft with the differential pressure transmitters at each end of the loop.

Along with the proper location of the differential pressure transmitters, the transmitters must be interrogated properly by the control system. As indicated earlier, the response time of the controller must be fast enough to prevent pump hunting, but it must hold the differential pressure to an error signal of ± 1 foot or less. Any variation greater than this for the controlling transmitter is unacceptable; if a greater variation occurs, it indicates that the pumps are hunting, and energy is being lost.

Following are several special applications of differential pressure transmitters on hot or chilled water systems. All these applications with 2 to 10 transmitters will utilize a low signal selection procedure that will select the controller that has deviated the farthest from it set point.

Figure 10.21b. A two-wing building usually requires a differential pressure transmitter at the end of each wing.

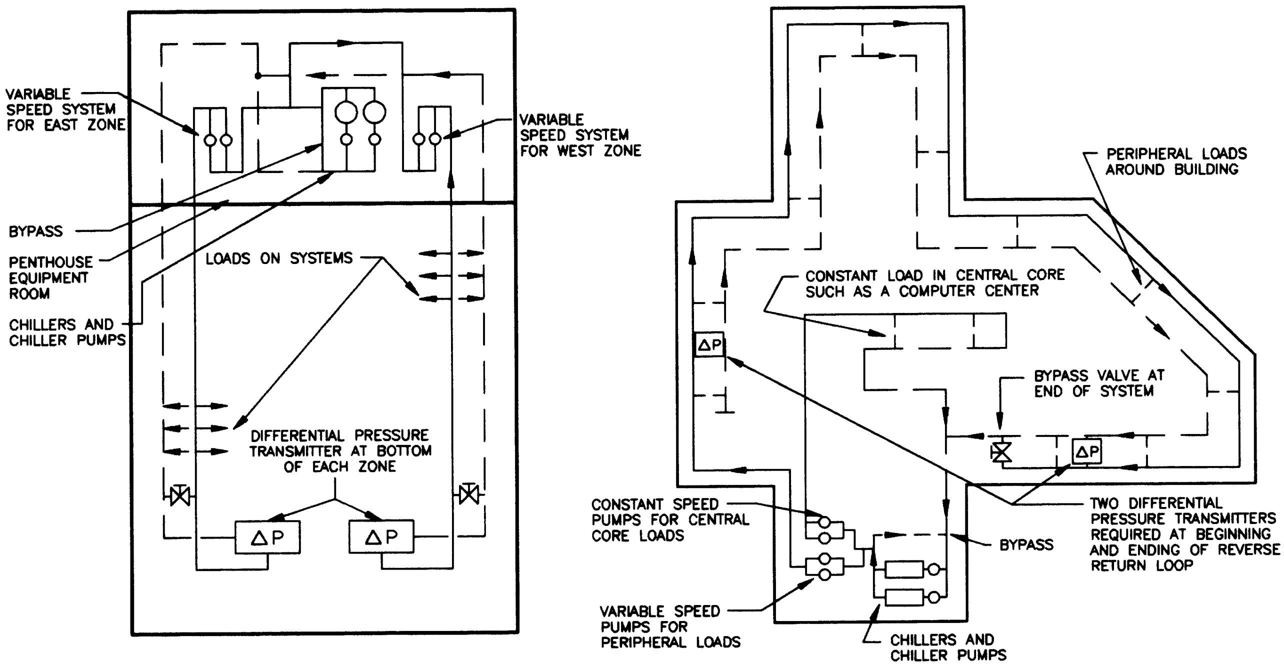
Figure 10.22a. When the chillers, boilers, and pumps are located on top of a high-rise building, the differential pressure transmitters should be located at the bottom of the building to eliminate the distribution friction.



a. Location of differential pressure transmitters on hot and chilled water, variable speed pumping systems.

b. Location of transmitters for building with two unequal zones.

Figure 10.21 Connection of differential pressure transmitters.



a. Variable speed pumping systems for high rise buildings with downfeed cooling system.

b. Location of transmitters for a low rise building with reverse return system.

Figure 10.22 Particular applications of differential pressure transmitters to HVAC hot and chilled water systems.

Figure 10.22b. This building is typical of reverse return systems requiring a differential pressure transmitter at each end of the loop. One differential pressure transmitter can be located at the center point of the reverse return loop if the distribution friction of the supply and return loops is less than 20 ft.

Buildings that have a great amount of glass and a pronounced sun load may require a differential pressure transmitter on both the east and west sides of the building, regardless of the configuration of the piping.

A number of control procedures are being developed to control variable-speed pumps; some have been successful, and some have not. Following are control techniques for loop-type variable-speed pumping systems that have *not* been successful:

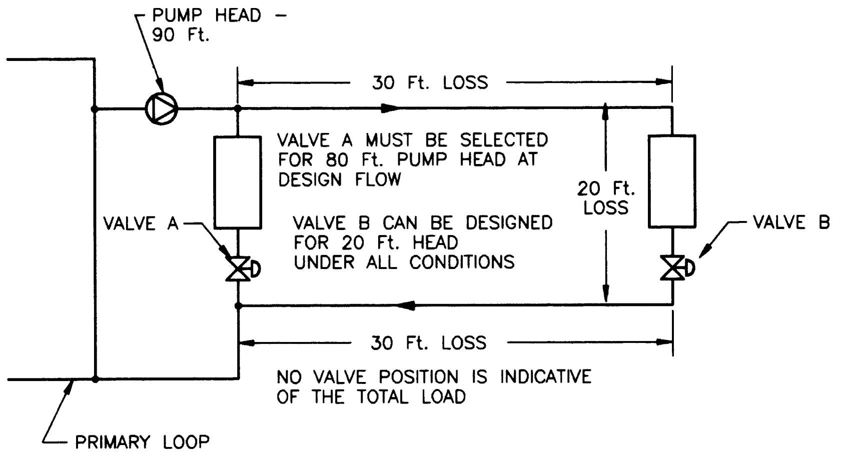
1. *Locating the differential pressure transmitter across the pumps instead of at the end of the loops.* There is little reason for using variable-speed pumps with this control procedure. The design pump head must be the set point for the differential pressure controller; therefore, there is very little reduction in pump speed, whatever the load on the building.

2. *Temperature control by valve stem position.* This method of controlling chilled and hot water systems can be expensive and difficult to calibrate. The position of a particular valve stem has no relationship to the flow of water passing through the valve. Figure 10.23*a* describes why this is so. Valve *A* close to the pumps will have a greater flow at a specific valve position than valve *B* at the end of the loop. It is difficult to correlate an analog representing valve position to pump speed without excessive hunting. Pumps and their controls are designed to respond to pressure changes; this is why the differential pressure control method has been so successful over the past 25 years.

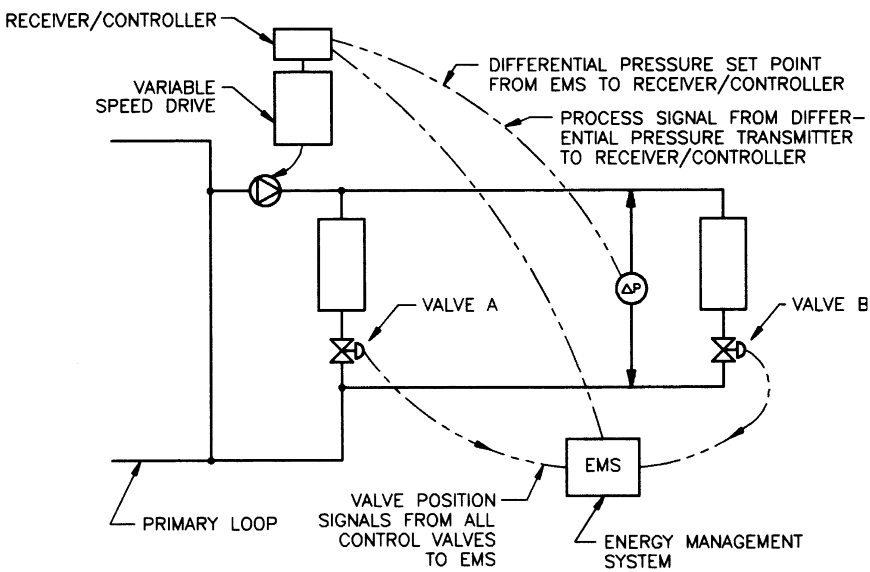
A combination of differential pressure control and valve position reset is possible, as shown in Fig. 10.23*b*. The differential pressure transmitter is still the principal means of controlling the pump speed, but the differential pressure set point is established by the energy management system, which changes the set point as the valves recede from full-open position. This is uneconomical unless the valve position of all the control valves is being sent to the building management system as part of the standard control system.

A typical differential pressure–valve position schedule would be

Any valve fully open:	25 ft
All valves 90 percent open:	22 ft
All valves 80 percent open:	19 ft



a. Problem of using valve position for pump speed control.



b. Differential pressure reset with control valve position.

Figure 10.23 Use of control-valve position for differential pressure reset.

All valves 70 percent open:	16 ft
All valves 60 percent open:	14 ft
All valves 50 percent open:	12 ft

3. *Return water temperature control.* Fortunately, this method of control is not seen very often. It absolutely will not work! Return

water temperature has no relationship to system load on variable-volume systems; it should be maintained as closely as possible to a constant value. For example, a chilled water system operating with 44°F supply temperature and 56°F return temperature should hold these temperatures whether the load is heavy or light on the system. Therefore, return temperature cannot possibly be used as a control parameter for variable-speed pumping. Often there has been confusion of variable return water temperature that results from the use of three-way valves; these systems were, of course, constant-volume systems and not used with variable-speed pumps for most applications.

10.11.6 Communication from remote transmitters

The method of communication with remote transmitters is particularly important to ensure that a noninterrupted signal is received at the pump controller at the rate of response specified by the pump control manufacturer. The route that the signal takes is of importance to the water system designer.

Most signals from remote transmitters are direct current and 4 to 20 mA in strength. These signals must be protected from electromagnetic and radiofrequency interference. Therefore, the interconnecting cabling must be shielded and grounded at the pump controller end. Table 10.11 provides typical distances between the transmitter and the pump controller that can be used with various sizes of wire.

These cables can be installed in conduit or cable trays that carry other instrument, data, or telephone signals. They must be shielded for electromagnetic and radio frequency interference, and the shield must be grounded at the end of the cable near the pumping system controller.

On some large installations, the cable installation for pump control can become expensive; an alternate procedure is to install modems

TABLE 10.11 Maximum Linear Distances for Transmitters from Pump Controllers

Wire size, AWG	Linear distance, ft
16	20,000
18	11,000
20	8000
22	5000
24	3500
26	2000

at the remote differential pressure transmitter and at the pumping system. This procedure allows the use of ordinary telephone cables for transmission of the control signals.

Care should be taken to avoid routing the control signals through building management systems that reduce the rate of response from the transmitter; the signal and data load on these central management systems may be such that the transmitter signal for pump speed control cannot be processed faster than 2 to 4 seconds. This is too slow for accurate pump speed control. This must not occur routinely or when the central management system is responding to emergency conditions such as fire or building power failure.

10.12 Effects of Water Systems on Pump Performance

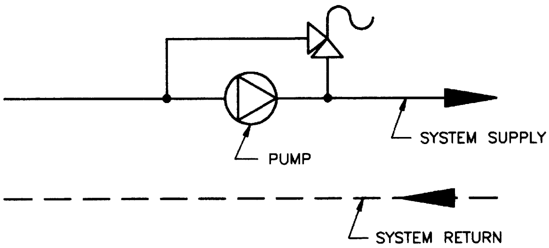
The pump is the heart of every water system; when it fails, the system fails. Unfortunately, many times pump failure is due to the water system's effects on the pump's performance and physical condition. The problems with cavitation and entrained air on pump performance and damage have already been discussed in Chap. 6.

Other deleterious effects on pumps are control systems that force pumps to run in the high-thrust areas, namely, at very low or high flow rates. The pump wears rapidly, and it is not the pump's fault.

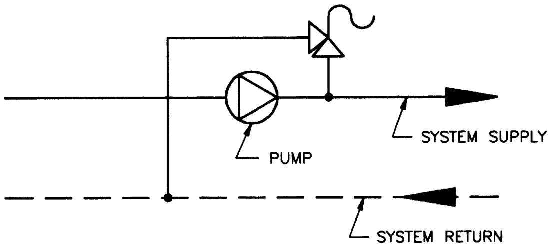
One of the most disastrous practices in pump application is the installation of a relief valve on a pump discharge that returns the water to the pump suction, as shown in Fig. 10.24*a*. It should be remembered that the thermal equivalent of a brake horsepower is 2544 Btu/h. All the energy destroyed by the relief valve is returned to the pump suction. If the system is operating at low loads, where the flow through the pump is low, it is very apparent that heat will build until the pump can become very hot. Also, hot water will surge through the system when the flow does increase.

Relief valves should be avoided wherever possible on chilled water systems because every brake horsepower destroyed by the relief valve adds one-fifth of a ton load on the chillers. If there is no other way to control the water through the system than by a relief valve, it should be connected as shown in Fig. 10.24*b*. The heat is returned to the chiller, and the pump continues to receive and deliver chilled water.

Heating and cooling coils that are dirty on the air or water side or are operating with laminar flow increase the system flow beyond the design flow rates. Often pumps are blamed for their inability to provide these greater flows; good system control is the answer for many system problems that cause unnecessary pump wear and maintenance.



a. Unacceptable installation.



b. Acceptable installation.
(Not recommended excepting as last resort if relief valve must be used).

Figure 10.24 Pump relief valve connections.

HVAC pumps should be long-lasting with very little repair. Proper installation and operation will provide many years of operation with a minimum of service and repair.

10.13 Bibliography

James B. Rishel, *The Water Management Manual,* SYSTECON, Inc., West Chester, Ohio, 1992.
James B. Rishel, *Variable Volume Pumping Manual,* Systecon Inc., West Chester, Ohio, 1982.