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Modeling for Improving Variable Flow Piping Design

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This month's column explores hydraulic modeling as a tool to optimize hydronic system design. Current hydraulic modeling software can assist designers in predicting hydronic system performance under various scenarios to improve piping system design. This tool can provide the information needed to properly select pumps and control valves. In addition, the computer model provides a good understanding of the interaction of pumps, pipelines, and control valves. Hydraulic modeling software also provides a common basis for design engineers, facility operators and design reviewers to communicate and document fluid piping systems.

In this column, I will point out how relatively simple it is to use this tool to better understand the impact of the initial pipe layout and sizing. As previously stated by Duda,[1] reverse return piping can be beneficial for some building layouts, especially in buildings with simple floor plates. This column will focus on hydronic design for more complex floor plates. Taylor and Stein[2] have provided valuable insight on balancing variable flow hydronic systems.

Hydraulic Model

Several computer software programs are available for analyzing the hydraulics of HVAC piping systems. The modeling software[3] used for this analysis calculates the balanced flow rates and pressures in fluid piping systems, showing how the entire piping system operates. Using the calculated results, one can see the flow rate in each pipeline; the pressure at each pipeline junction; and details of the operation of pumps, control valves, and components. This section briefly describes the calculation methodology used by the program.

The hydraulic modeling software uses several equations to calculate the head loss in a pipe. The Reynolds Number must first be calculated, then the friction factor, and then the Darcy-Weisbach head loss equation is used to calculate the head loss.[4] The software calculates the balanced flow rates and pressures in a piping system using the simultaneous path adjustment method. This method starts by using the Hardy Cross method[5] and, once the program is near a solution, it switches to the linear method to complete the calculation. The program automatically sets up the equations for the network calculations by tracing the system loops and developing the flow and pressure drop equations needed for the network calculations.

Input Data

The first step is to define the fluid properties used in the piping system. This includes the fluid average temperature, density and viscosity. A piping diagram can be input to reflect the entire piping system and components. *Figure 1* shows common components included in the pipe model. The piping material, lengths and fittings are defined for each pipe segment between nodes. A node is used to join pipes or components.

All of the associated fittings can be entered for each pipe segment. The standard valve and fitting tables used in the software contain all of the valve and fitting types contained in Crane Technical Paper 410.[6] Custom valve and fitting tables can be created for various materials and pipe specifications. Coils can be modeled as a curve differential pressure (DP) device using the pressure drop at design flow through the coil. Flow control valves can be used to set the design flow for the coils. The flow control valve

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will automatically adjust to balance flows, and the most hydraulically remote branch flow control valve will have a zero pressure differential. A sizing pump can be used to calculate the required head to operate the system.

Example Model

A variable flow chilled water system for a new three-story college gymnasium is used (*Table 1*) to demonstrate how hydraulic modeling can better inform the designer. The building is 480 ft (146 m) long in one dimension and includes seven air handlers. The building is served by a campus chilled water distribution system that maintains a maximum of 20 psi (138 kPa) differential under peak cooling design. The client preference was to eliminate building booster pumps, if possible, to reduce additional space and maintenance. The campus standard required redundant N+1 building booster pumps if the building is designed to operate at a higher differential pressure. The air handler cooling coils required the flow and corresponding pressure drops shown in *Table 1*.

AHU-5 and AHU-7 are VAV air handlers, while the remaining air handlers are indirect/direct evaporative cooling air handlers with supplemental chilled water cooling coils. It is anticipated the building will operate roughly 3,800 hours per year. In general, pipes have been initially sized to comply with the minimum pipe sizing criteria in ASHRAE/IES Standard 90.1-2013, Table 6.5.4.6,[7] using the "> 2,000 and ≤ 4,400 Hours/Year Variable Flow/Variable Speed" column. Pipes smaller than 2.5 in. (63.5 mm) have been initially sized to not exceed 4 ft per 100 ft (12 kPa per 30 m) piping friction loss. *Figure 2* shows Case 1 initial pipe-sizing scenario. Flow control valves have been used to set the desired maximum flow for each cooling coil.

FIGURE 1 Pipe model diagram.

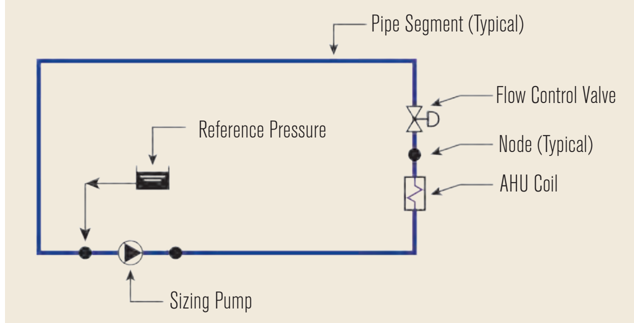

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Figure 2 shows the results based on the initial pipe sizes. AHU-4 is the most hydraulically remote load since the flow control valve shows no pressure drop. The remaining flow control valves indicate the excess differential pressure that would need to be throttled to balance flow. The building would require roughly 97 ft head (290 kPa) in addition to the AHU-4 control valve full open pressure drop to operate under this pipe-sizing scenario. Since the central plant only provides 20 psi or 46 ft head (138 kPa) differential at the building connection, each redundant booster pump would need to provide the additional head required.

TABLE 1 Example variable flow chilled water system.

AIR HANDLER	FLOW RATE (GPM)	CHW COIL ΔP (FT HEAD)
AHU-1	59	5.7
AHU-2	63	6.4
AHU-3	14	1.5
AHU-4	67	6.1
AHU-5	36	6.0
AHU-6	44	6.0
AHU-7	15	3.5

Booster Pump Feet Head =
97 − 46 = 51 + AHU-4 Control Valve

Booster Pump kPa =
290 − 138 = 152 + AHU-4 Control Valve

The initial model provides useful information to determine modifications that would lower the required head when operating the system at peak load. The author typically tries to design the building piping system so all the cooling coil control valves are within a range of 0 to 10 psi (0 to 70 kPa) differential. This allows the system to be better balanced and control valves to operate better at lower differential pressure. The air handler flow control valve pressure drops are shown in *Figure 2* and provide an indication of how balanced or unbalanced the system performs.

The flow control valve pressure drops range from 0 to 27 psi (0 to 186 kPa) differential under the Case 1 scenario. Balancing valves could be used to overcome the 27 psi (186 kPa) difference in differential pressure, but would waste pumping energy since there are times when each of the AHUs is the most demanding coil due to changing loads. Assuming a specific gravity of 1.0 for water, balancing valve pressure drop would decrease significantly at lower flows since,

$$\Delta P = \left(\frac{Q}{cv}\right)^2$$

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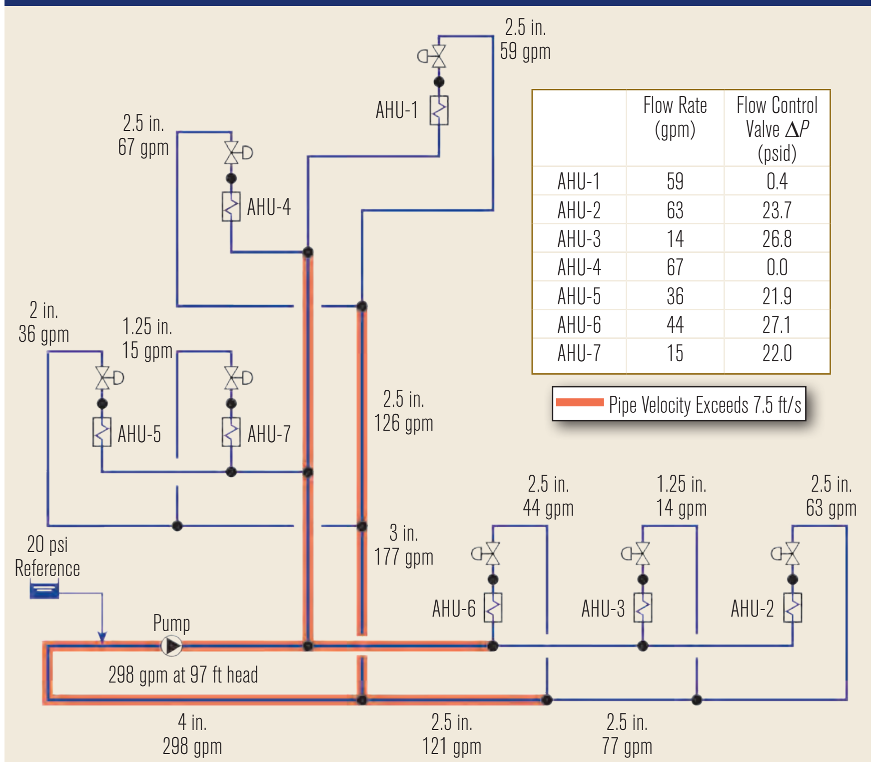
where

ΔP = psi and Q = gpm

The highlighted piping in *Figure 2* shows where the velocity in the piping mains exceeds 7.5 ft/s (2.3 m/s).

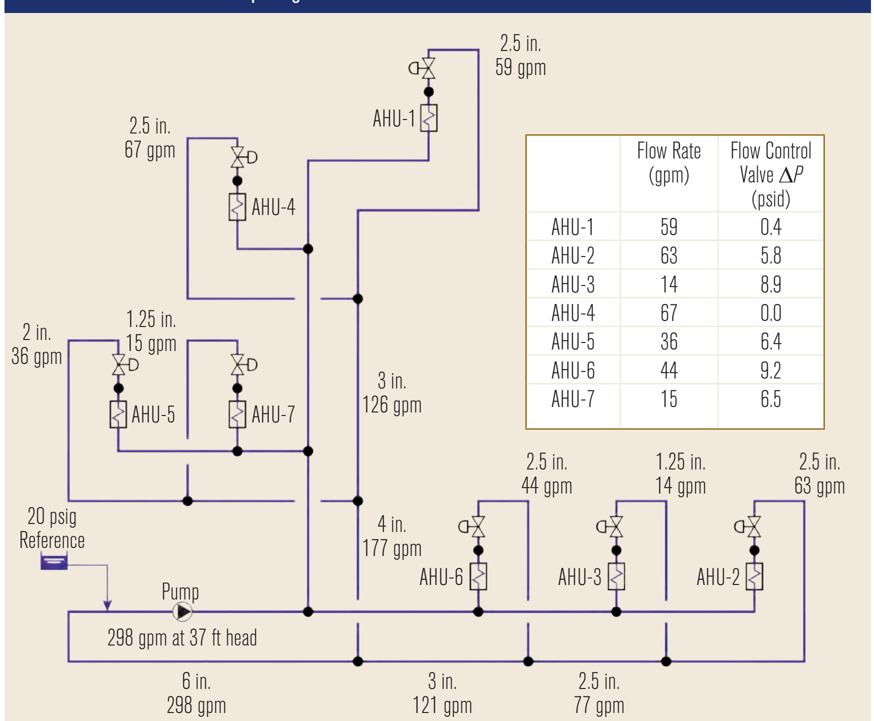
Figure 3 shows the results of simply upsizing the highlighted mains from *Figure 2*. The resulting flow control valve pressure drops range from 0 to 9.2 psi (0 to 63 kPa) differential as the system is better balanced. The building would require roughly 37 ft of head (110 kPa) in addition to the AHU-4 control valve pressure drop to operate under this pipe-sizing scenario. The result is the available 20 psi (138 kPa) differential from the central plant connection would be adequate to supply the building under peak load without the use of building booster pumps.

FIGURE 2 Case 1: Model with initial pipe sizing.



	Flow Rate (gpm)	Flow Control Valve ΔP (psid)
AHU-1	59	0.4
AHU-2	63	23.7
AHU-3	14	26.8
AHU-4	67	0.0
AHU-5	36	21.9
AHU-6	44	27.1
AHU-7	15	22.0

FIGURE 3 Case 2: Model with upsizing mains.



	Flow Rate (gpm)	Flow Control Valve ΔP (psid)
AHU-1	59	0.4
AHU-2	63	5.8
AHU-3	14	8.9
AHU-4	67	0.0
AHU-5	36	6.4
AHU-6	44	9.2
AHU-7	15	6.5

Conclusion

Hydraulic modeling tools are beneficial to improving piping system design and have become much easier to use in the past 20 years. Engineers and designers laying out and sizing piping systems can use these tools to inform their design at both peak-load and part-load operation to help predict how the system components will operate. This example has shown a technique for accomplishing greatly reduced pump head, improved system balance, avoiding additional pumps, and optimized pipe sizes in a way that would not have been achieved without the hydraulic modeling.

References

1. Duda, S. 2015. "Reverse return reexamined." *ASHRAE Journal* 57(8):40–44.

2. Taylor, S., J. Stein. 2002. "Balancing variable flow hydronic systems." *ASHRAE Journal* 44(10):17–24.

3. Engineered Software. 2015. PIPE-FLO Professional, Version 15.

4. *2013 ASHRAE Handbook—Fundamentals*, Chap. 22.

5. Cross, H. 1936. "Analysis Of Flow In Networks Of Conduits Or Conductors." Engineering Experiment Station. Bulletin No. 286. University of Illinois.

6. Crane & Co. 2009. *Flow of Fluids through Valves, Fittings and Pipe (TP-410)*. Stamford, Ct.: Crane & Company.

7. ANSI/ASHRAE/IES Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Table 6.5.4.5 "Piping System Design Maximum Flow Rate in GPM (I-P)." ■