Variable-Speed Pumping Control Strategies

Kyle DelPiano- Bell & Gossett Business Development Manager

Outline of Presentation

ASHRAE 90.1 and Variable Speed Pumping

Control Curve and Control Area Review

Control Curve Pump Control Strategy

- Pump Head Control
- Full System Flow Sensor
- Sensorless

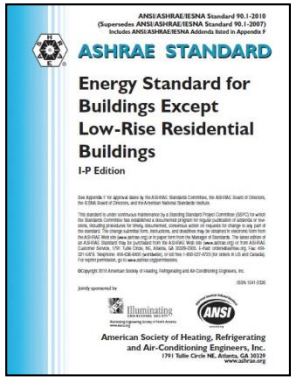
Control Area Pump Control Strategies

- Remote DP
- Remote DP with valve position reset
- Custom Pump Controller

Summary

ANSI/ASHRAE/IES Standard 90.1-2010/13

HEATING, VENTILATING, AND AIR CONDITIONING



SECTION 6.5
Prescriptive Path

6.5.4 Hydronic System Design and Control.

6.5.4.1 Hydronic Variable Flow Systems. HVAC pumping systems having a total pump system power exceeding 10 hp that include control valves designed to modulate or step open and close as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate.

Individual chilled water pumps serving variable flow systems having motors **exceeding 5 hp** shall have controls and/or devices (**such as variable speed control**) that will result **in pump motor demand of no more than 30% of design wattage at 50% of design water flow.**

Exceptions:

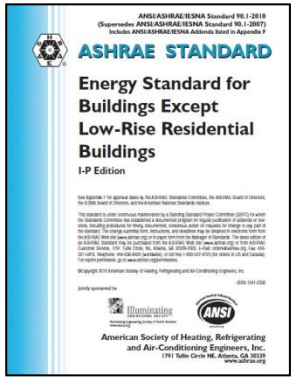
a. Systems where the minimum flow is less than the minimum flow required by the equipment *manufacturer* for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.

b. Systems that include no more than three control valves.

ANSI/ASHRAE/IES Standard 90.1-2010/13

HEATING, VENTILATING, AND AIR CONDITIONING

SECTION 6.5
Prescriptive Path



6.5.4 Hydronic System Design and Control.

6.5.4.1 Hydronic Variable Flow Systems. HVAC pumping systems **….**

The controls or devices shall be controlled as a **function of desired flow or to maintain a minimum required differential pressure**. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure. **The differential pressure setpoint shall be no more than 110% of that required to achieve design flow through the heat exchanger.**

Exceptions:

a. Systems where the minimum flow is less than the minimum flow required by the equipment *manufacturer* for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.

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ANSI/ASHRAE/IES Standard 90.1-2010/13

HEATING, VENTILATING, AND AIR CONDITIONING

SECTION 6.5
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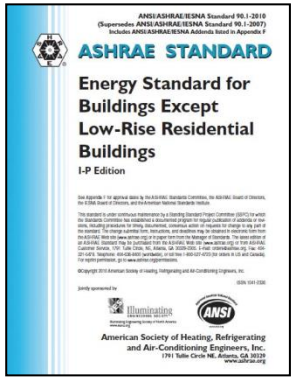

6.5.4 Hydronic System Design and Control.

6.5.4.1 Hydronic Variable Flow Systems. HVAC pumping systems ….

Where differential pressure control is used to comply with this section and DDC controls are used the setpoint shall be reset downward based on valve positions until one valve is nearly wide open.

Exceptions:

a. Systems where the minimum flow is less than the minimum flow required by the equipment *manufacturer* for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.

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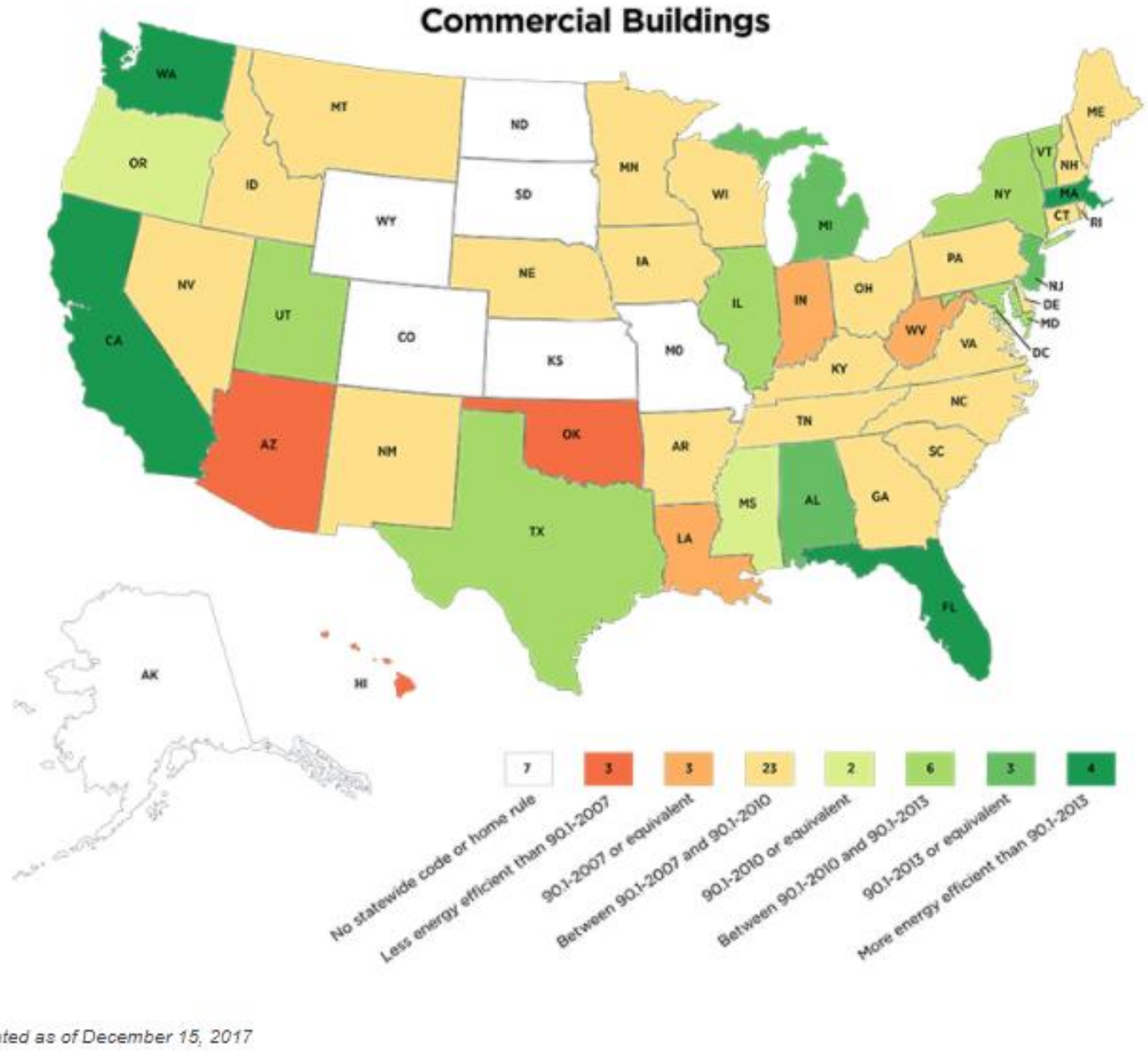

December 15th, 2017 – www.energycodes.gov

Ohio 90.1 2010 Update?

Approved Compliance Tools:	Can use COMcheck
Approximate Energy Efficiency:	Equivalent to 2012 IECC
Effective Date:	Nov. 01, 2017
Adoption Date:	Sep. 30, 2016
Code Enforcement:	Mandatory
DOE Determination:	ASHRAE 90.1-2007: Yes ASHRAE 90.1-2010: No ASHRAE 90.1-2013: No Energy cost savings for Ohio resulting from the state updating its commercial and residential building energy codes in accordance with federal law are significant, estimated to be on the order of nearly $230 million annually by 2030. Ohio DOE Determination Letter, May 31, 2013 Ohio State Certification of Commercial and Residential Building Energy Codes

DOE Letter:

May 31st 2013 requesting 90.1 2010 compliance by October 18 2013

https://www.energycodes.gov/sites/default/files/documents/OhioDOEDeterminationLetter05312013.pdf

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Control Curve Pump Control Strategy

- Pump Head Control
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- Sensorless

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- Remote DP
- Remote DP with valve position reset
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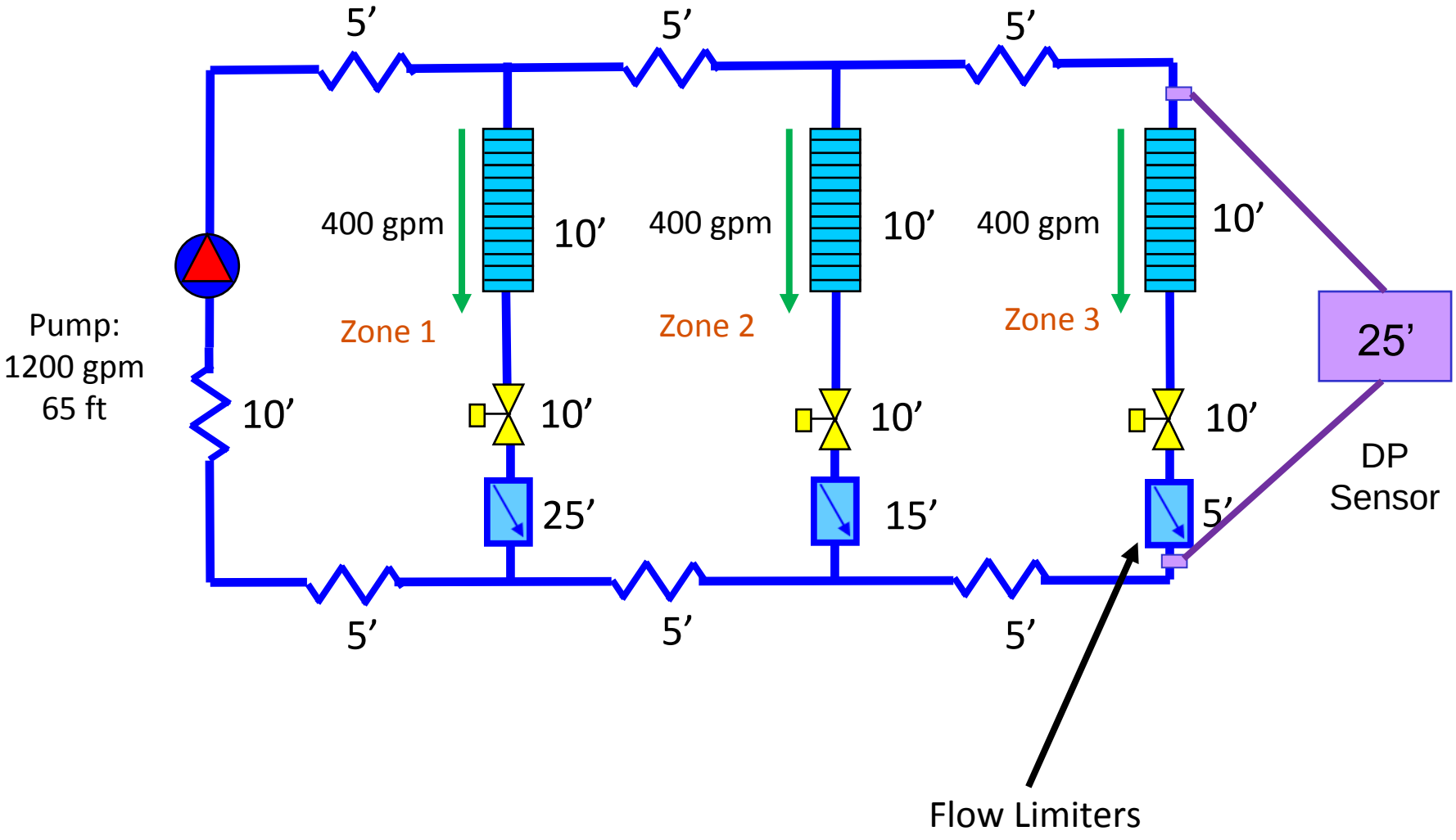
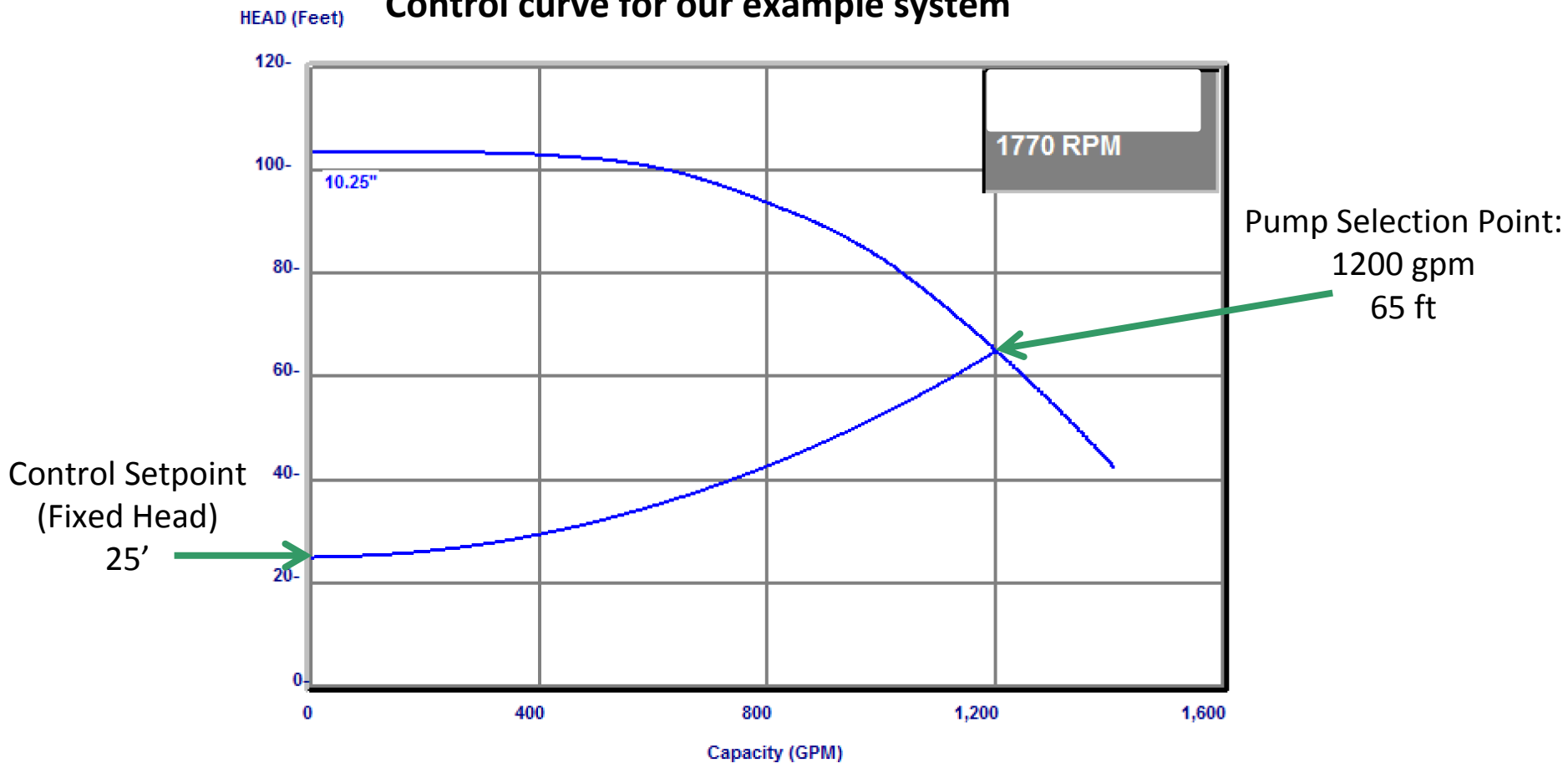
Summary

Our Example System



Control curve for our example system



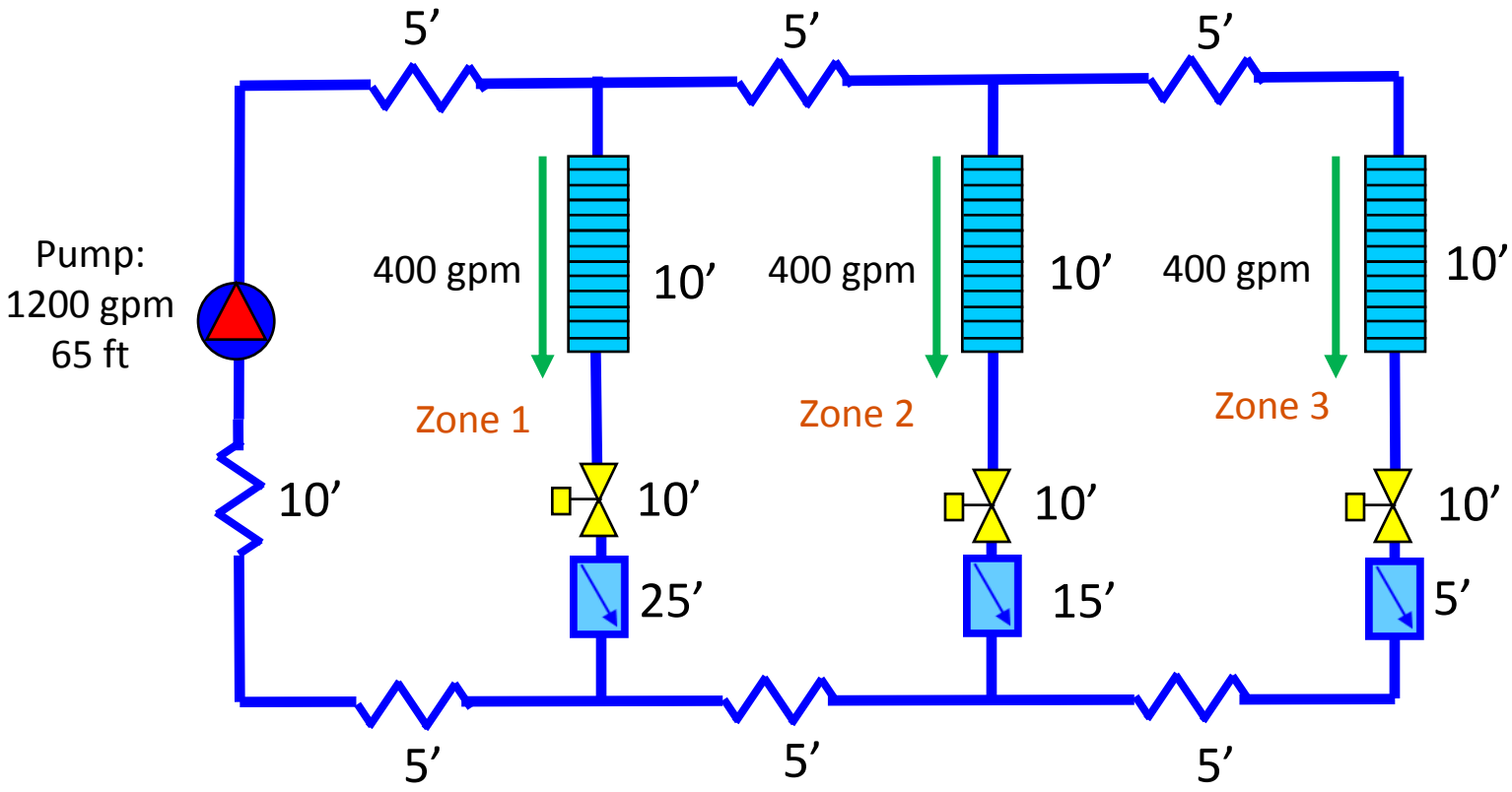
Control Curve Pump Control adjusts pump speed to keep the pump operating on the **control curve**. To do this, the controller must know where the pump is operating on the pump curve. This is achieved with one of these 3 combination of inputs:

- Pump differential pressure and RPM (requires a local DP sensor)
- Pump flow and RPM (requires a local flow measuring device)
- Motor HP and RPM (this is known in the market as *sensorless pumping*)

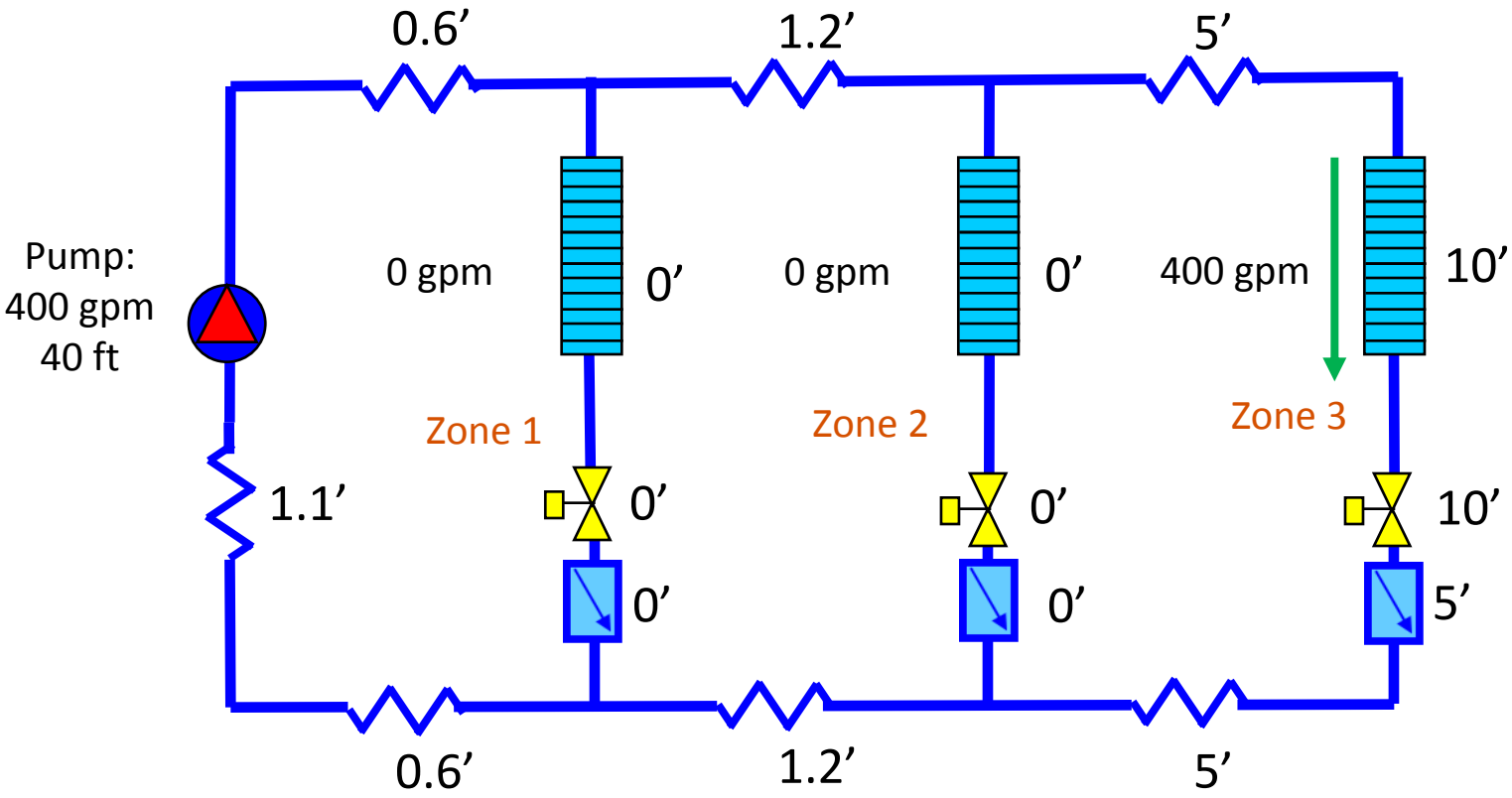
Variable Speed Pumping System

Control Area Review

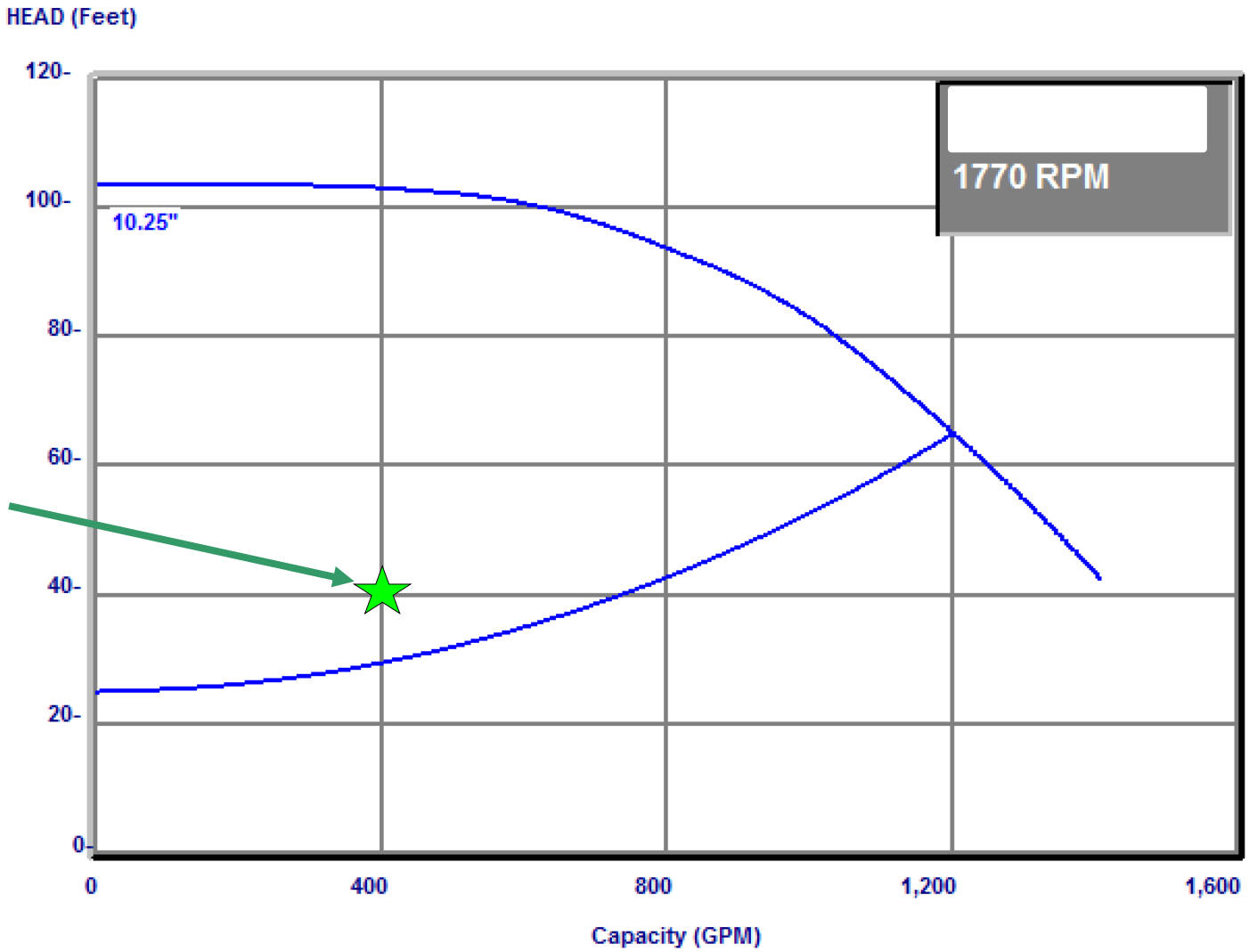
How much pump head does our example system need at 400 gpm?



Answer: It depends on where the load is!



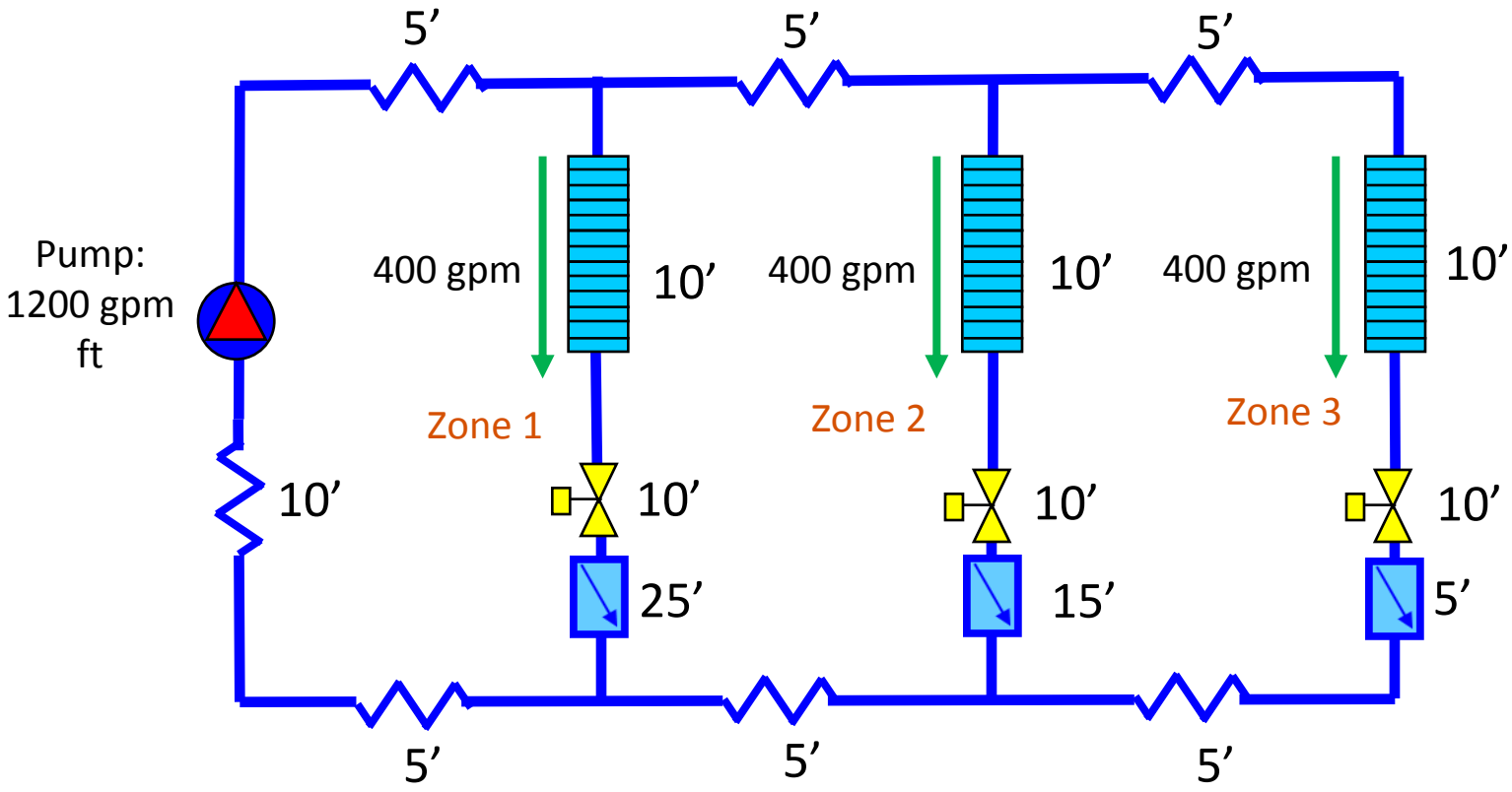
If all 400 gpm is through Zone 3, required pump head is 40 feet



400 gpm, 40 ft

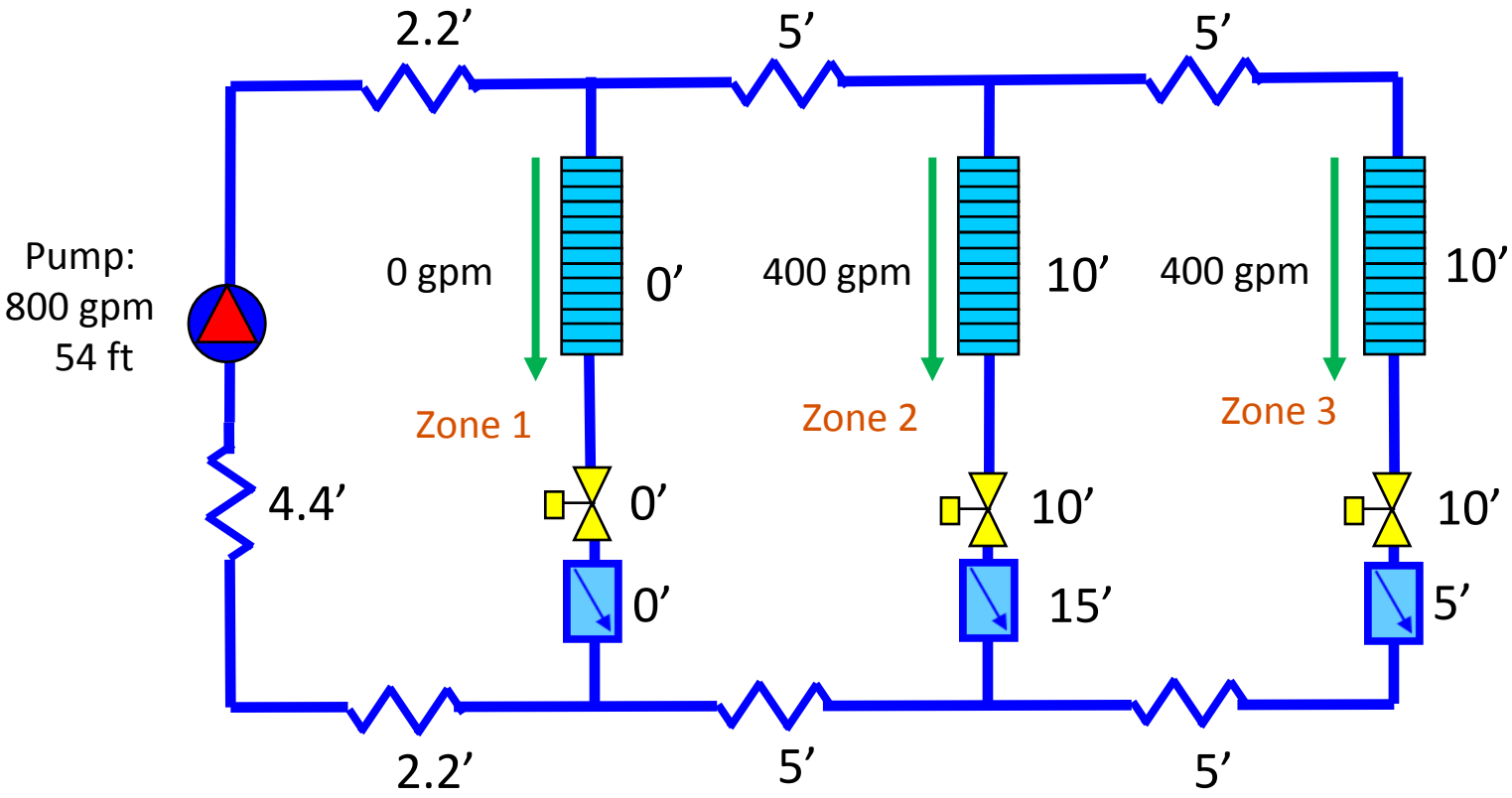
Note that this point is **above** the control curve. Hydronic systems will need to operate **above and below** the control curve if exact flow demands are delivered.

How much pump head does our example system need at 800 gpm?



Answer: It depends on where the load is!

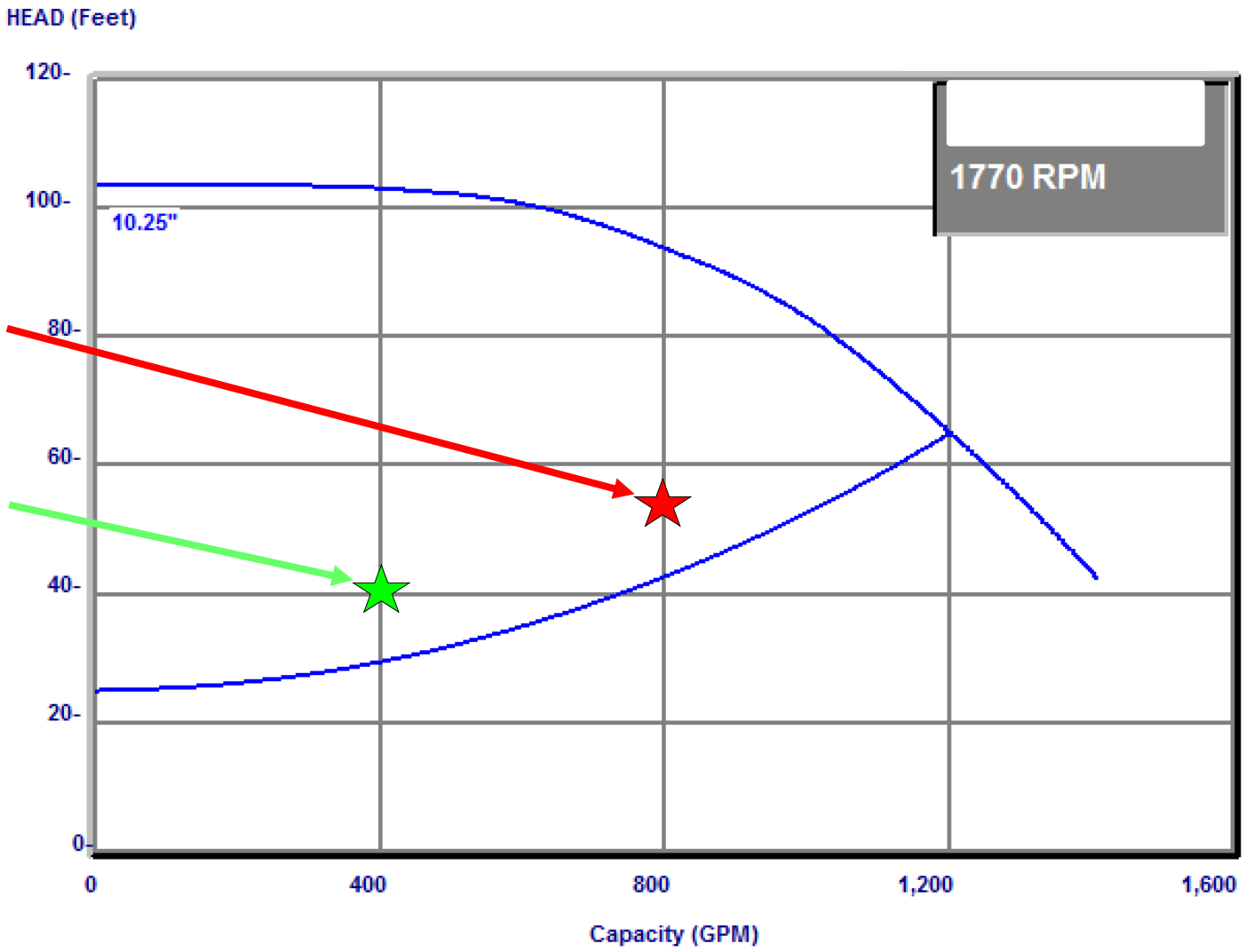
How much pump head will this control system generate at 800 gpm?



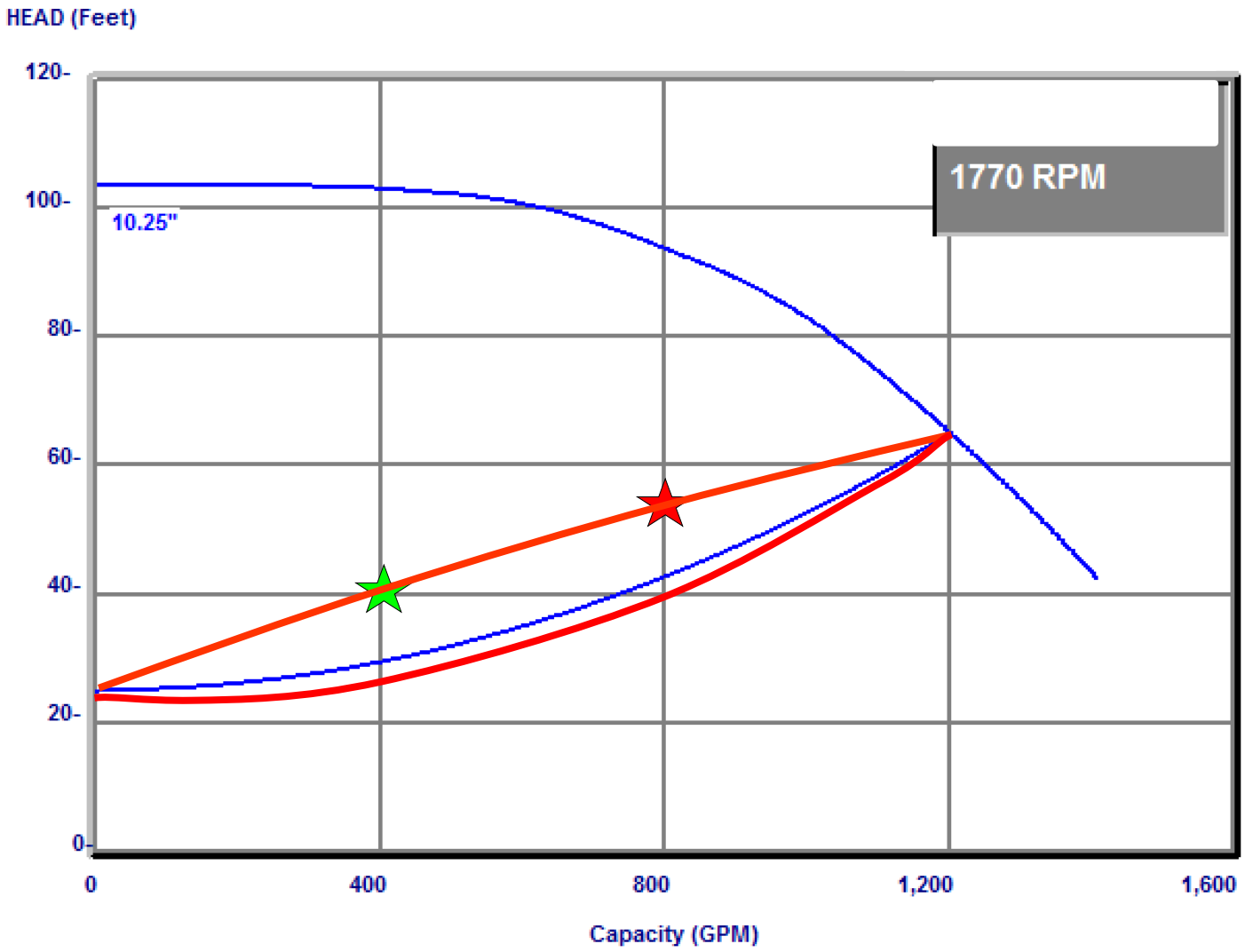
With Zones 2 and 3 fully loaded, pump head is 54 feet.

800 gpm, 54 ft

400 gpm, 40 ft

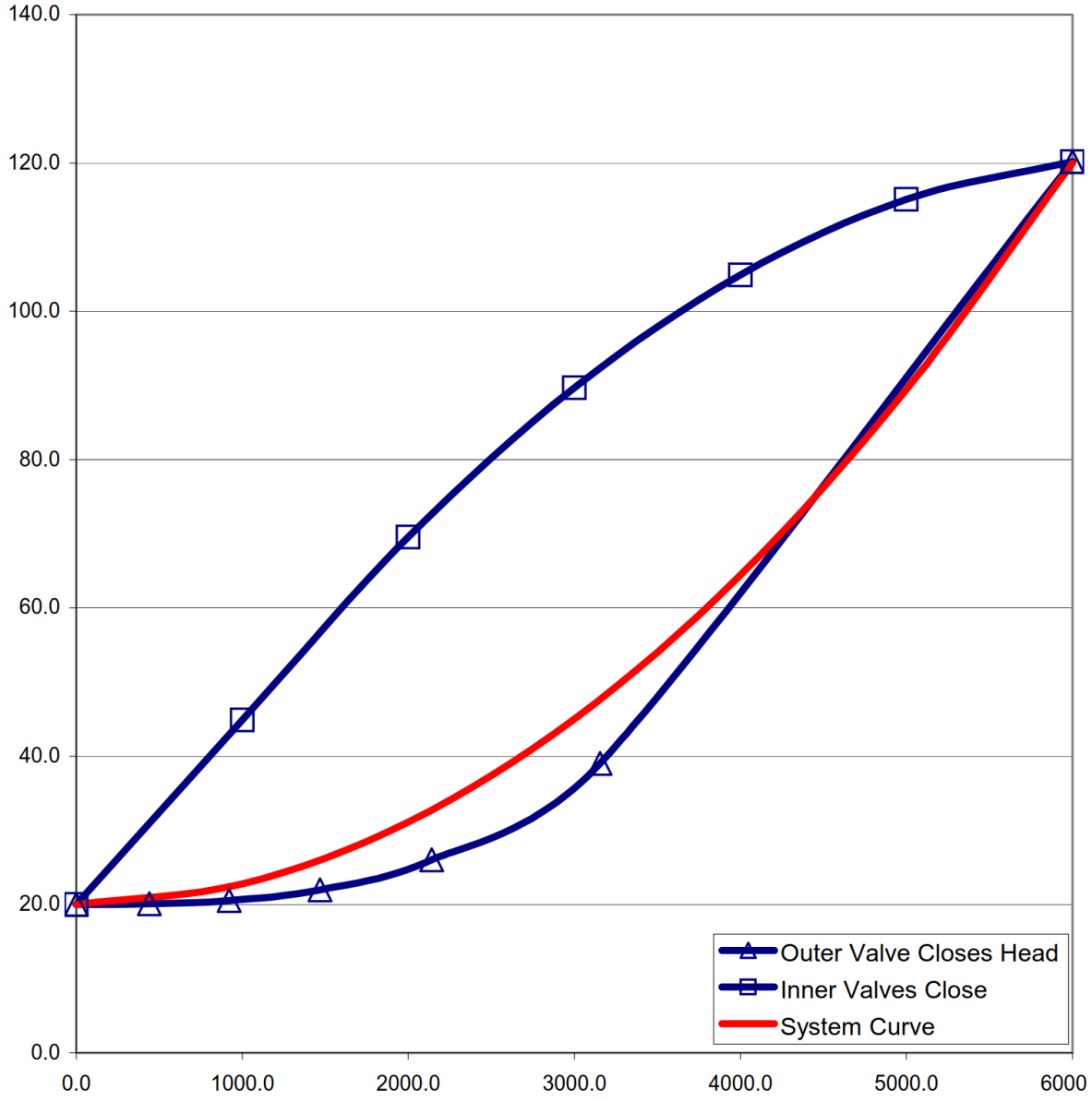


Once again, we are operating above the control curve



We can plot all of these possible operating points and end up with the *control area*.

Another Control Area Example



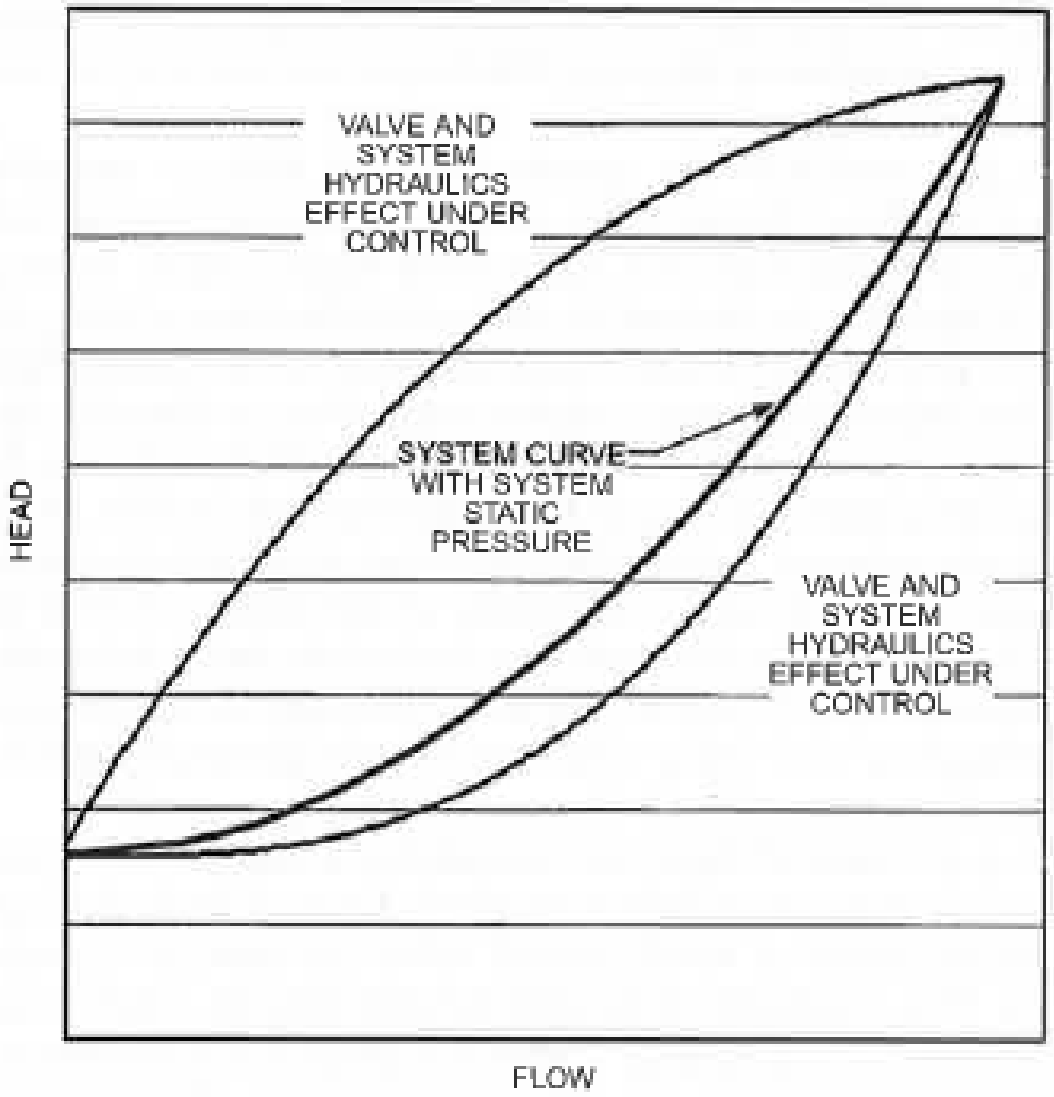


Fig. 13 System Curve with System Static Pressure (Control Area)

Flow will be at 50% are less the majority of the time with typical load profiles

2012 ASHRAE Systems and Equipment Handbook, p 13.9

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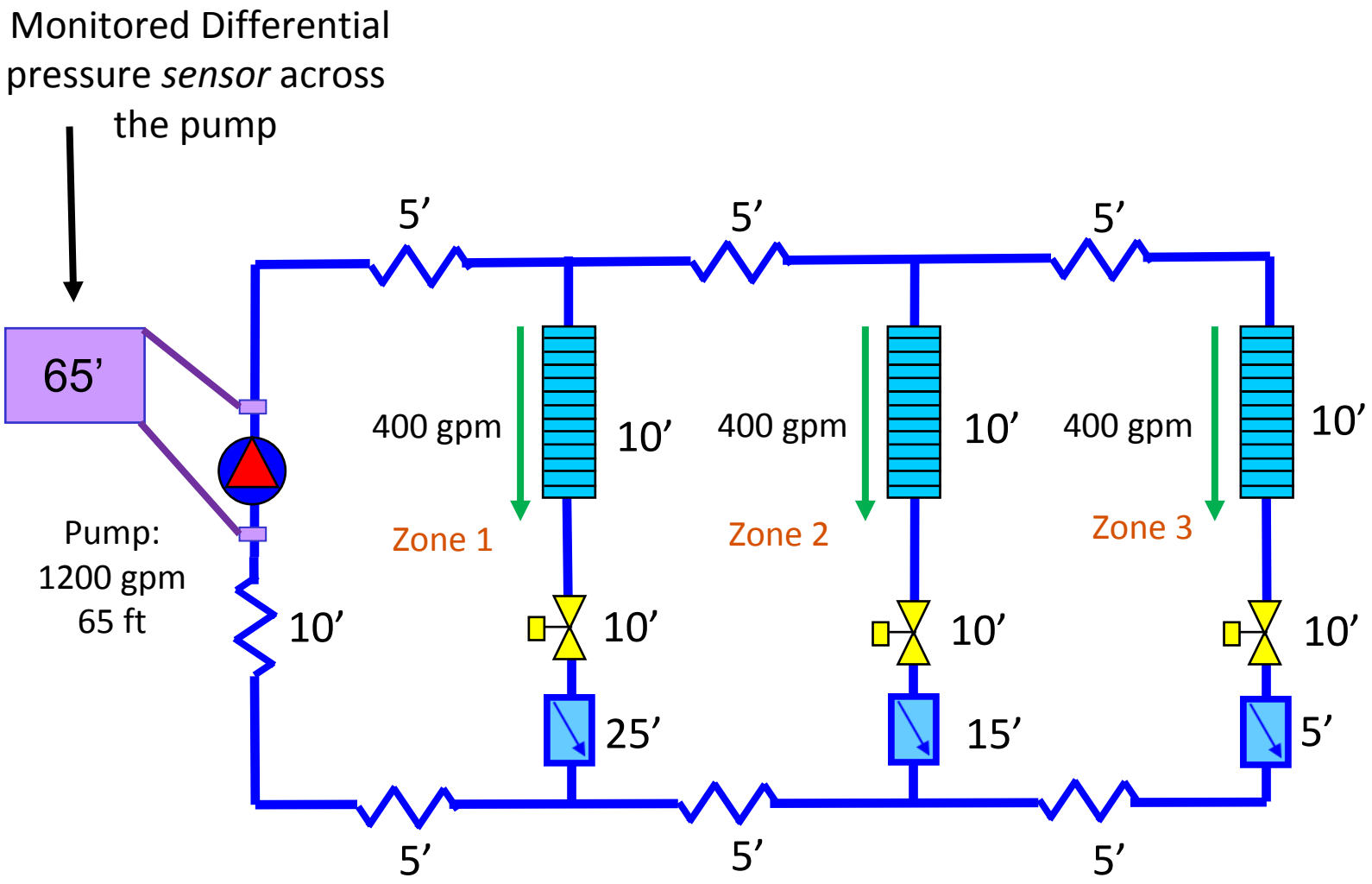
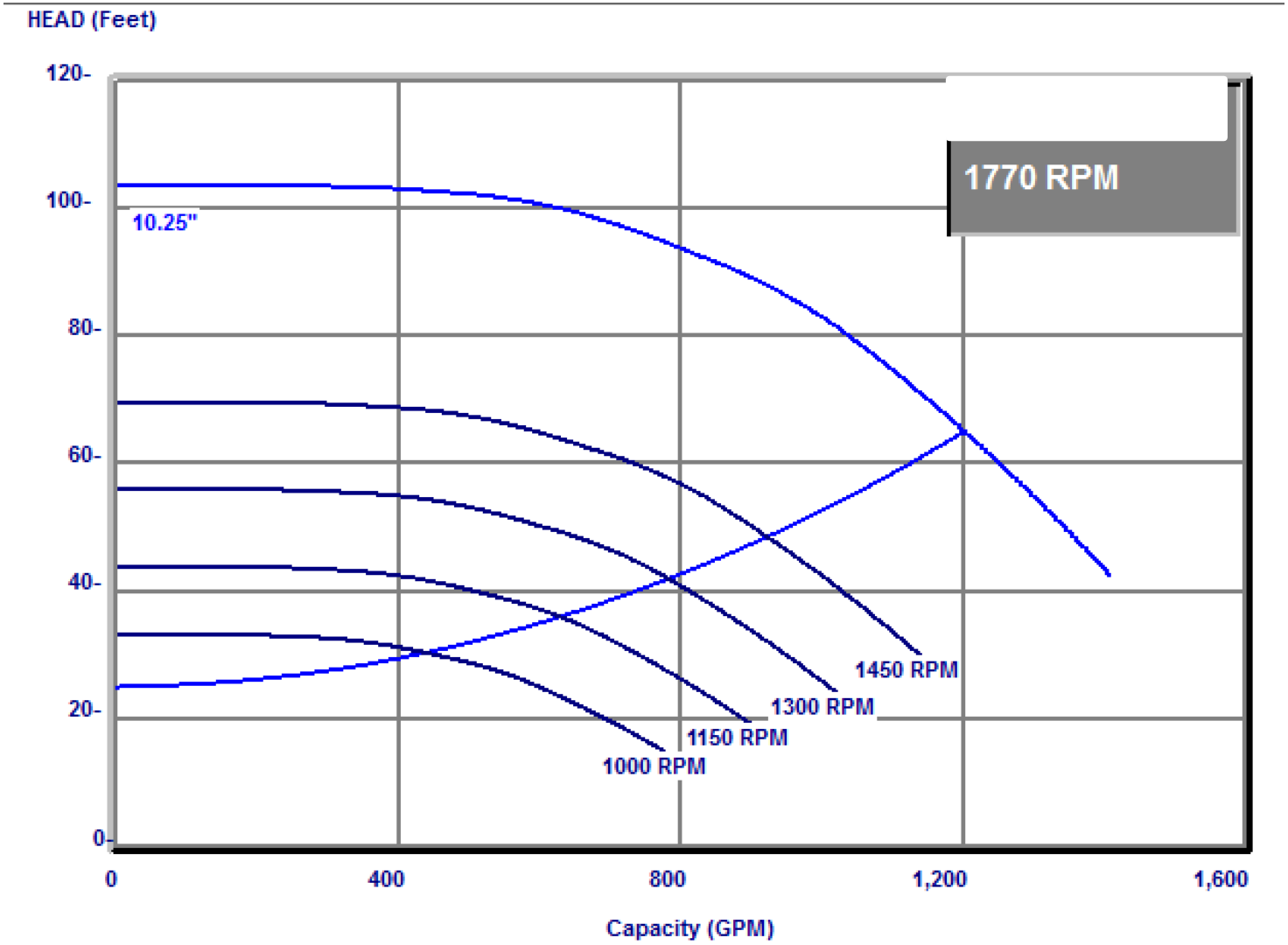
Pump Head Control

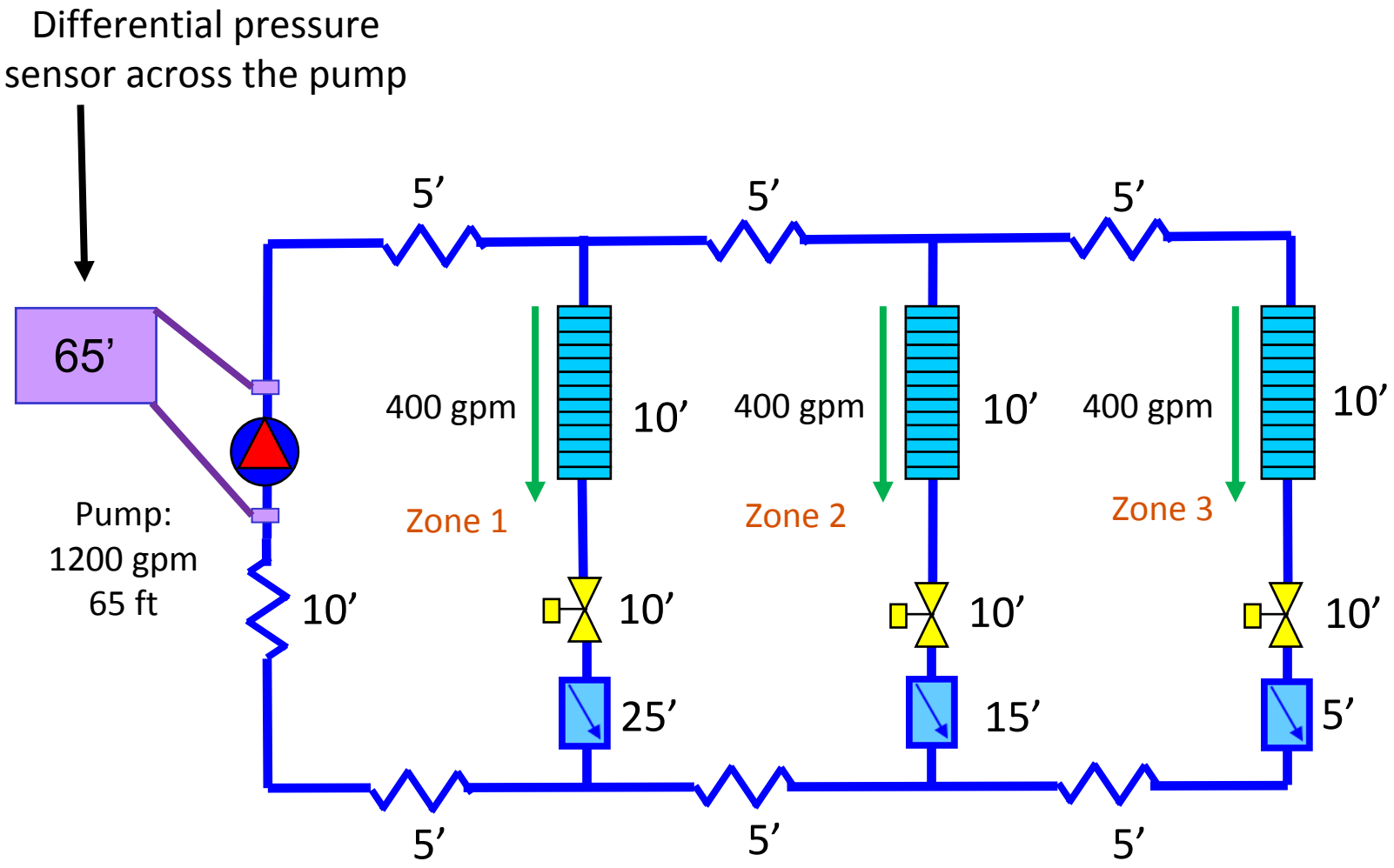




There is a unique speed for each head point on the control curve

Control Curve Pump Control will operate on the control curve

Pump Head Control



- Works with any drive manufacturer
- Works with any pump (as we will see, some pumps are not suitable for sensorless pump control)

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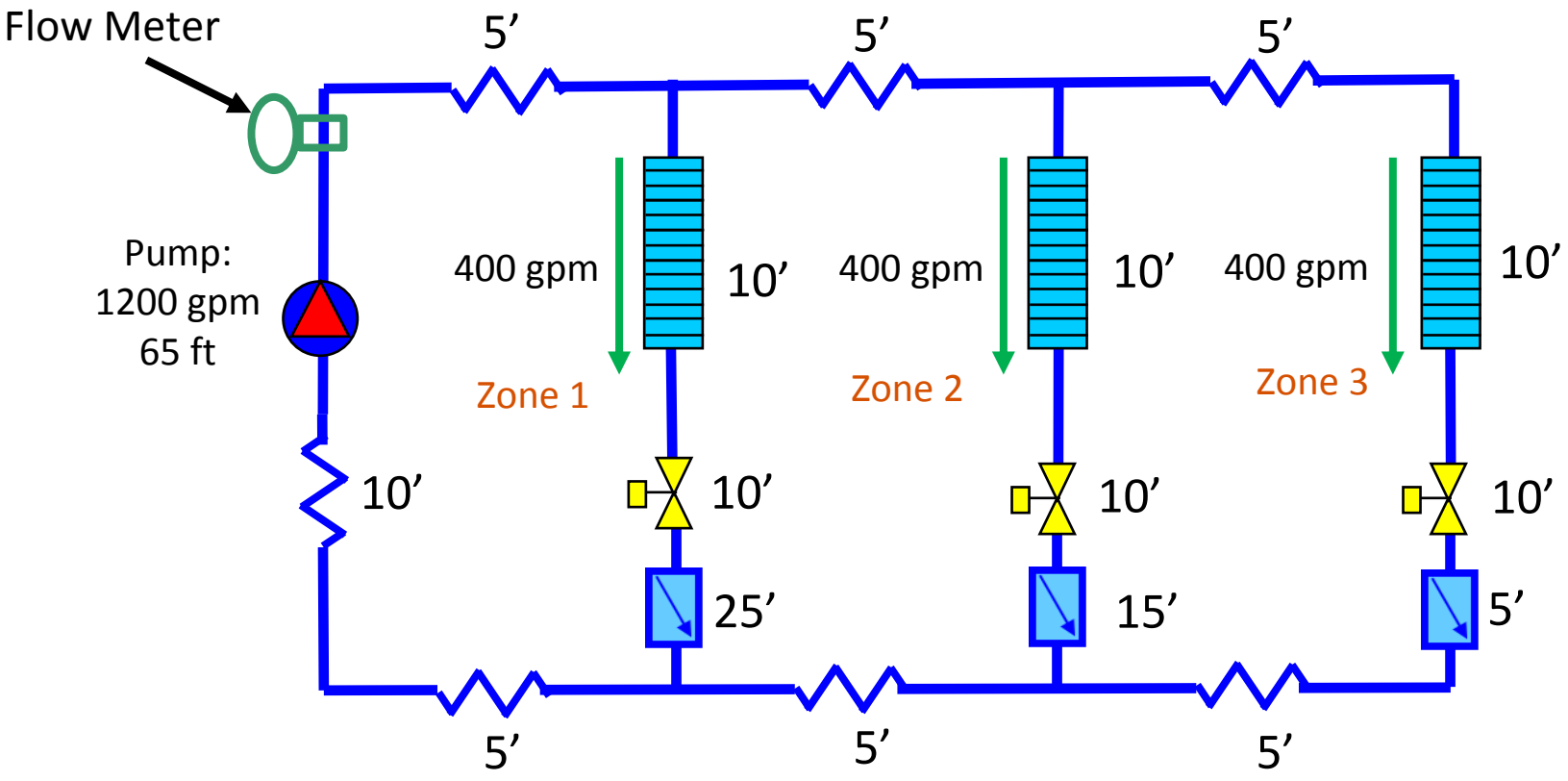
Control Curve Pump Control (with local flow measuring device)



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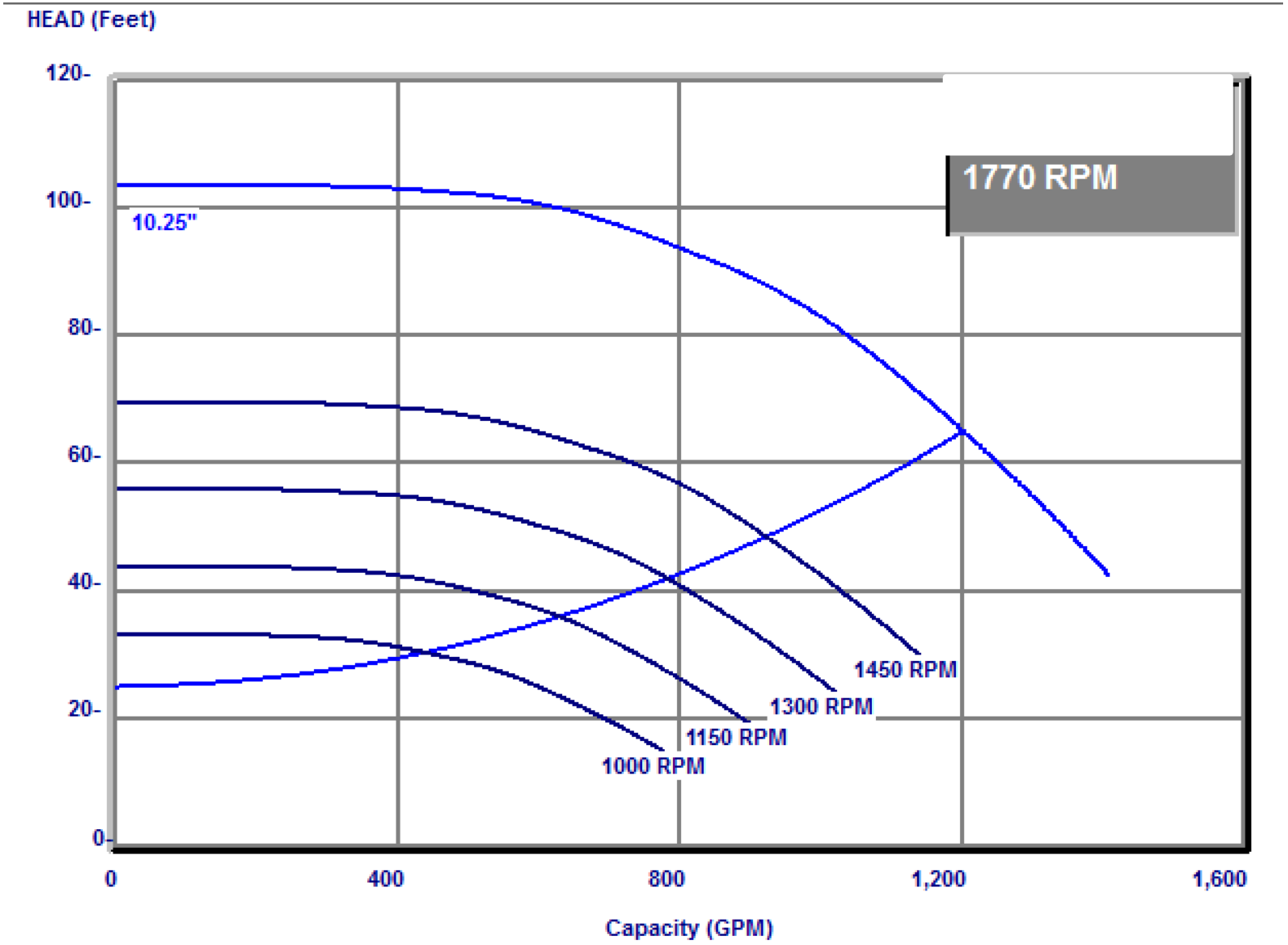

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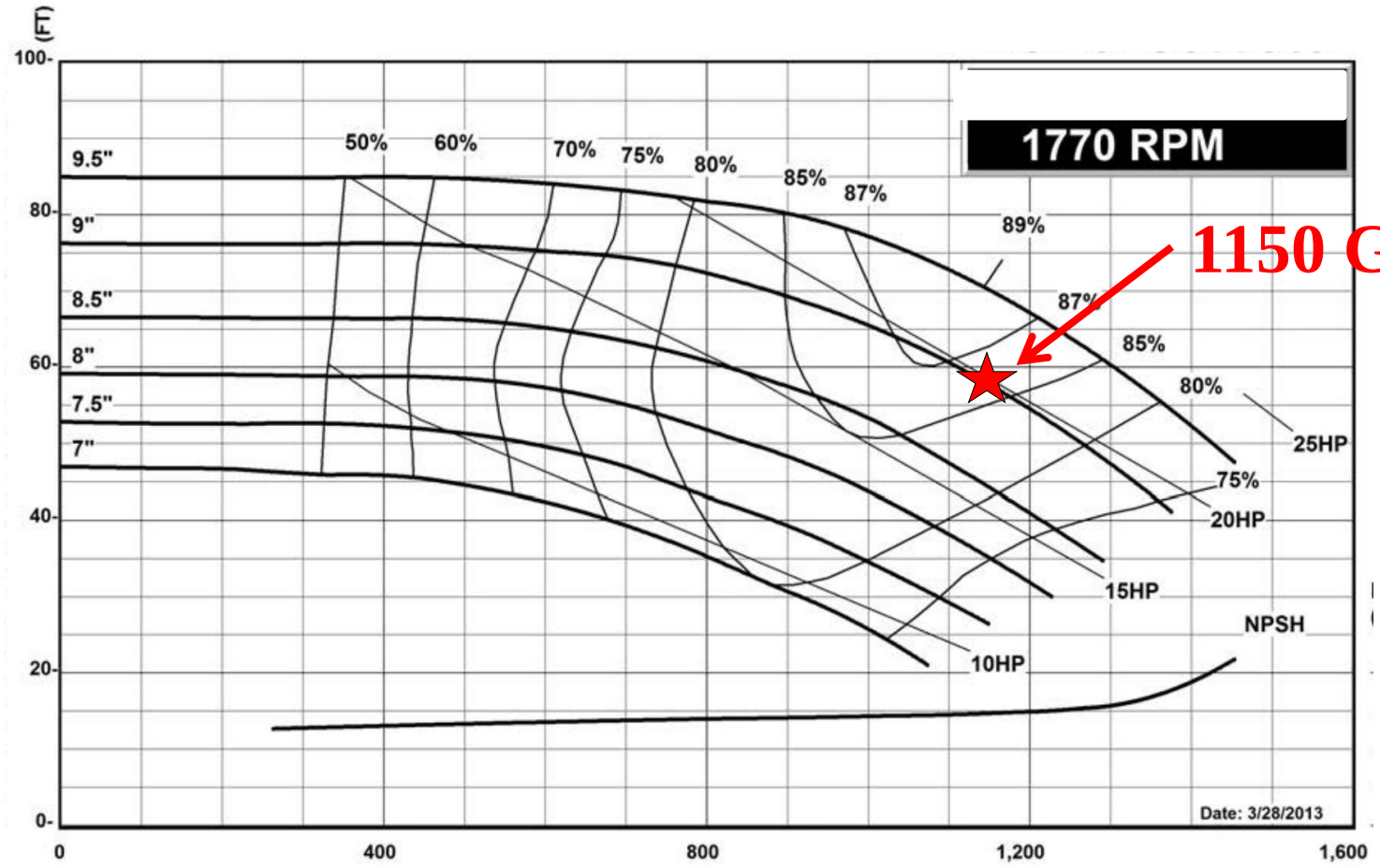
Sensorless Pumping (Curve Control)

Sensorless Pumping

Sensorless pumping continuously does the following:

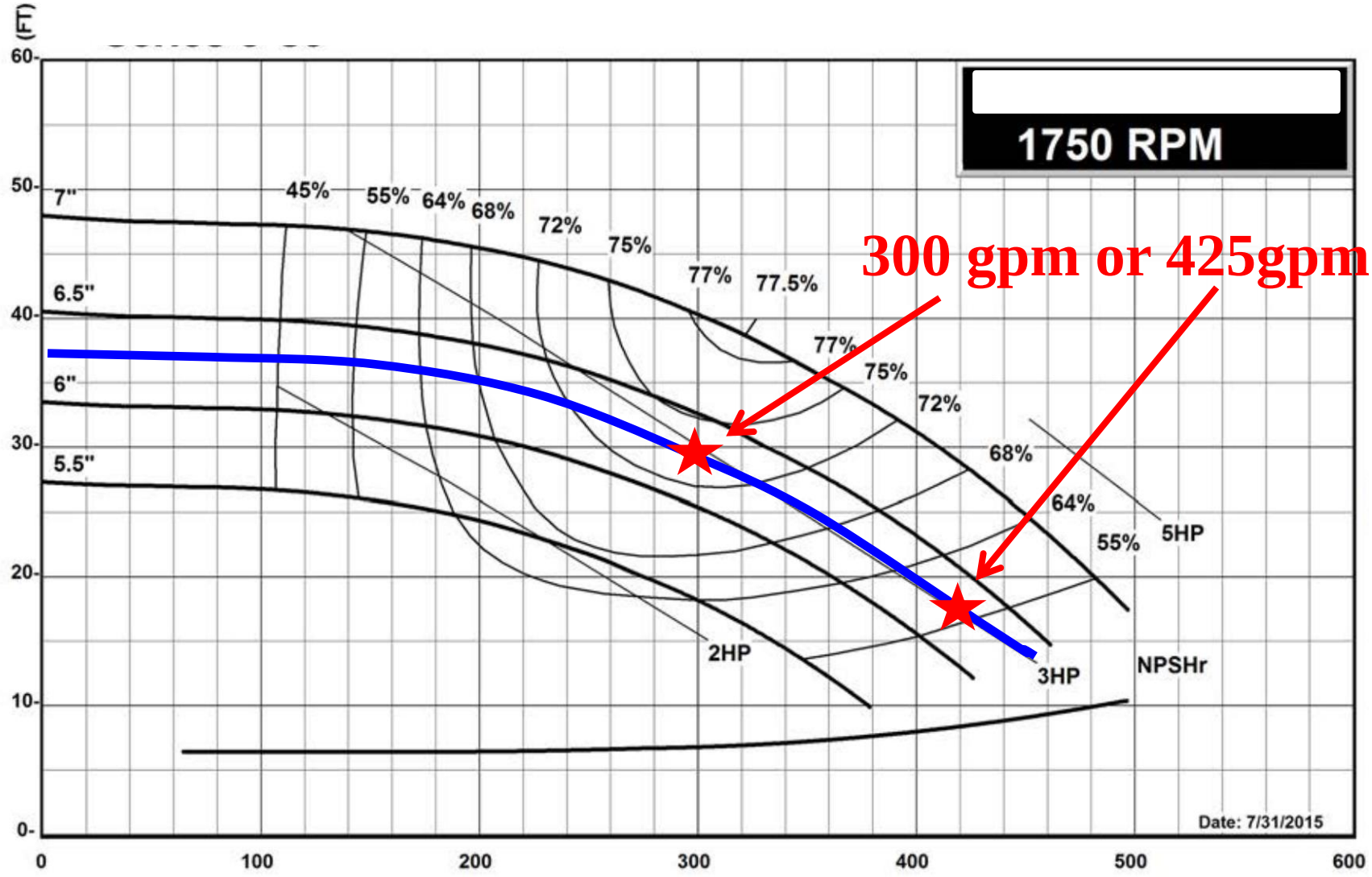
1. **Flow calculation (from RPM and HP)**
2. **Uses this flow to set the new RPM based on the control curve**

Sensorless Flow Calculations



With 9” impeller, at 1770 RPM and 20 HP (both read from the VFD), what is our flow?

Sensorless Flow Calculations

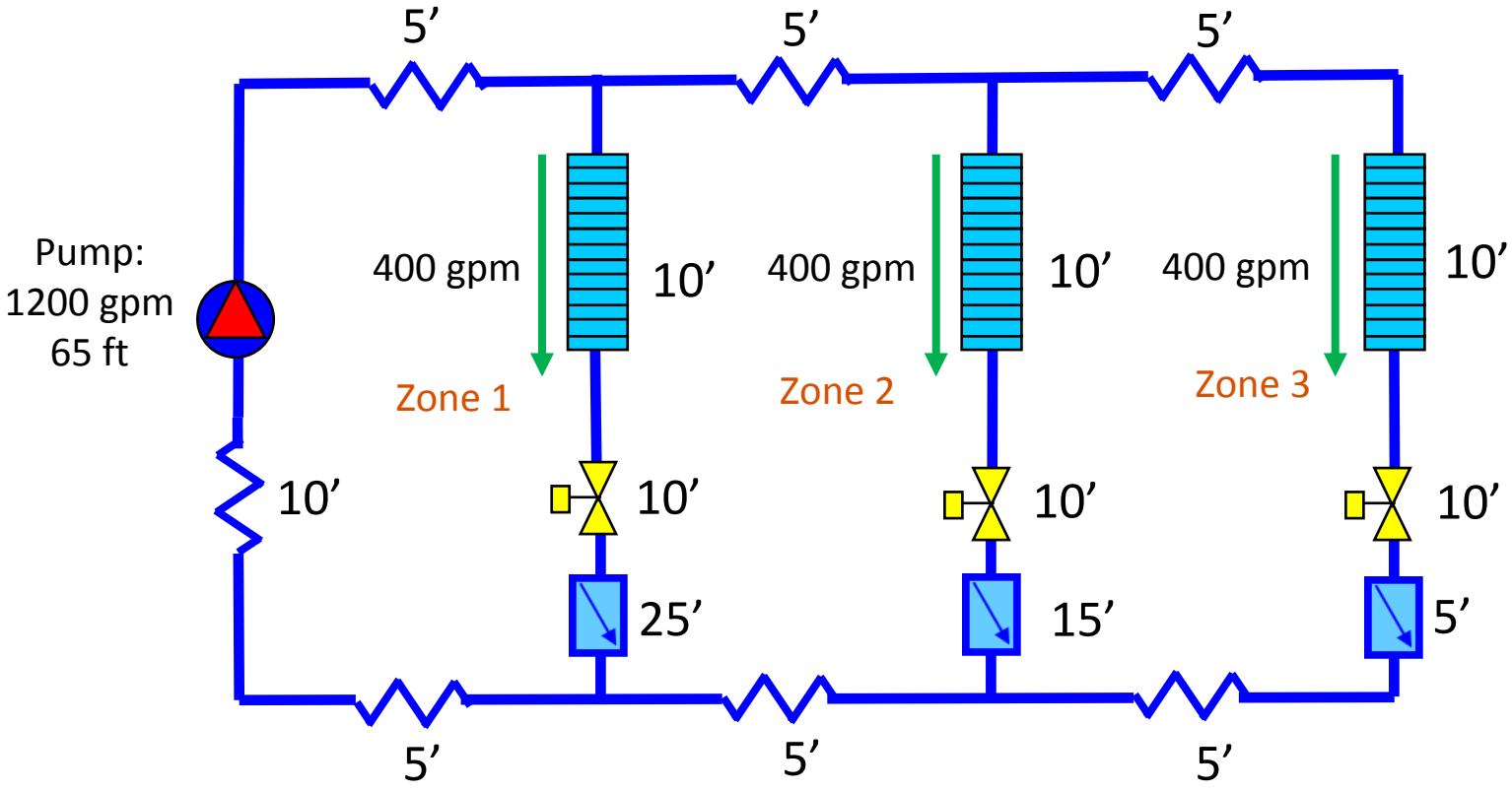


With 6.25” impeller, at 1750 RPM and 3 HP (both read from the VFD), what is our flow?

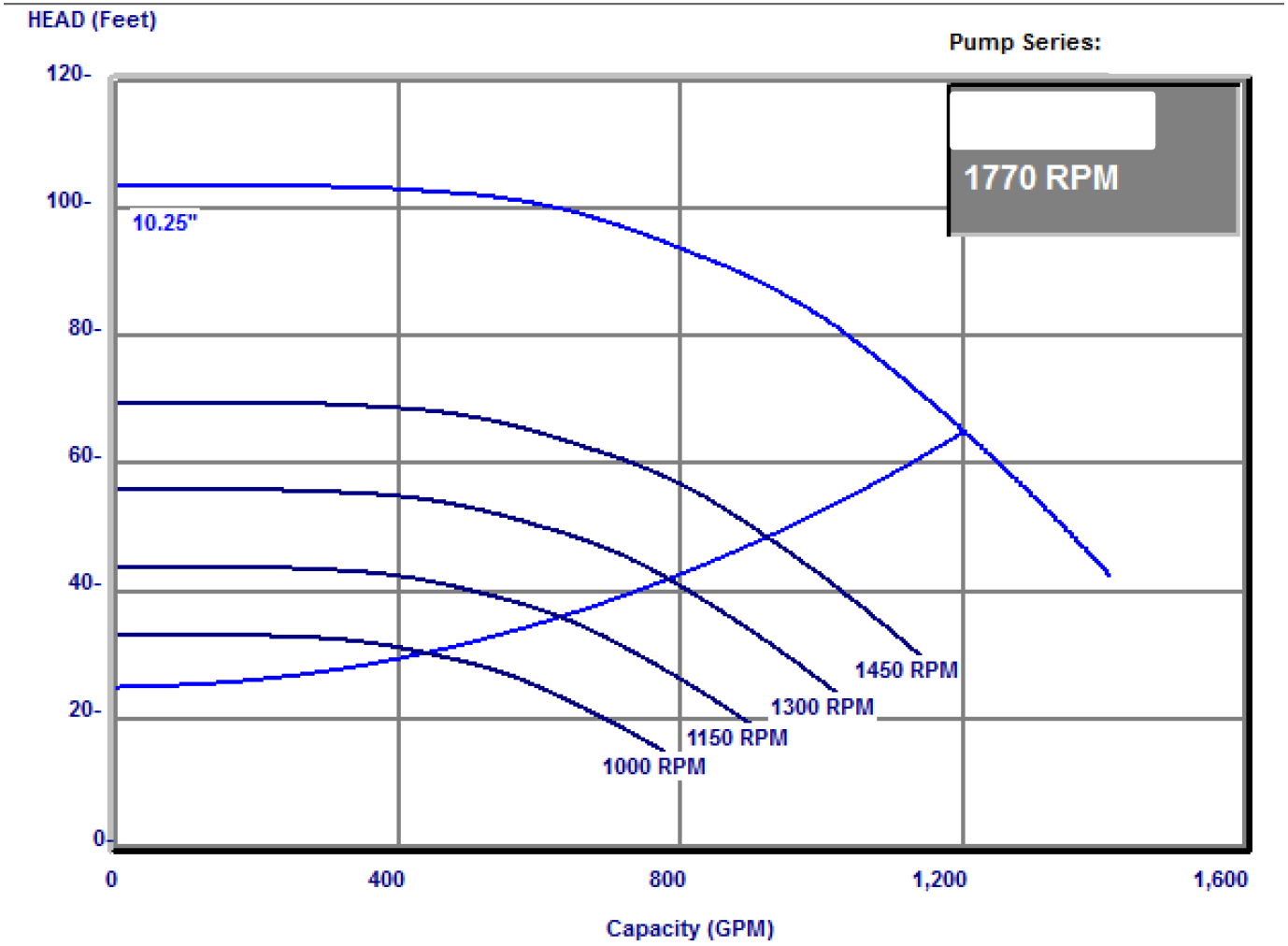
This pump isn’t suitable for sensorless pumping in certain flow ranges

Pump Control (Sensorless)*

- Sensorless control head = 25 ft
- No external sensors or wires are needed
- Flow limiters are used



*** Sensorless Pumps default to 40% TDH**



There is a unique speed for each flow point on the control curve

Sensorless pumping continuously does the following:

1. Flow calculation (from RPM and HP)
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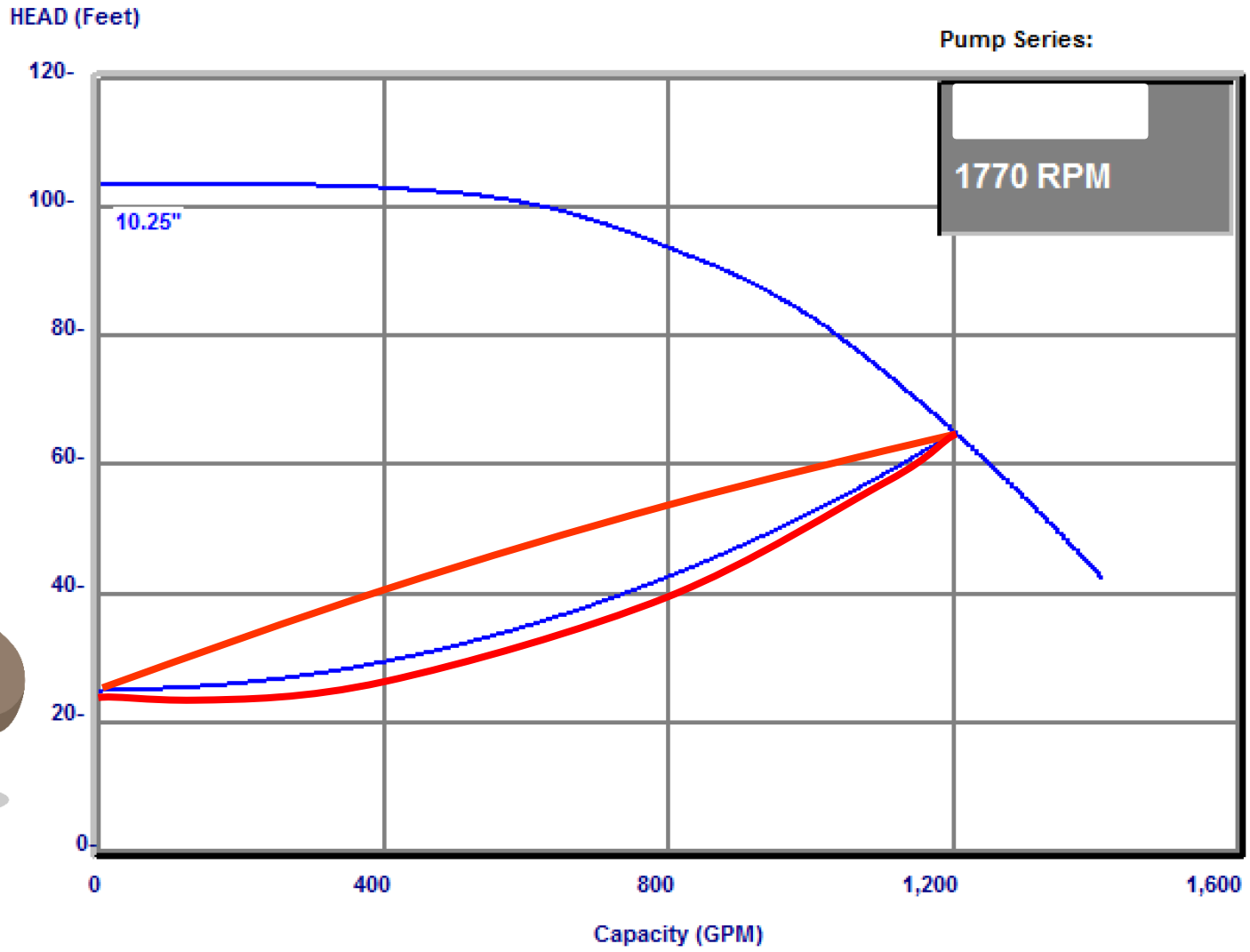
A sensorless pump operates on the control curve



The control area of our system is shown in red.

Since Control Curve Pump Control operates on the control curve, there will be times when a coil is short of flow. We call this a **“miss”.**

Flow Tolerance- ASHRAE

TERMINOLOGY

Balanced System. A system designed to deliver heat transfer required for occupant comfort or process load at design conditions. A minimum heat transfer of 97% should be provided to the space or load served at design flow. The flow required for minimum heat transfer establishes the system's flow tolerance. The fluid distribution system should be designed to allow flow to maintain the required tolerance and verify its performance.

Heating

140 degree supply 30 degree delta T flow tolerance is 10%

Cooling

45 degree supply 12 degree delta T flow tolerance is 10%

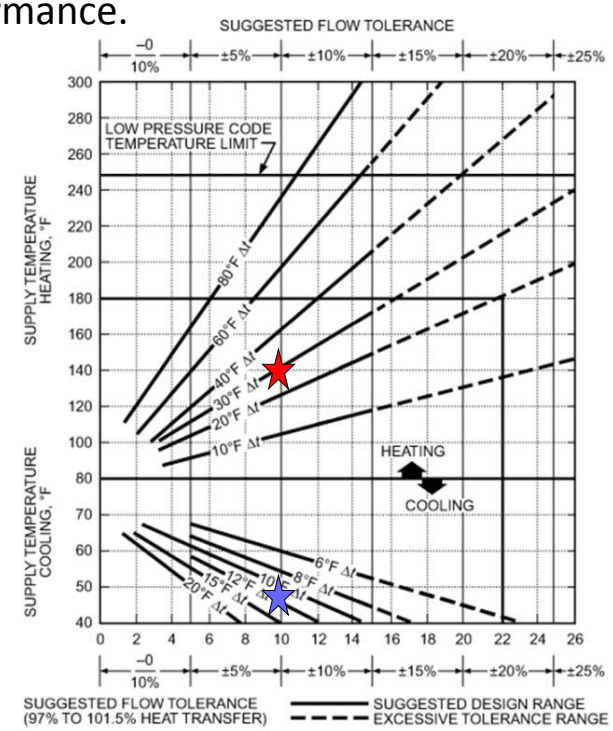
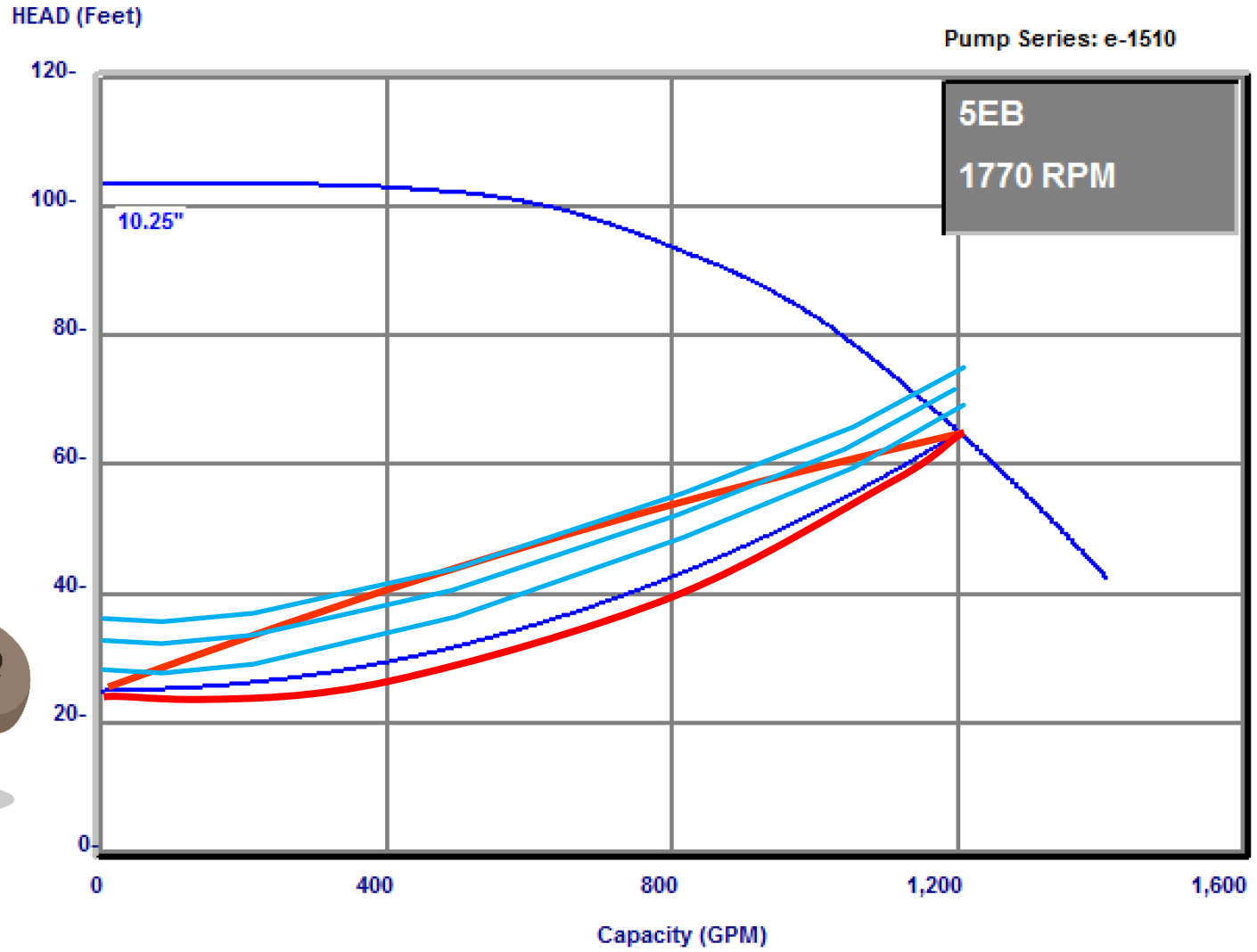


Fig. 34 Recommendations for Coil Flow Tolerance to Maintain 97% Design Heat Transfer
(Carlson 1981)

2015 ASHRAE Handbook, HVAC Applications

Control Head Creep: The phenomenon of control head increasing in value over months and years in an installed variable-speed pumping system. This can occur when the pump control system underflows coils, causing coil flow “misses”.

Someone increases the control head value to fix problems



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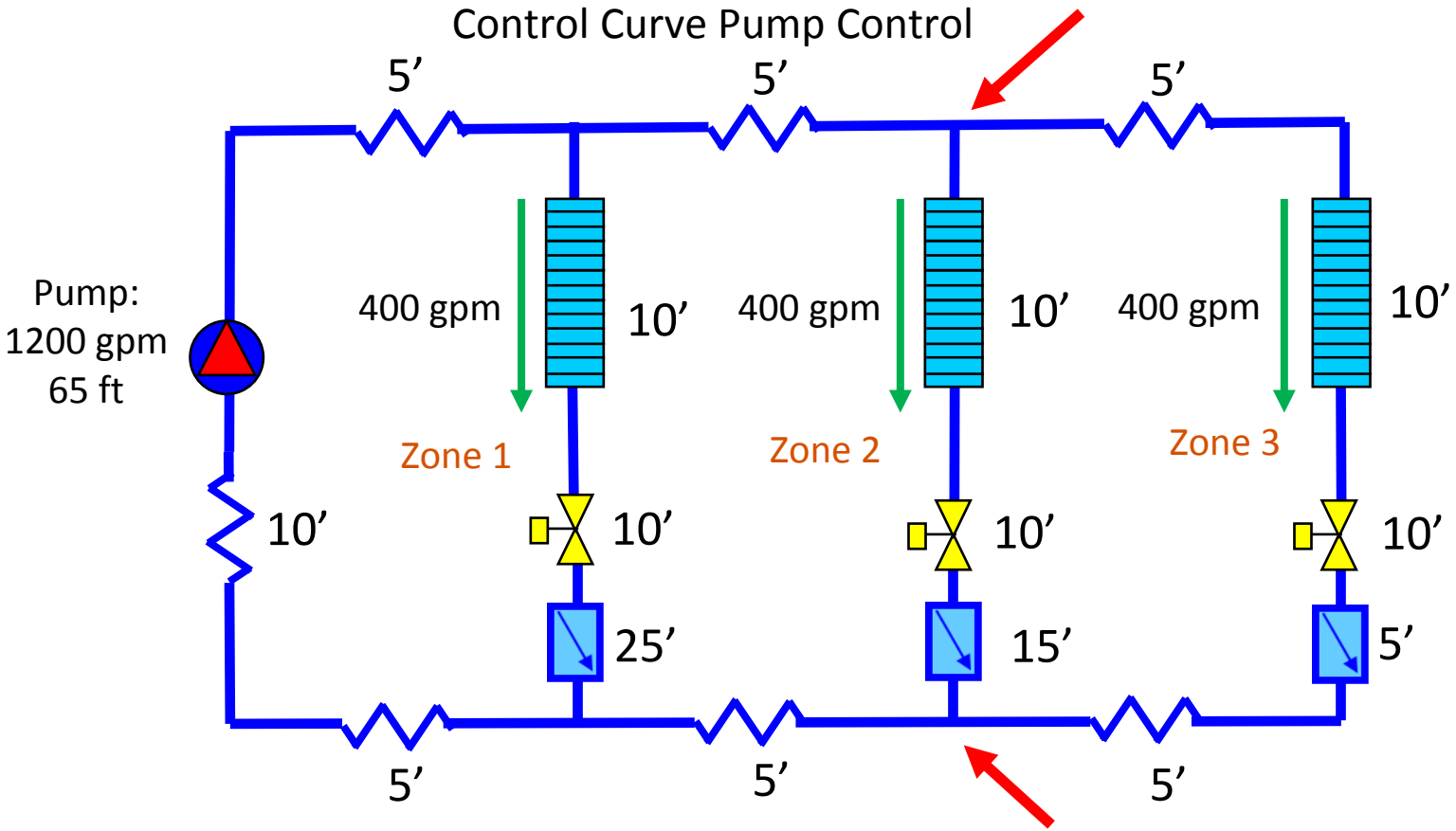

Guidelines for Control Curve Pump Control (e.g. sensorless) with Flow Limiters or PICVs:

Specify the control head to equal the pressure drop through the last zone, including the piping loss between the last tees.

This is based on typical systems to give you a reasonable flow tolerance with the last 2 zones at 100% demand. This guideline will help minimize the effect of misses.

Note: depending on the system, this guideline may not meet 90.1 – 30% kW savings requirement

Control Curve (Sensorless, DP, Flow meter) Pump Control

Percent Load	*Hours per year*	*Flow*	*Pump Head*	*HP required*
100%	43.2	1200	65	29
75%	1814.4	900	52	17
50%	1944	600	43	10
25%	518.4	300	37	4

Annual operating cost = $3190* (based on 35 ft control head)

PLEV (IPLV) load profile, 6 months of operation per year

Do we meet ASHRAE 90.1?(30% Watt at 50% Flow)

$$\frac{10\ hp}{29\ hp} = 35\% \leq 30\% Watts$$

*based on 8 cents per kWh

Pump Control- Rules of Thumb!

Control Strategy	When to consider	When to be cautious	Energy Savings	Comments
Sensorless	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded. Some pumps are incompatible with Sensorless due to their kW-flow relationship on the pump curve.***	Better than constant speed.	Does an estimate of flow. Limited choice of drive manufacturers. Uses a controller-calculated set point that assumes all zones are equally loaded.
Control Curve Control	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded.***	Better than constant speed.	Works with any drive manufacturer. Uses a DP or flow sensor which is more accurate than Sensorless flow calculations. Works with any pump (some pumps are not suitable for Sensorless).

***be cautious of control valve authority and proportional manual balance in these systems

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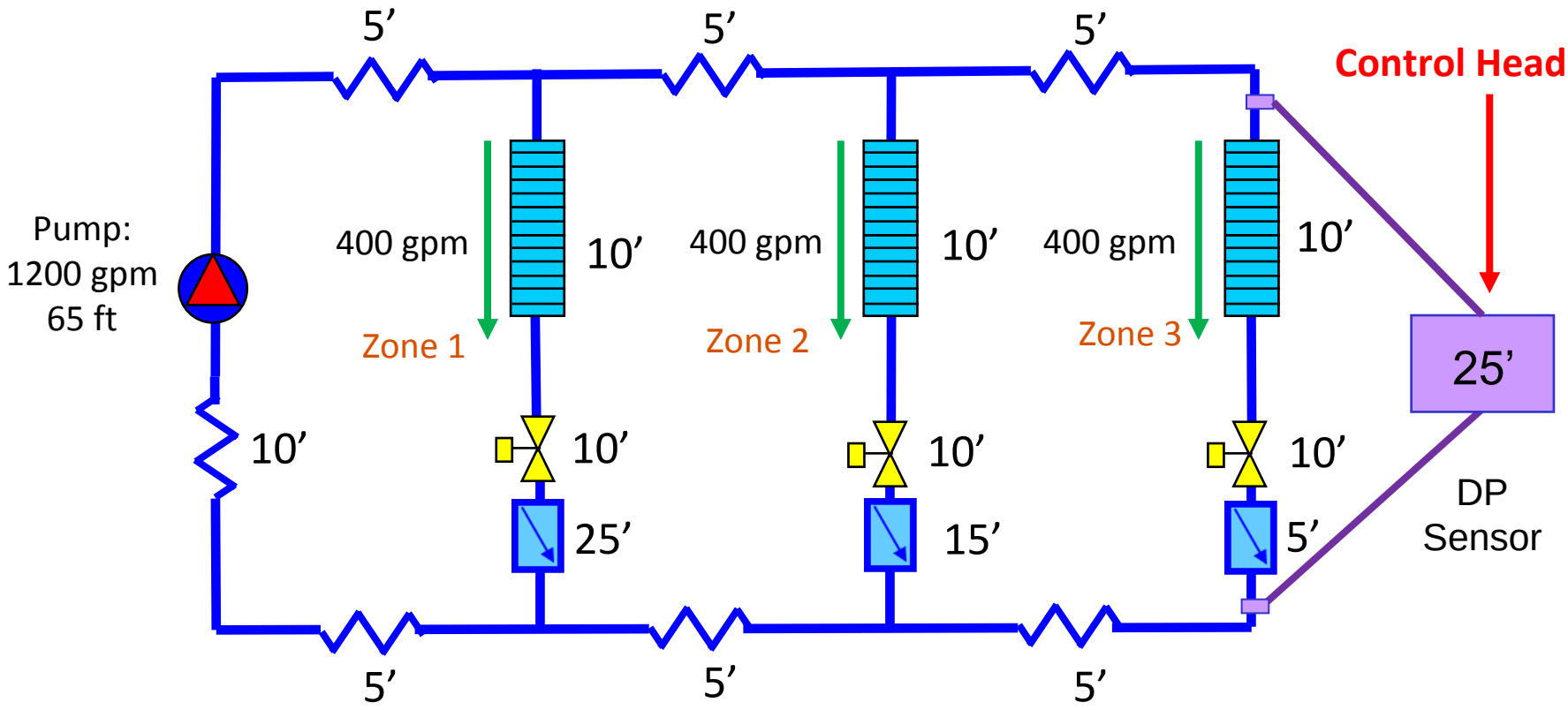
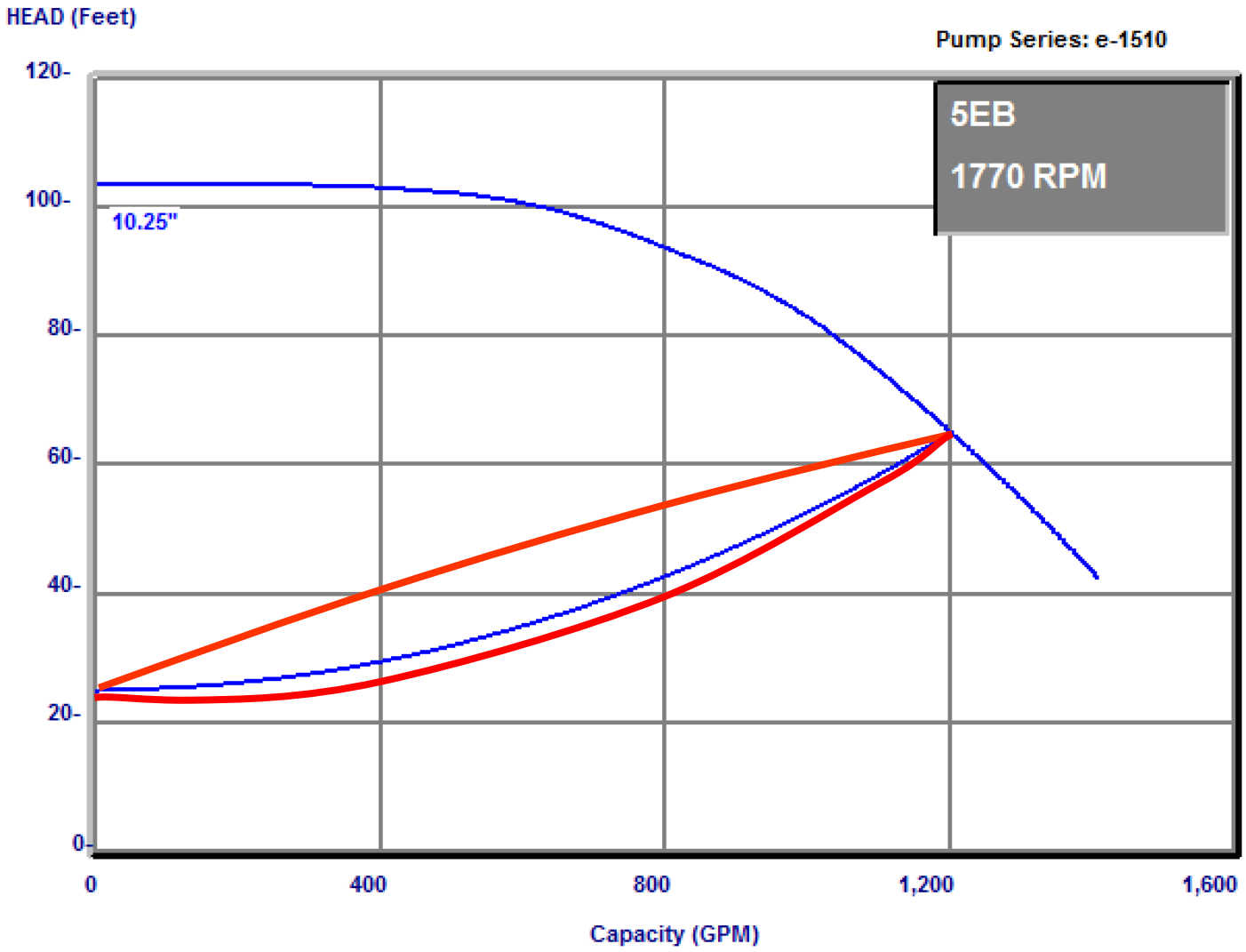
Sensor with fixed DP setpoint

- *Control head* is 25 ft (*pressure drop of coil, control valve and flow limiter*)
- Pump control maintains the control head across DP sensor at all times





Remote DP sensor operates within the control area and does not have “misses”

Sensor with fixed DP setpoint

Percent Load	*Hours per year*	*Flow*	*Pump Head*	*HP required*
100%	43.2	1200	65	29
75%	1814.4	900	48	16
50%	1944	600	35	8
25%	518.4	300	28	3

Annual operating cost = $2804*

PLEV (IPLV) load profile, 6 months of operation per year

Do we meet ASHRAE 90.1?(30% Watt at 50% Flow)

$$\frac{8\ hp}{29\ hp} = 28\% \leq 30\% Watts$$

*based on 8 cents per kWh

Pump Control- Rules of Thumb!

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Remote DP	Hot water. Chilled water with pump motors ≤ 5HP.	***	Better	Uses a true measured remote set point. 90.1-2010/13 does not require variable-speed pumping in hot water systems.

***be cautious of control valve authority and proportional manual balance in these systems

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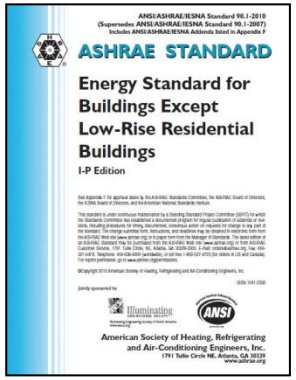
ANSI/ASHRAE/IES Standard 90.1-2010/13

HEATING, VENTILATING, AND AIR CONDITIONING



SECTION 6.5
Prescriptive Path

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6.5.4.1 Hydronic Variable Flow Systems. HVAC pumping systems ….

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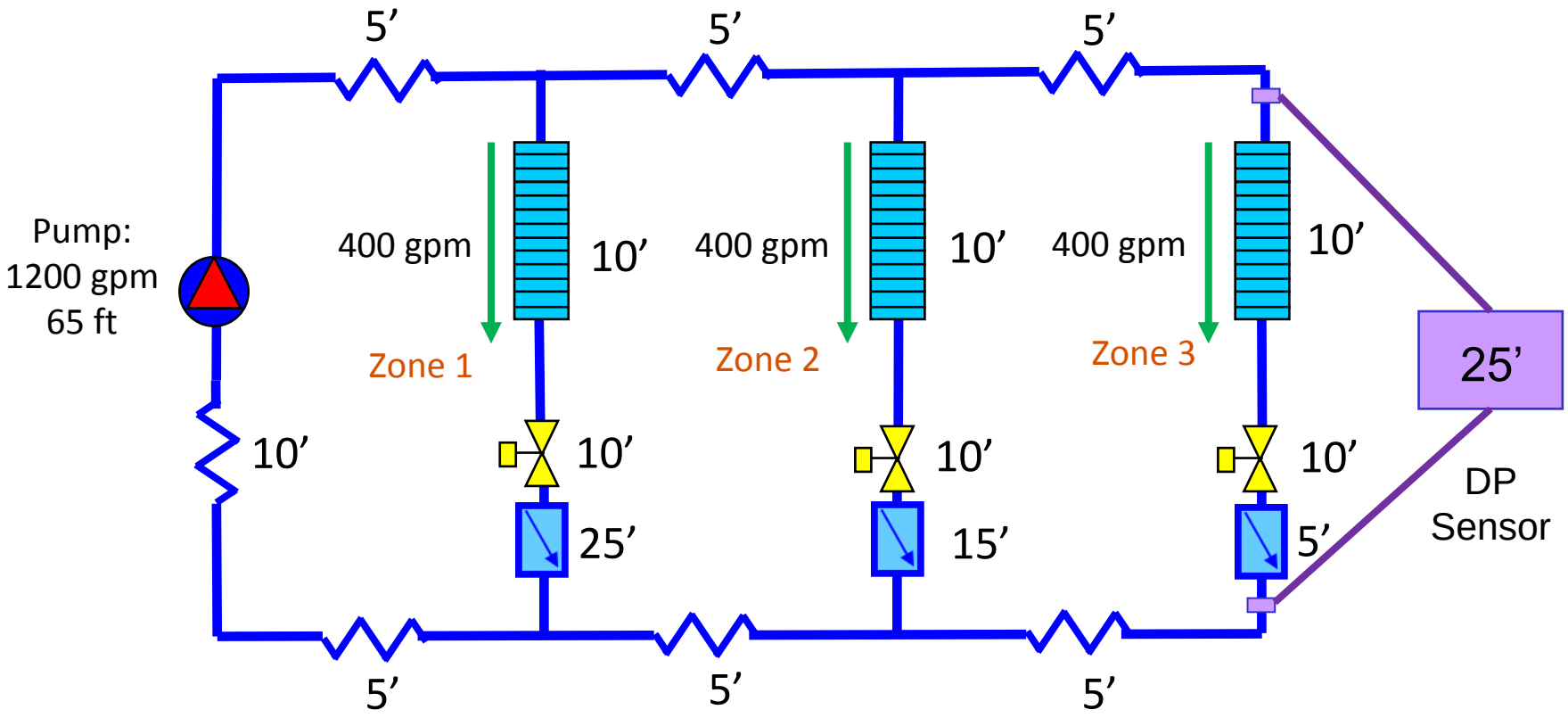
Exceptions:

a. Systems where the minimum flow is less than the minimum flow required by the equipment *manufacturer* for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.

b. Systems that include no more than three control valves.

Remote DP with Valve Position Reset

- Setpoint is 25 ft at full load, and is reset downward at part load
- Required by ASHRAE 90.1-2010/13 in chilled water if pump motors exceed 5HP and DDC controls are used
- Must be able to monitor valve position of all control valves- (DDC Poling time- 90 secs?)
- Setpoint is reset to keep one control valve *nearly* wide open



Sensor with DP Setpoint Reset

Percent Load	*Hours per year*	*Flow*	*Pump Head*	*HP required*
100%	43.2	1200	65	29
75%	1814.4	900	41	14
50%	1944	600	24	5
25%	518.4	300	13	2

Annual operating cost = $2225*

PLEV (IPLV) load profile, 6 months of operation per year

Do we meet ASHRAE 90.1?(30% Watt at 50% Flow)

$$\frac{5\ hp}{29\ hp} = 17\% \leq 30\% Watts$$

Model based on 10 ft of control head across control valve

*based on 8 cents per kWh

Pressure Independent Control Valve

CONTROL PANEL

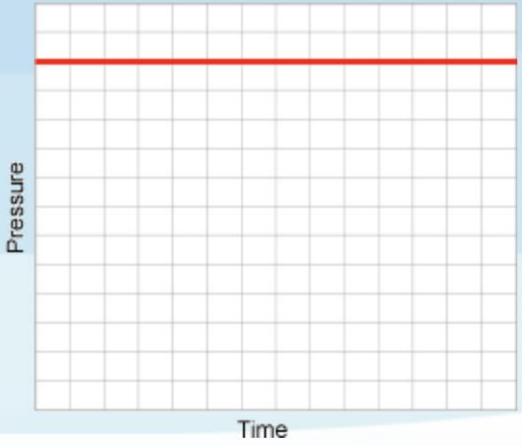
Differential Pressure

Min Max

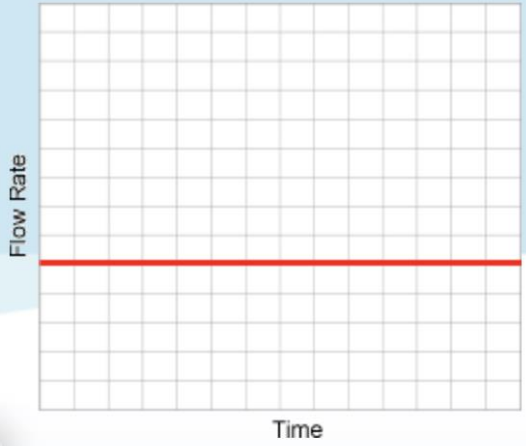
Presetting GPM Dial

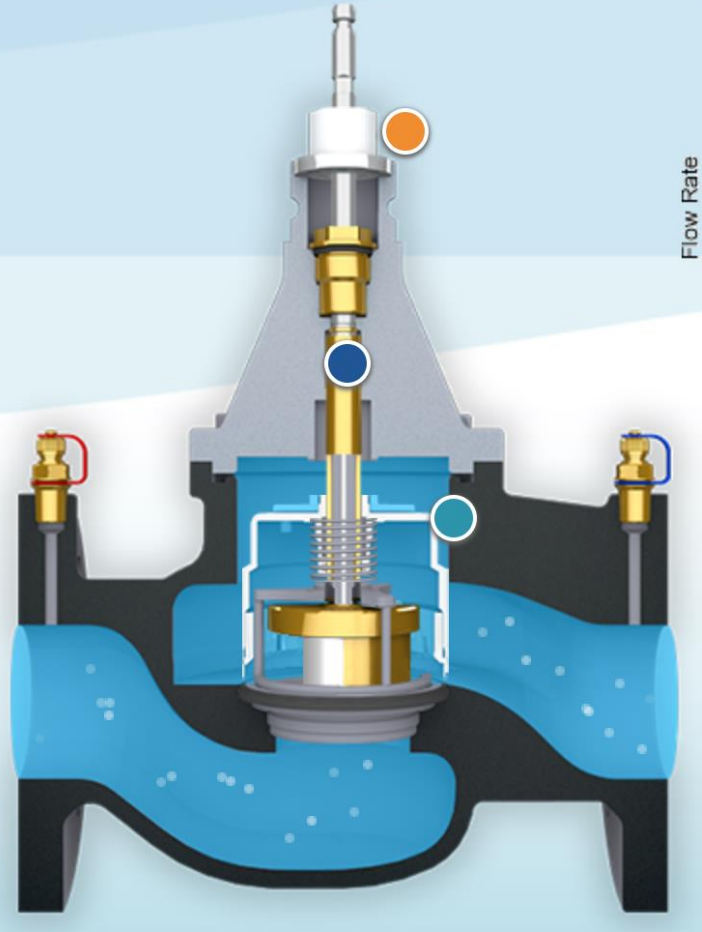
Stem Position

Differential Pressure



Flow Rate





Pressure Independent Control Valve

CONTROL PANEL

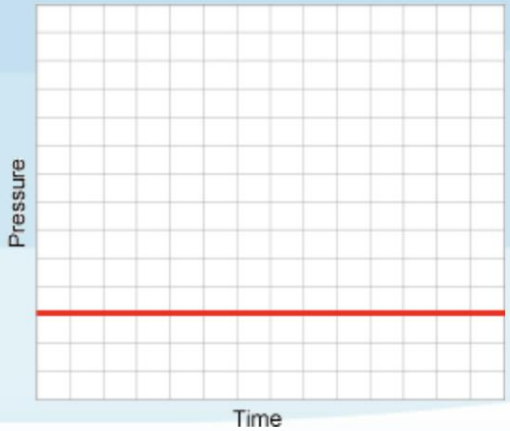
Differential Pressure

Min Max

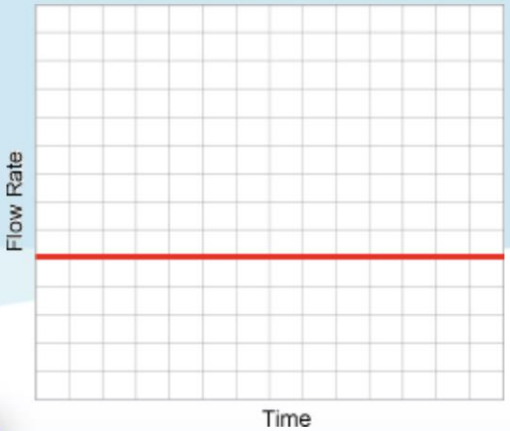
Presetting GPM Dial

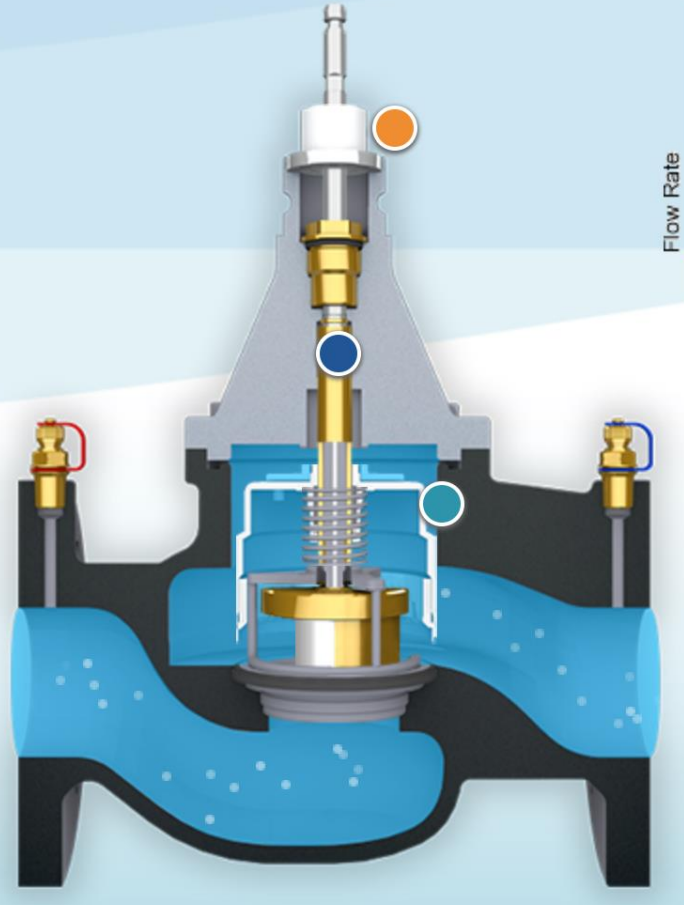
Stem Position

Differential Pressure



Flow Rate





Pump Control- Rules of Thumb!

Control Strategy	When to consider	When to be cautious	Energy Savings	Comments
Sensorless	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded. Some pumps are incompatible with Sensorless due to their kW-flow relationship on the pump curve.***	Better than constant speed.	Does an estimate of flow. Limited choice of drive manufacturers. Uses a controller-calculated set point that assumes all zones are equally loaded.
Control Curve Control	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded.***	Better than constant speed.	Works with any drive manufacturer. Uses a DP or flow sensor which is more accurate than Sensorless flow calculations. Works with any pump (some pumps are not suitable for Sensorless).
Remote DP	Hot water. Chilled water with pump motors ≤ 5HP.	***	Better	Uses a true measured remote set point. 90.1-2010/13 does not require variable-speed pumping in hot water systems.
Remote DP with 90.1 reset	Required by 90.1-2010/13 if chilled water with pump motors > 5HP AND BMS can read control valve position.	Not recommended with PICVs.***	Best	

***be cautious of control valve authority and proportional manual balance in these systems

Outline of Presentation

ASHRAE 90.1 and Variable Speed Pumping

Control Curve and Control Area Review

Control Curve Pump Control Strategy

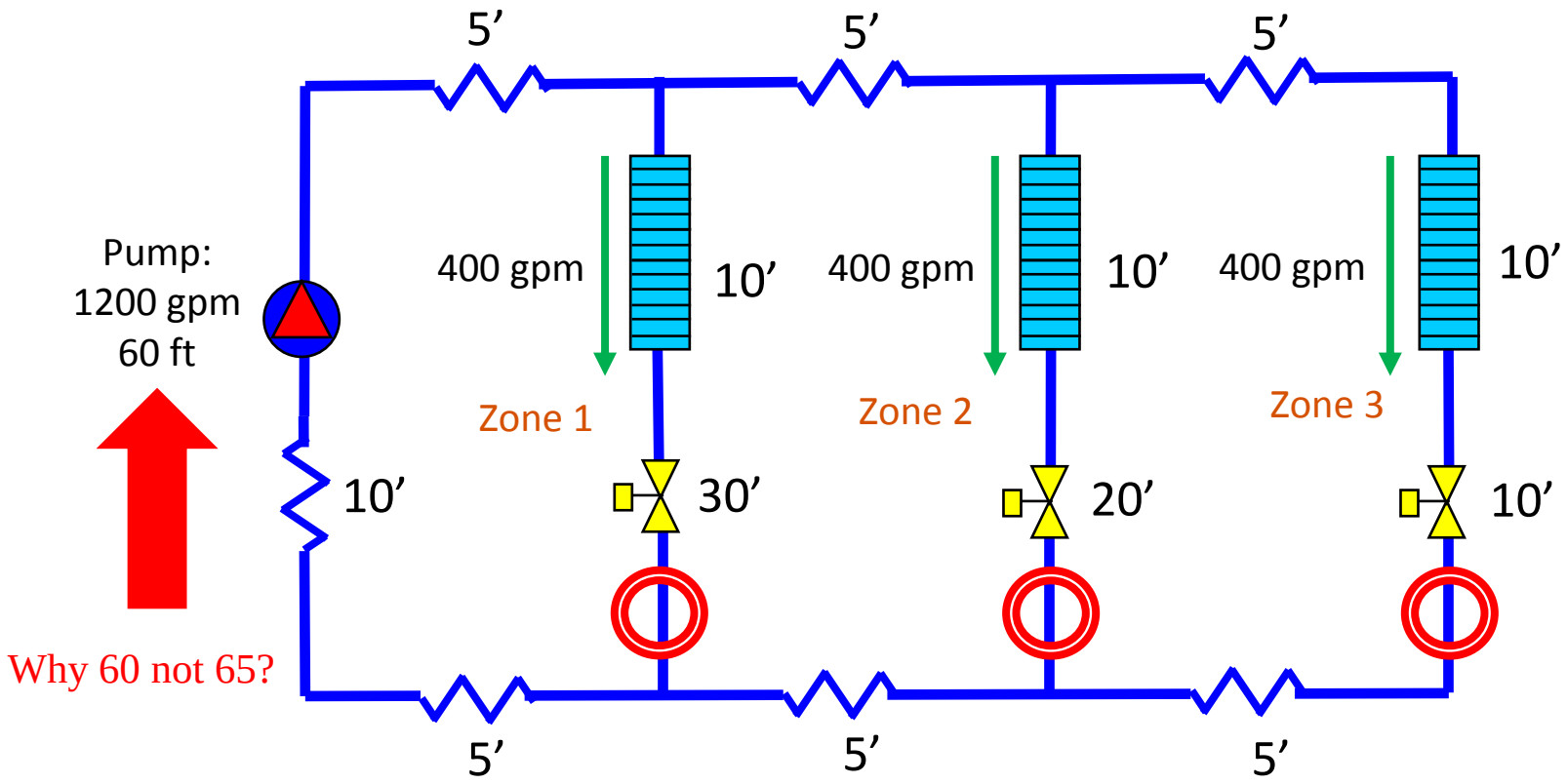
- Pump Head Control
- Full System Flow Sensor
- Sensorless

Control Area Pump Control Strategies

- Remote DP
- Remote DP with valve position reset
- Custom Pump controller

Summary

Example System (shown at full load)- PICV



Pressure Independent Control Valves
(note: flow limiters are no longer needed)
Lowest end of PICV control range: 10 ft

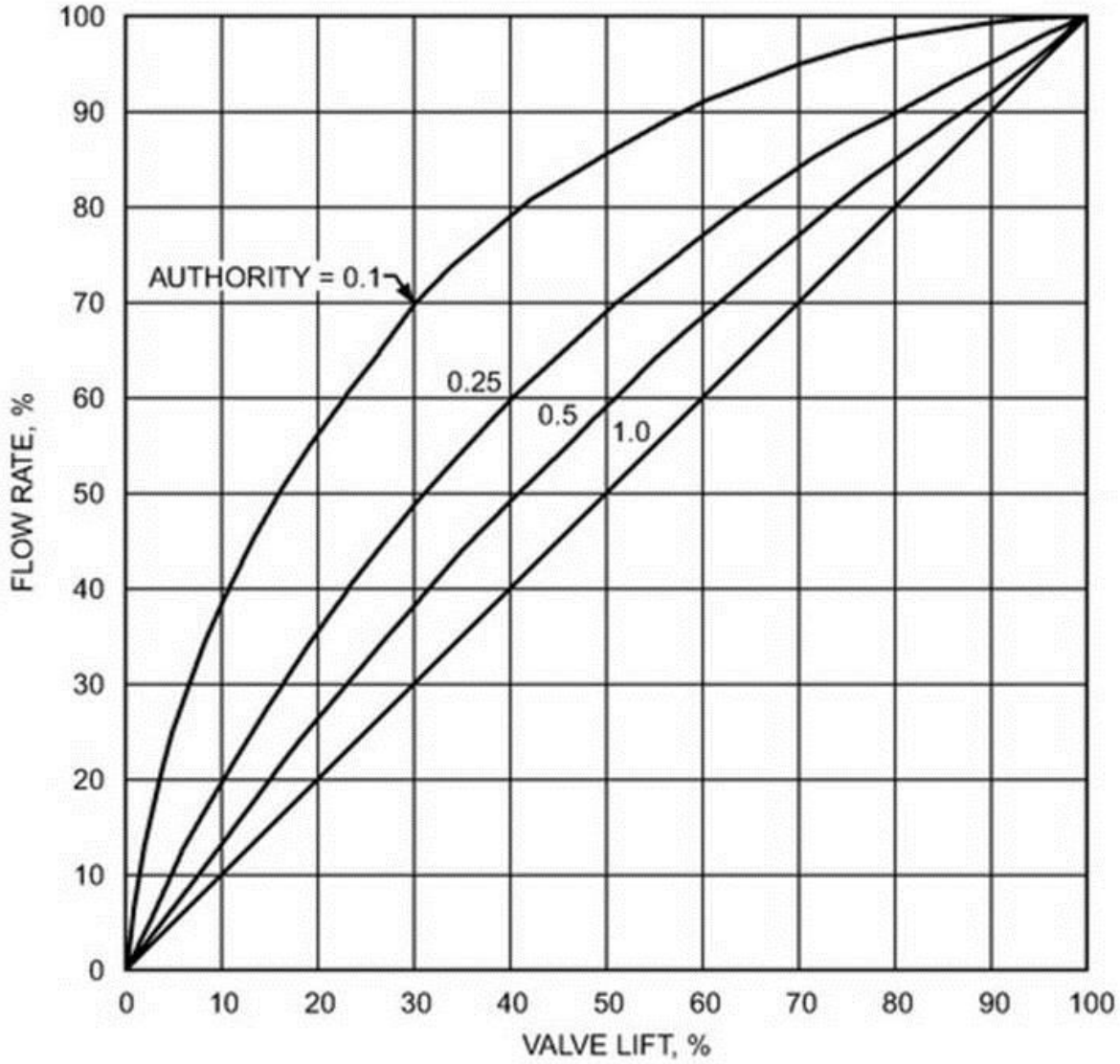


Figure 18. Authority Distortion of Linear Flow Characteristics

Pressure Independent Control Valve

CONTROL PANEL

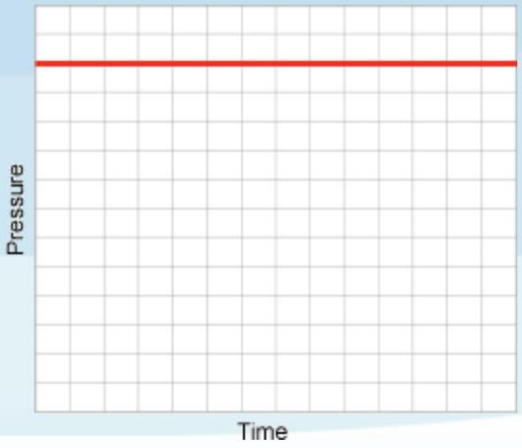
Differential Pressure

Min Max

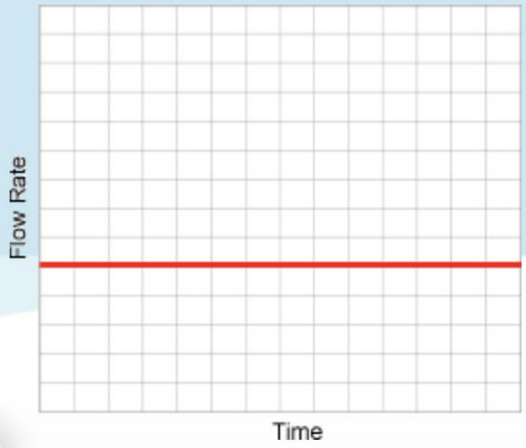
Presetting GPM Dial

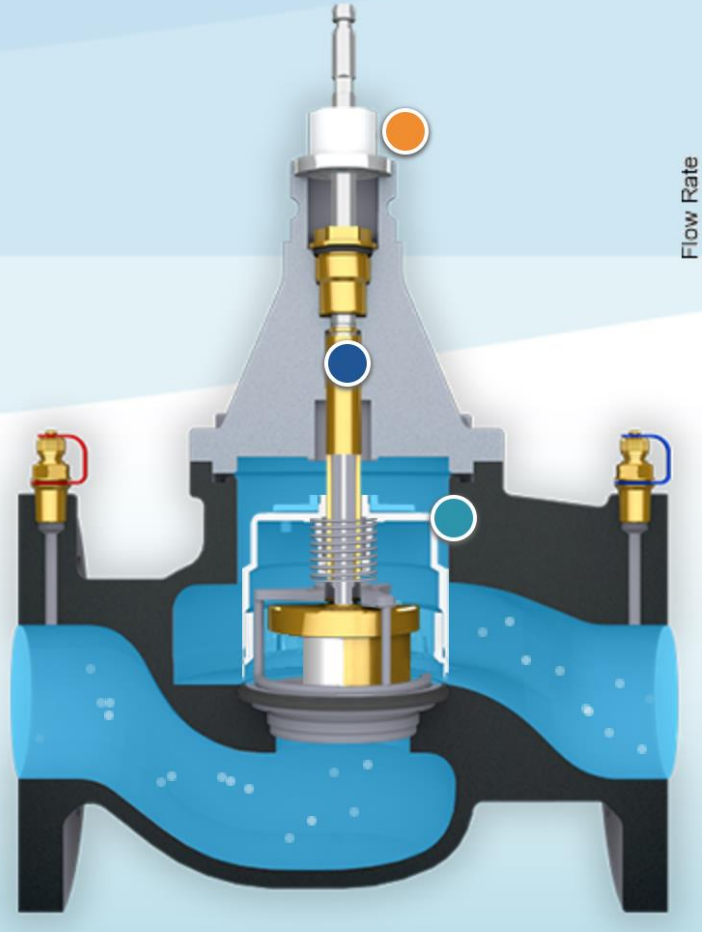
Stem Position

Differential Pressure



Flow Rate





Pressure Independent Control Valve

CONTROL PANEL

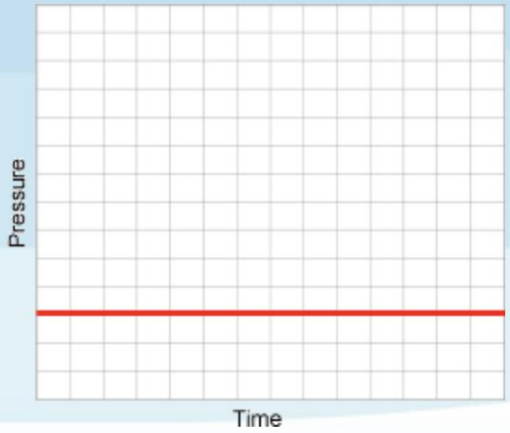
Differential Pressure

Min Max

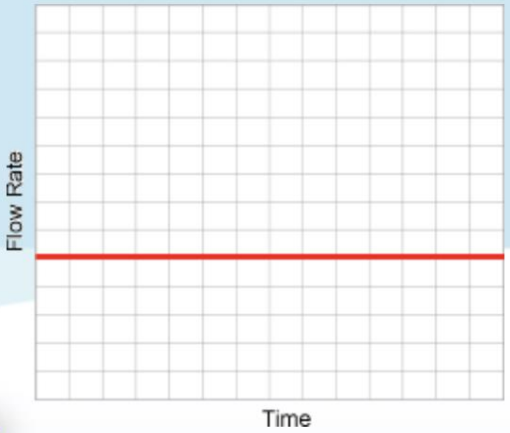
Presetting GPM Dial

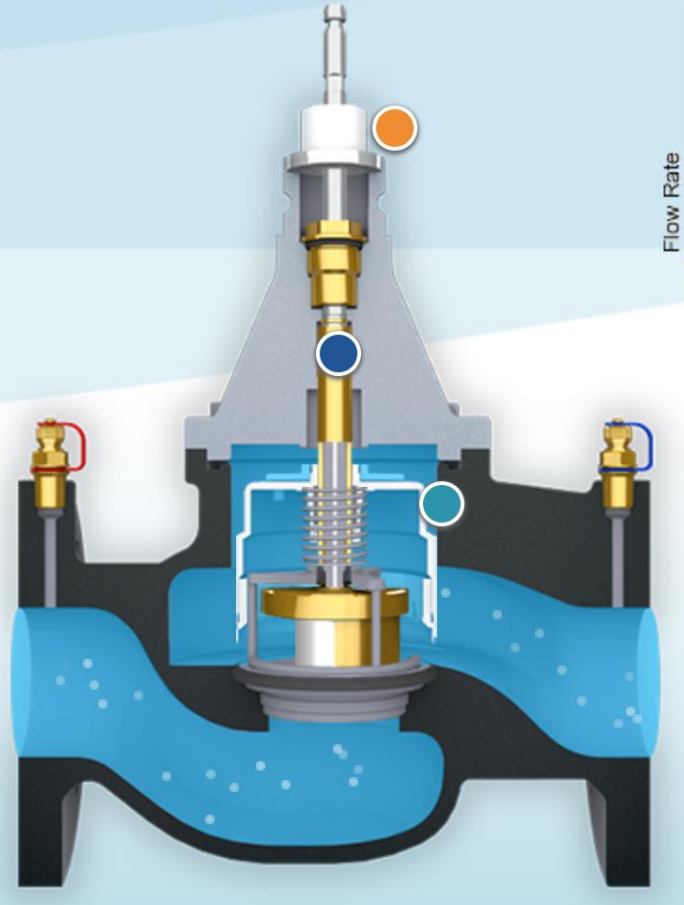
Stem Position

Differential Pressure

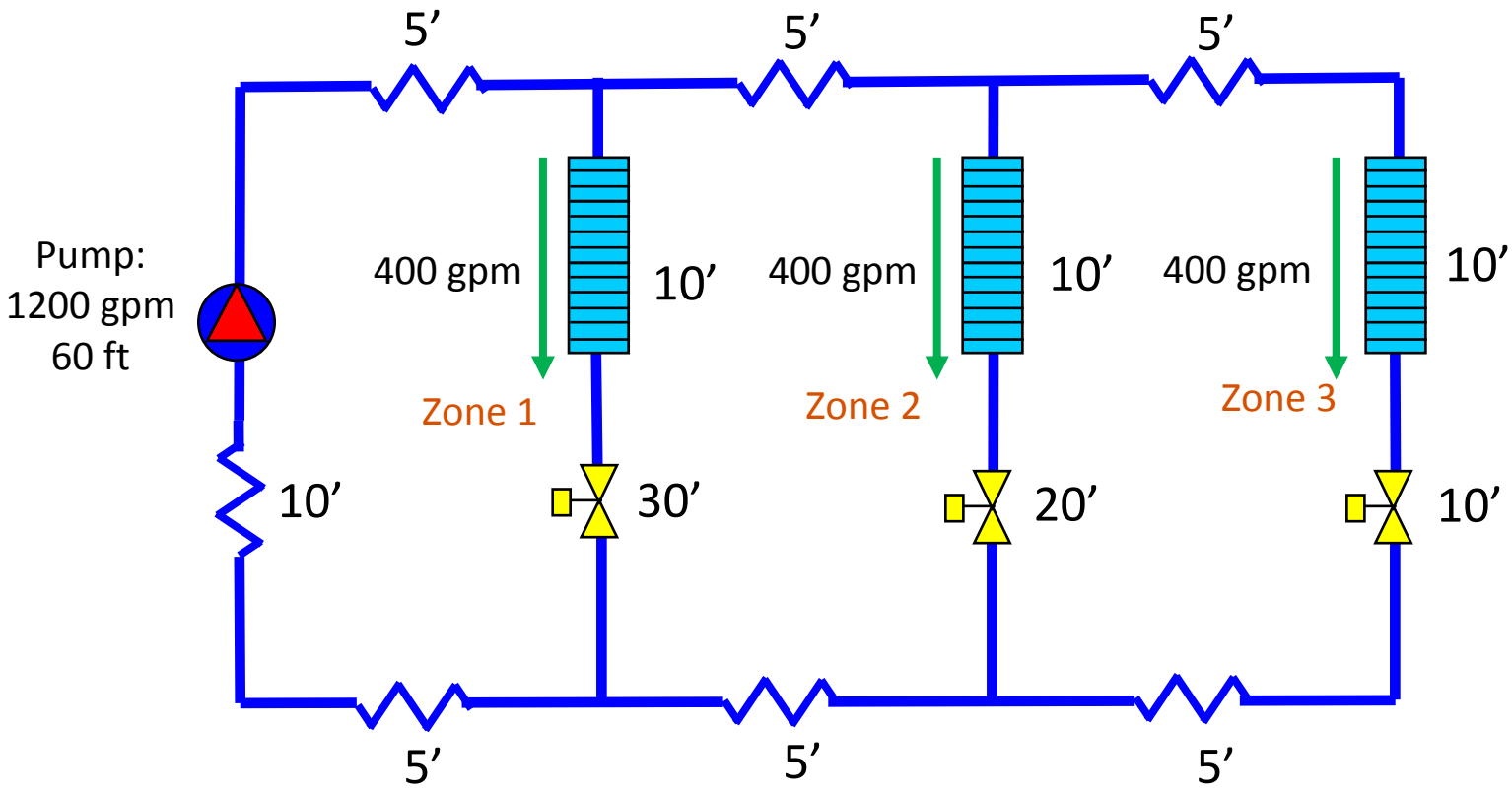


Flow Rate



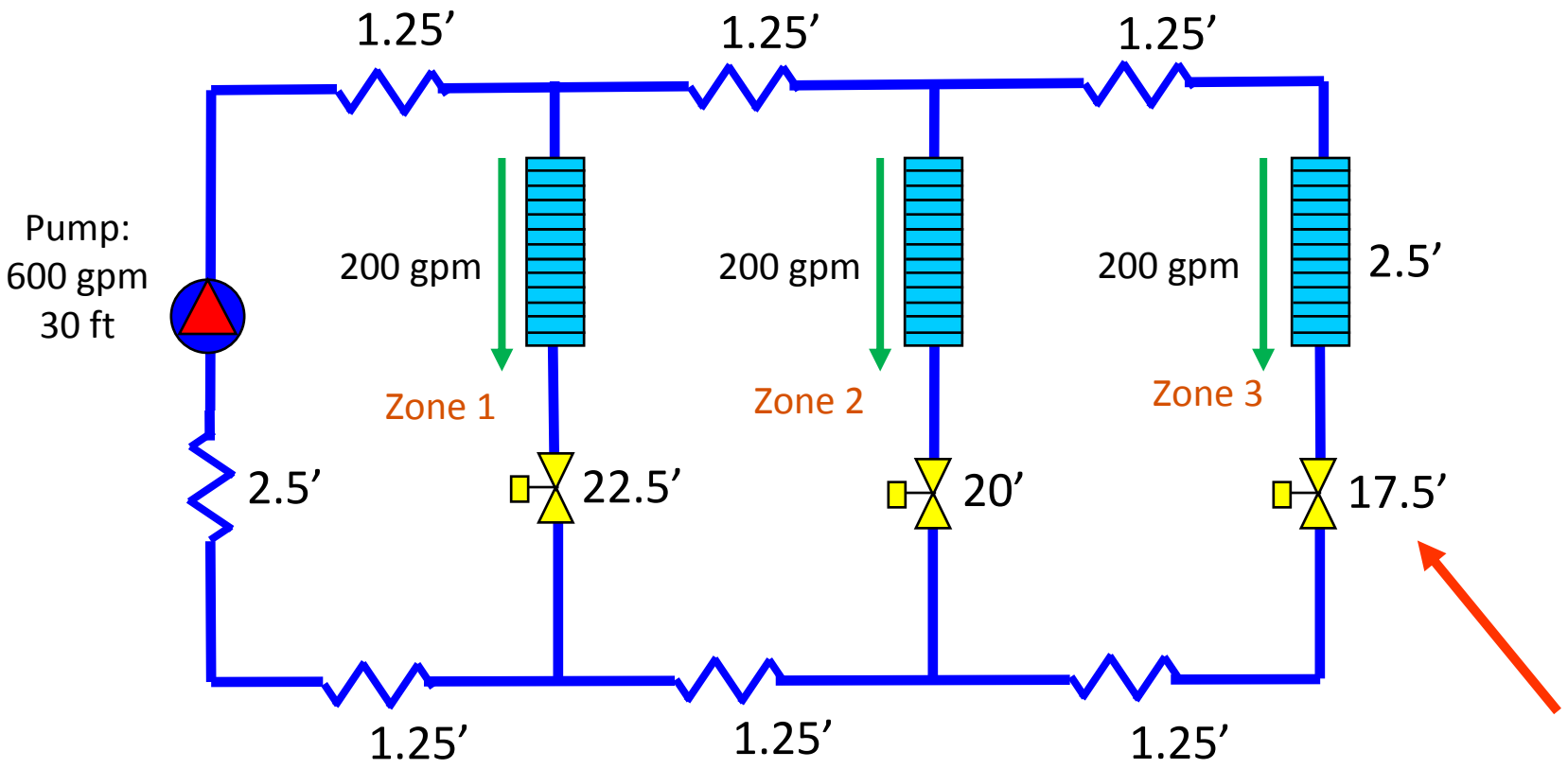


Example System with PICVs



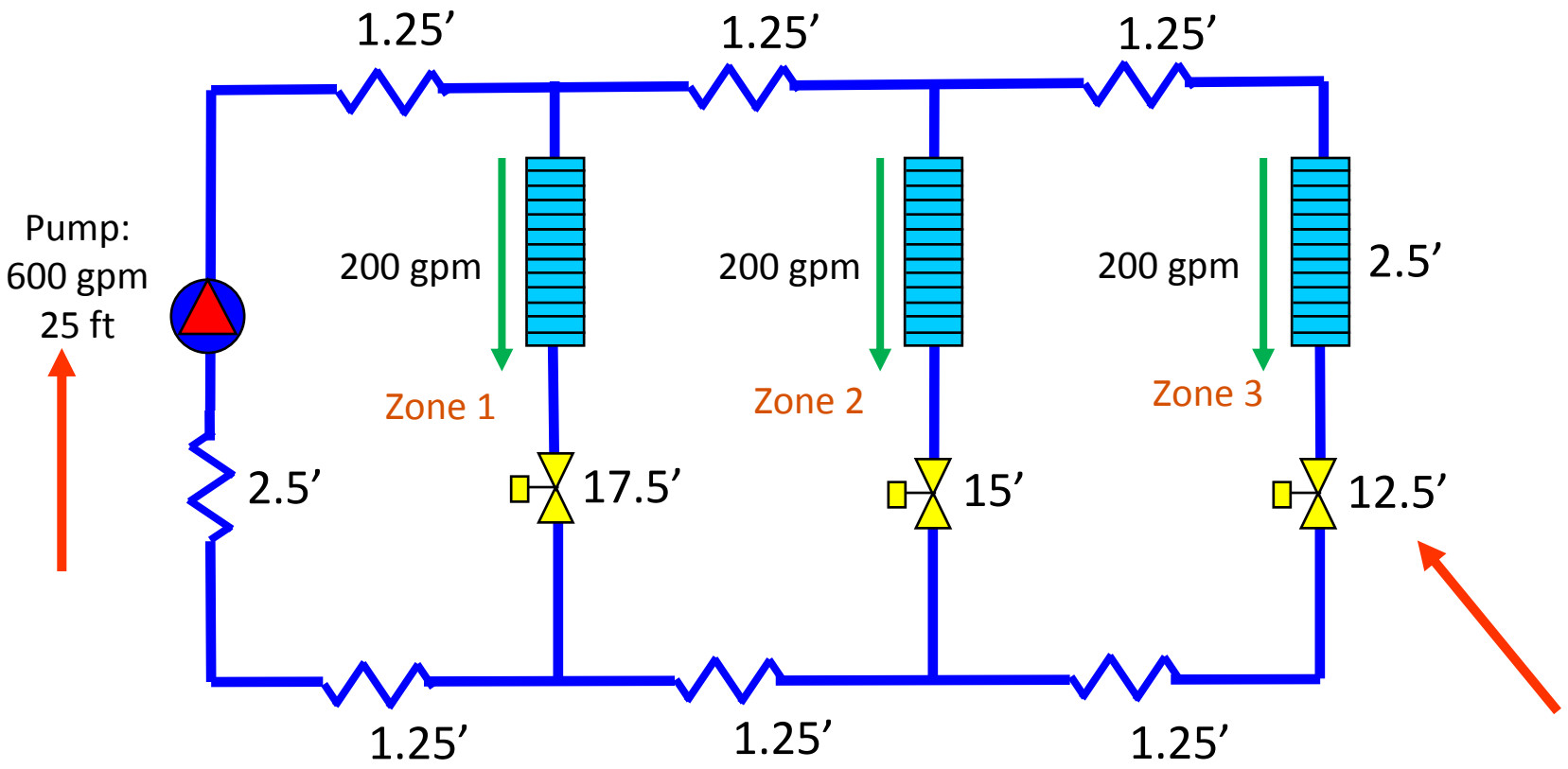
Let’s look at this system at half load…

Example System with PICVs



Let’s decrease pump speed by a small amount…

Example System with PICVs

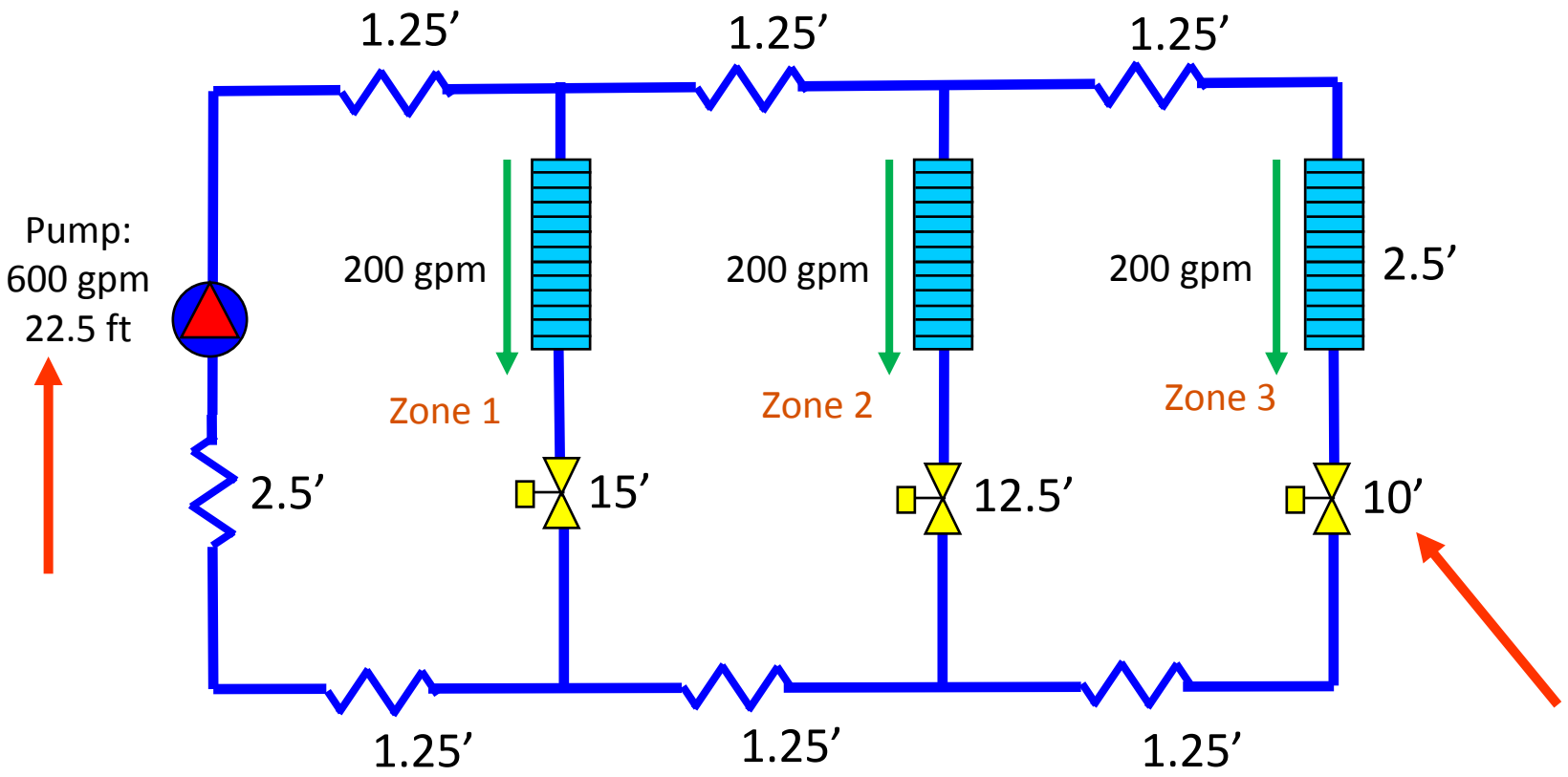


The pump flow did not change!

Let’s again decrease pump speed by a small amount…

Example System with PICVs

Again, pump flow did not change. These were good decisions to decrease the pump seed.



This PICV control range begins a 10’ (4.3 PSI) . What happens when we decrease the pump speed again?

The pump flow will decrease. A custom Controller will immediately increase speed back to the prior speed to provide 10 feet across the critical PICV

Custom Pump Controller

Percent Load	*Hours per year*	*Flow*	*Pump Head*	*HP required*
100%	43.2	1200	60	27
75%	1814.4	900	38	13
50%	1944	600	23	5
25%	518.4	300	13	1

Annual operating cost = $2084*

PLEV (IPLV) load profile, 6 months of operation per year

Do we meet ASHRAE 90.1?(30% Watt at 50% Flow)

$$\frac{5\ hp}{27\ hp} = 18\% \leq 30\% Watts$$

Model based on 10 ft of control head across control valve

*based on 8 cents per kWh

Annual Pump Operating Costs in our example system

1. Control Curve Pump Control (Sensorless) -- $3190
2. Sensor with fixed DP setpoint -- $2804
3. Sensor with DP setpoint reset -- $2225
4. Custom Pump Controller -- $2084***

***design pump head is 5 ft less due to elimination of balance valves

PLEV (IPLV) load profile, 6 months of operation per year

Outline of Presentation

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- Full System Flow Sensor
- Sensorless

Control Area Pump Control Strategies

- Remote DP
- Remote DP with valve position reset
- Custom Pump Controller

Summary

Summary of Pump Control- Rules of Thumb!

Control Strategy	When to consider	When to be cautious	Energy Savings	Comments
Sensorless	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded. Some pumps are incompatible with Sensorless due to their kW-flow relationship on the pump curve.***	Better than constant speed.	Does an estimate of flow. Limited choice of drive manufacturers. Uses a controller-calculated set point that assumes all zones are equally loaded.
Control Curve Control	Hot water. Pumps with motors ≤ 5HP (consider ECM motors in this case). If you don't have a DDC BMS. Retrofit of old systems. When engineering calculations are not used.	When HVAC zone air temperature is critical. When zones are unequally loaded.***	Better than constant speed.	Works with any drive manufacturer. Uses a DP or flow sensor which is more accurate than Sensorless flow calculations. Works with any pump (some pumps are not suitable for Sensorless).
Remote DP	Hot water. Chilled water with pump motors ≤ 5HP.	***	Better	Uses a true measured remote set point. 90.1-2010/13 does not require variable-speed pumping in hot water systems.
Remote DP with 90.1 reset	Required by 90.1-2010/13 if chilled water with pump motors > 5HP AND BMS can read control valve position.	Not recommended with PICVs.***	Best	
Custom Pump Controller	If all control valves are full-stroke PICVs.		Best	PICVs have full valve authority which leads to better flow control and improved system delta-T. No programmed setpoints nor commissioning is needed. Works with any drive manufacturer.

***be cautious of control valve authority and proportional manual balance in these systems