Understanding the Proper Approach to Hydronic System Testing and Balancing

Jim Hall, P.E., CxA
Systems Management & Balancing, Inc.
8:30 a.m. – 10:00 a.m.

This session will cover:

Pumps, pump curves, different types of hydronic systems, and constant vs. variable volume systems. Selection, sizing and proper use of balancing devices. System setup for testing. Data recording and reporting.

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Course Description

This in-depth, practical presentation is geared to helping commissioning providers, engineers, and test and balance professionals understand the proper approach to hydronic testing and balancing and the balance process. The TAB experts will emphasize how to apply AABC's recently updated National Standards to challenges encountered in the field.

The presentation starts at the component level and summarizes the approach at the system level.

Learning Objectives

- Understand pumps and the use of pump curves.
- Discuss the factors involved in the selection, sizing, and proper use of balancing devices.
- Be able to distinguish important differences between different types of hydronic systems.
- Understand proper system setup for testing, as well as data recording and reporting.

Pumps

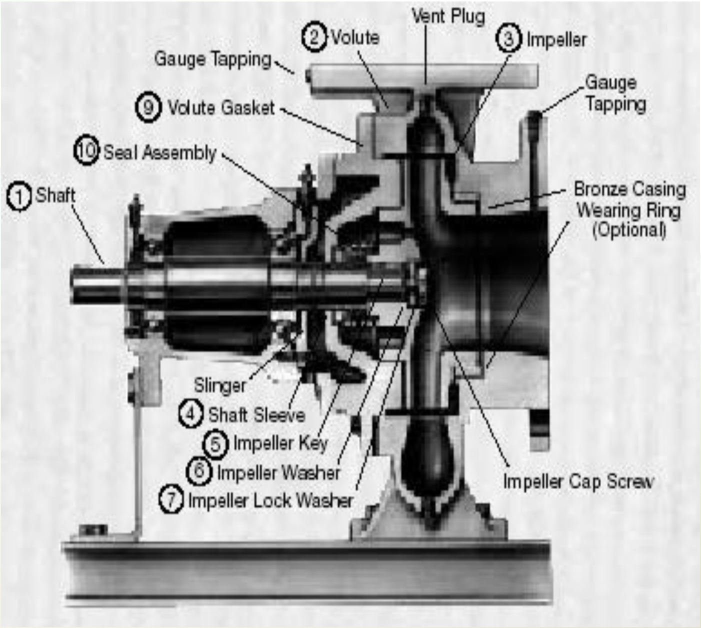
Merriam-Webster defines a pump as:

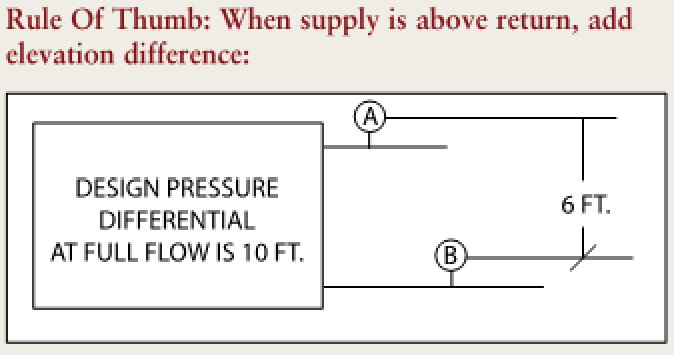
- A device that raises, transfers, delivers, or compresses fluids or that attenuates gases especially by suction or pressure or both.

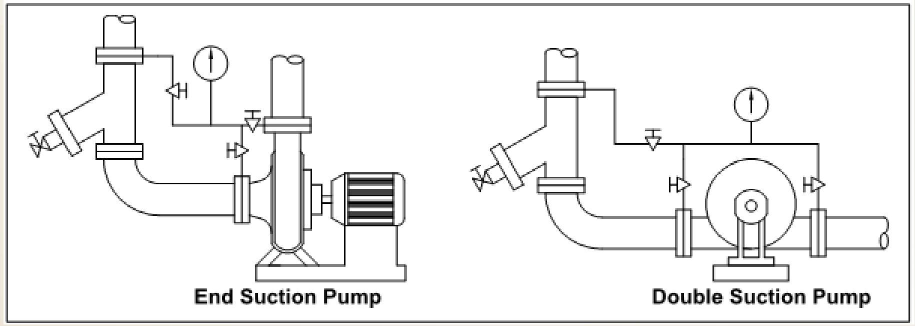
In HVAC terms: The pump develops the pressure and flow required to overcome the resistance of the piping and system components.

Pump Pressure (Head) Measurement

- Provide test ports/pump taps at the pumps – Extend outside of insulation and correct tap location.
- Use gauge cocks and a **one** gauge.
- If using a field hydronic manometer referenced to atmosphere, make sure the meter elevation is the same for both measurements.

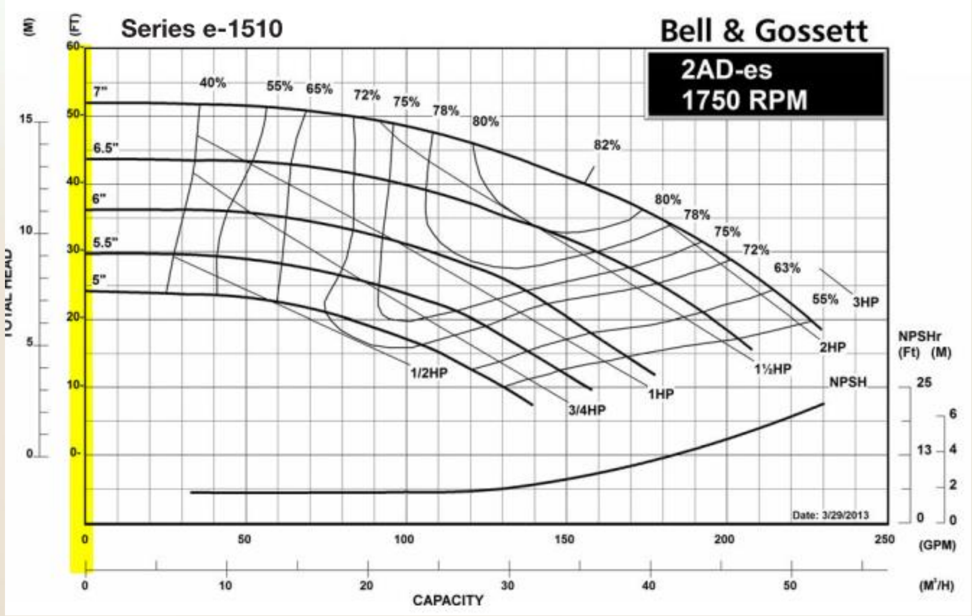






Pumps & Impeller Size Verification

- Perform a “No Flow” or “Shut-Off Head” pump pressure measurement.
  - Close the discharge valve of the pump and obtain the suction and discharge pump pressure measurements at “No Flow”. (Follow AABC National Standards Section 13.3 for complete procedures)
  - Plot the “Shut-Off Head” on the pump curve.



Pumps & Pump Curves – Variable Speed Drives

- The pump curve can be corrected for a pump operating at speeds other than 60 Hz or the rated impeller speed
- The manufacturer can print new curves at different speeds, use the affinity laws, or obtain SOH at the required pump/impeller speed.

Affinity Laws: Effect of change of speed or impeller diameter on centrifugal pumps.

	GPM Capacity	Ft. Head	BHP
Impeller Diameter Change	$Q_2 = \frac{D_2}{D_1} Q_1$	$H_2 = \left(\frac{D_2}{D_1}\right)^2 H_1$	$P_2 = \left(\frac{D_2}{D_1}\right)^3 P_1$
Speed Change	$Q_2 = \frac{RPM_2}{RPM_1} Q_1$	$H_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 H_1$	$P_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 P_1$

Where Q = GPM, H = Head, P = BHP, D = Impeller Dia., RPM = Pump Speed

Pumps & Pump Curves – Variable Speed Drives

B&G Series e-1510 1.25AD 1750 RPM Pump

What is water flow with the pump operating at 39.4 Hertz (1150 RPM) and a measured operating head of 20 Ft?

- Utilize Shut-Off Head measured at 60 Hz (1750 RPM): Measured 57 Ft = 7” Impeller
- Calculate the Shut-Off Head for pump operating at 39.4 Hertz (or perform Shut-Off Head at 39.4 Hertz): $57' \times (1150/1750)^2 = 24.6'$

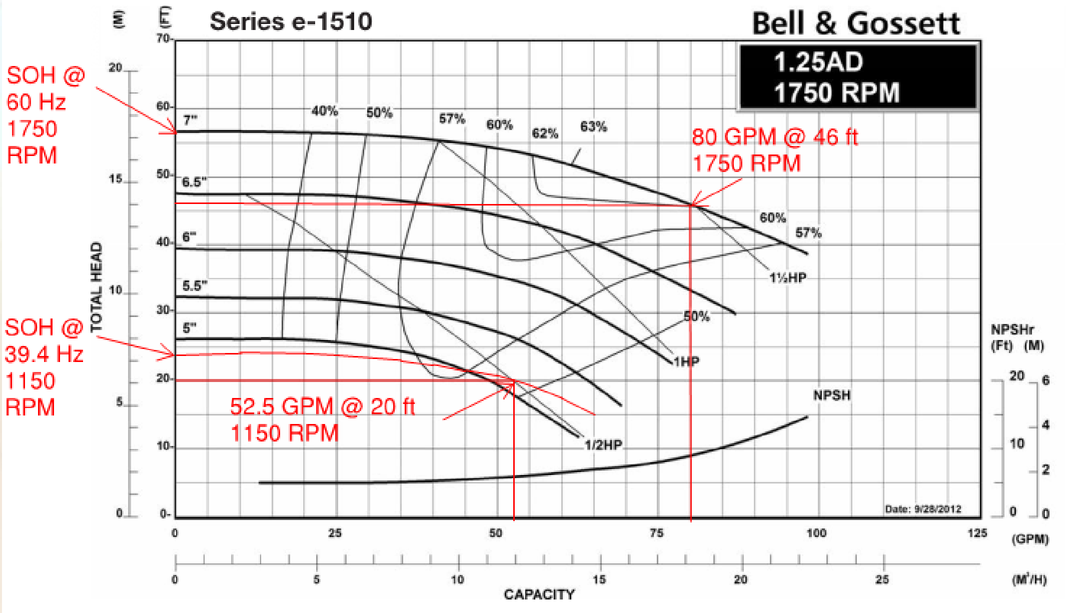
  Draw corrected pump curve on the 1750 RPM pump curve.

  Determine water flow at the 20 Ft operating point

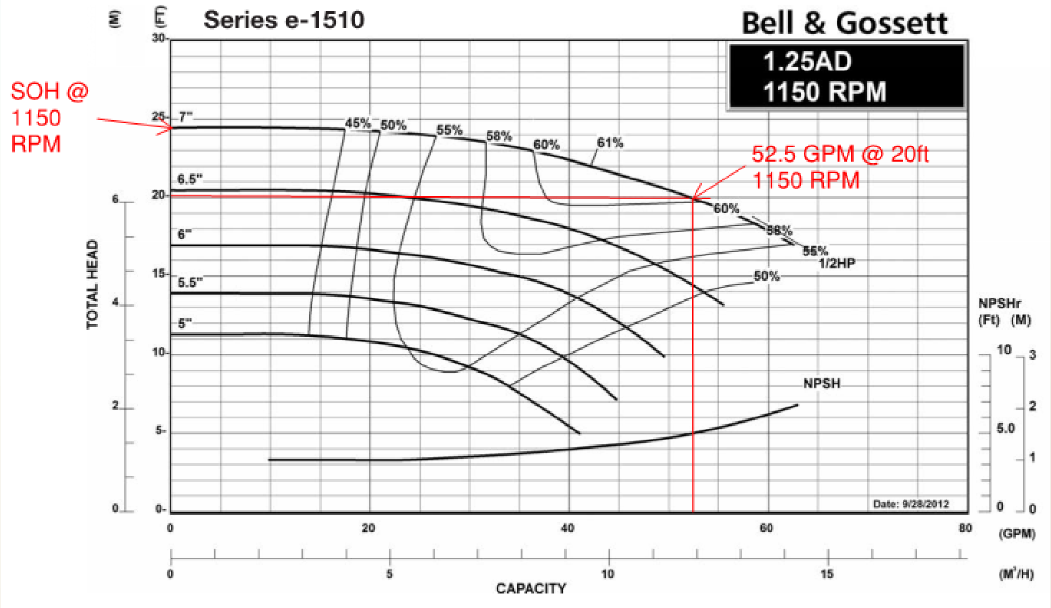
  Water flow is 52.5 GPM

Pumps & Pump Curves – Variable Speed Drives

B&G Series e-1510 1.25AD 1750 RPM



B&G Series e-1510 1.25AD 1150 RPM

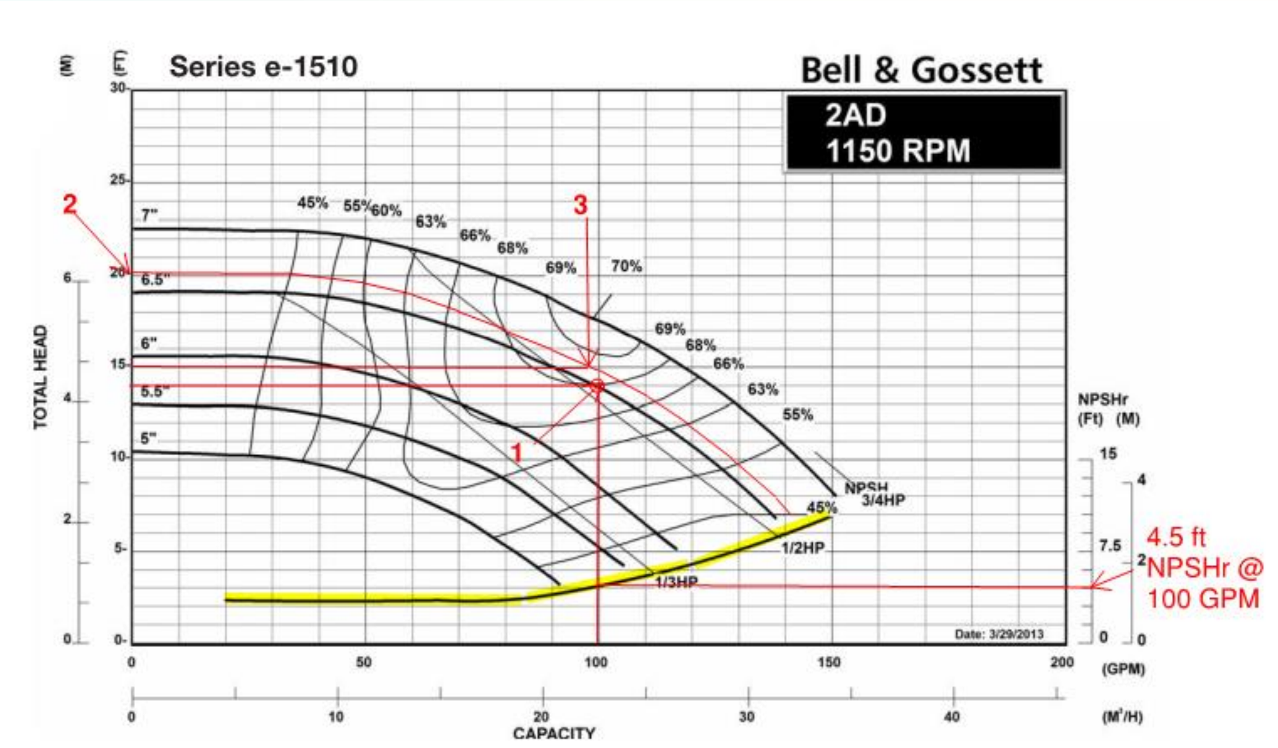


Pumps & Pump Curves – Cavitation

- When the pump inlet pressure at the eye of the impeller is lower than the vapor pressure of the liquid being pumped, then the liquid vaporizes in the pump and "cavitation" occurs. This creates a "crackling" type noise, vibration, drop in pump pressures, reduced brake horsepower and/or reduced water flow.
- "Cavitation" can result in pitting and erosion of the vanes or impeller, reducing pump life and performance.

Pumps & Pump Curves – Cavitation

Net Positive Suction Head Required (NPSHr) – The minimum pressure required at the suction port of the pump to keep the pump from cavitating.



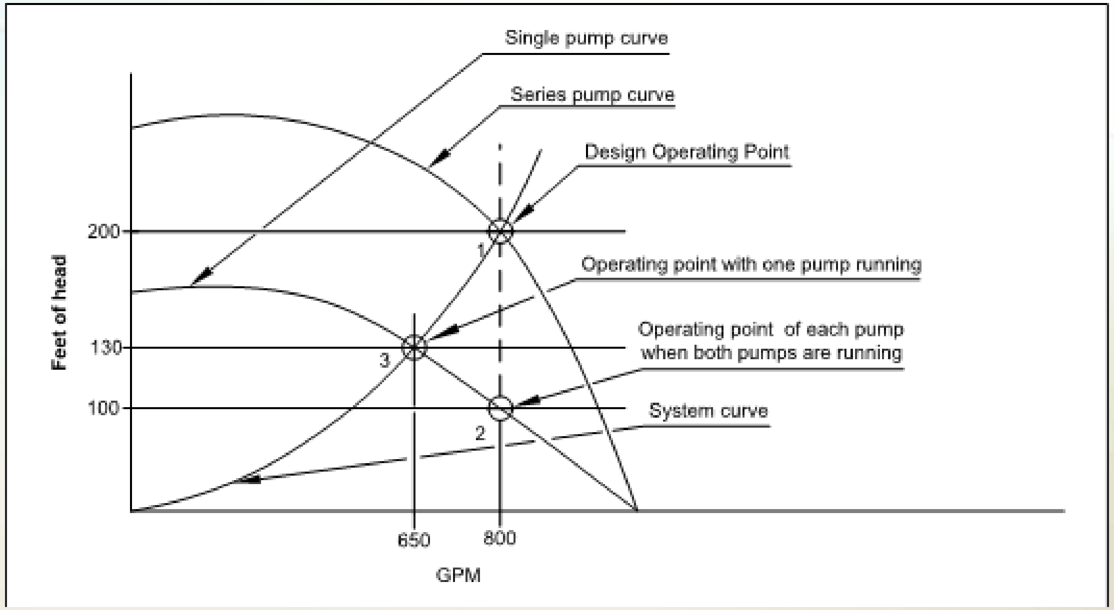
Pumps – Series Operation

When two identical pumps operate in series, the pump flow remains constant and the head doubles (800 GPM at 100 ft per pump).

Point 1: Design operating point with 2 pumps in operation.

Point 2: Operating point of each pump when both pumps are running.

Point 3: Operating point with one pump running.



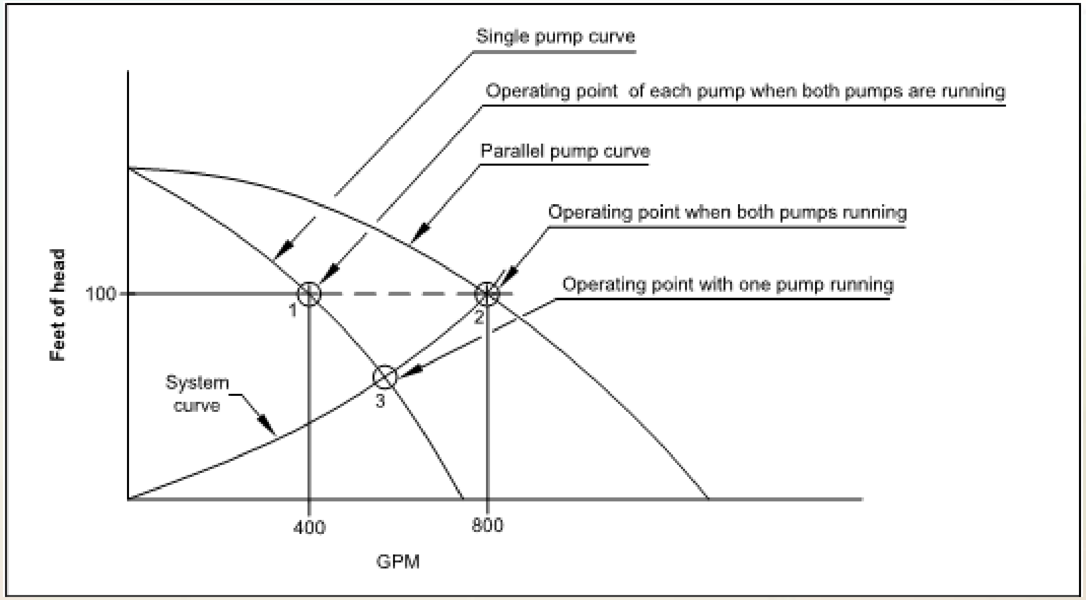
Pumps – Parallel Operation

When two identical pumps operate in parallel, the head remains constant and the flow doubles (800 GPM at 100 ft per pump).

Point 1: Operating point of each pump when both pumps are running.

Point 2: Design operating point with 2 pumps in operation.

Point 3: Operating point with one pump running.



Pumps & Pump Curves – Flow Determination

Design Requirements (Point 1)

100 GPM @ 14’

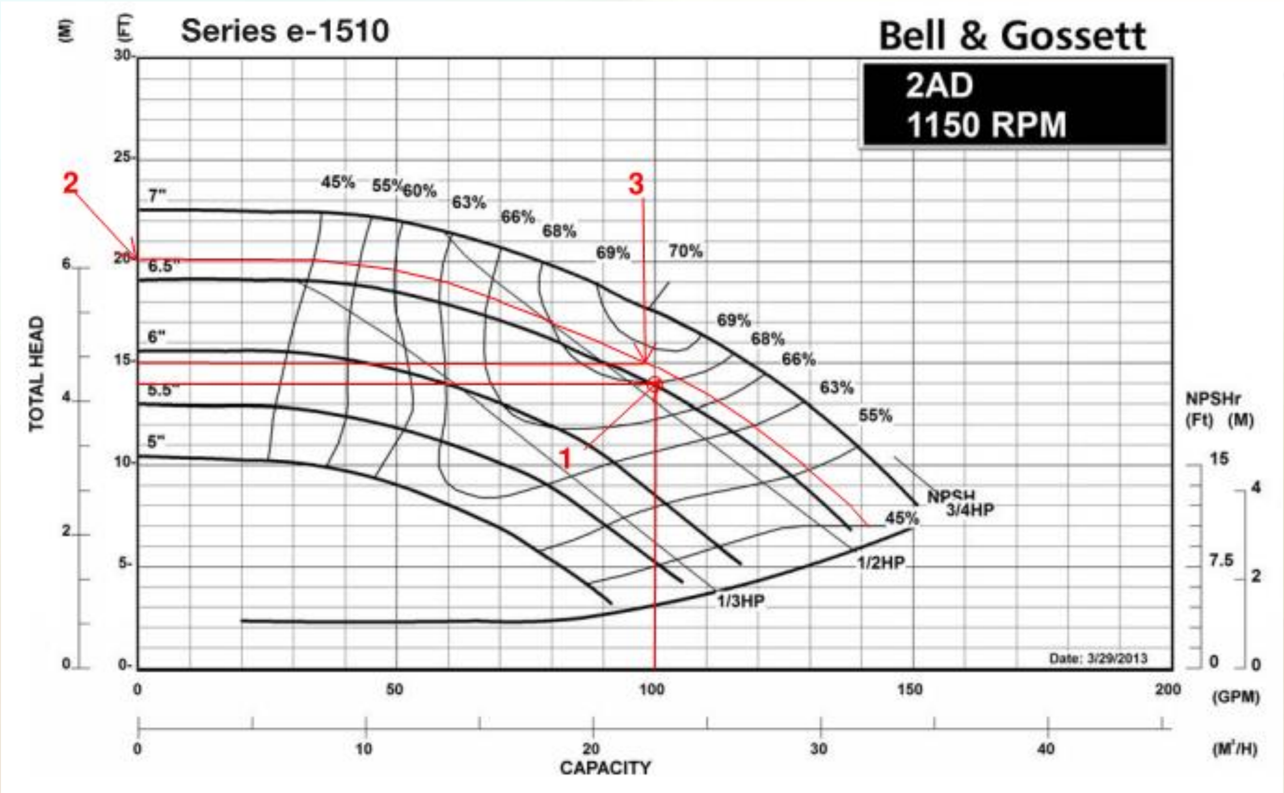
6.5” Impeller

Field Measurements

- Shutoff ΔP = 20’ (Point 2)
- Operating ΔP = 15’ (Point 3)

Pump Curve Results

- Actual: 98 gpm w/ 6.6” imp



Pumps & Pump Curves – Flow Determination – Flat Pump Curve

Design Requirements (Point 1)

220 GPM @ 19’

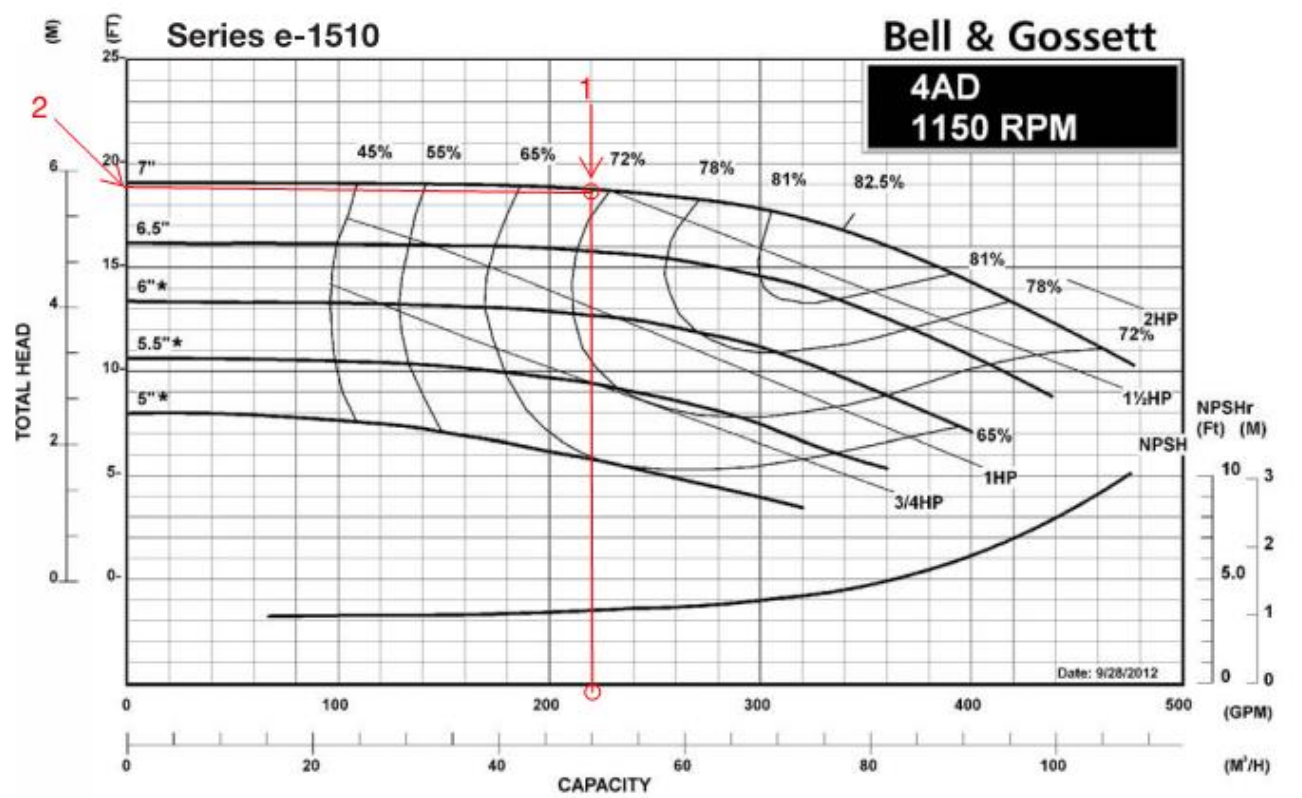
7.0” Impeller

Field Measurements

- Shutoff ΔP = 19’ (Point 2)
- Operating ΔP = 19’ (Where should Point 3 be plotted?)

Pump Curve Results

- Actual: 0 to 220 GPM w/ 7.0” imp

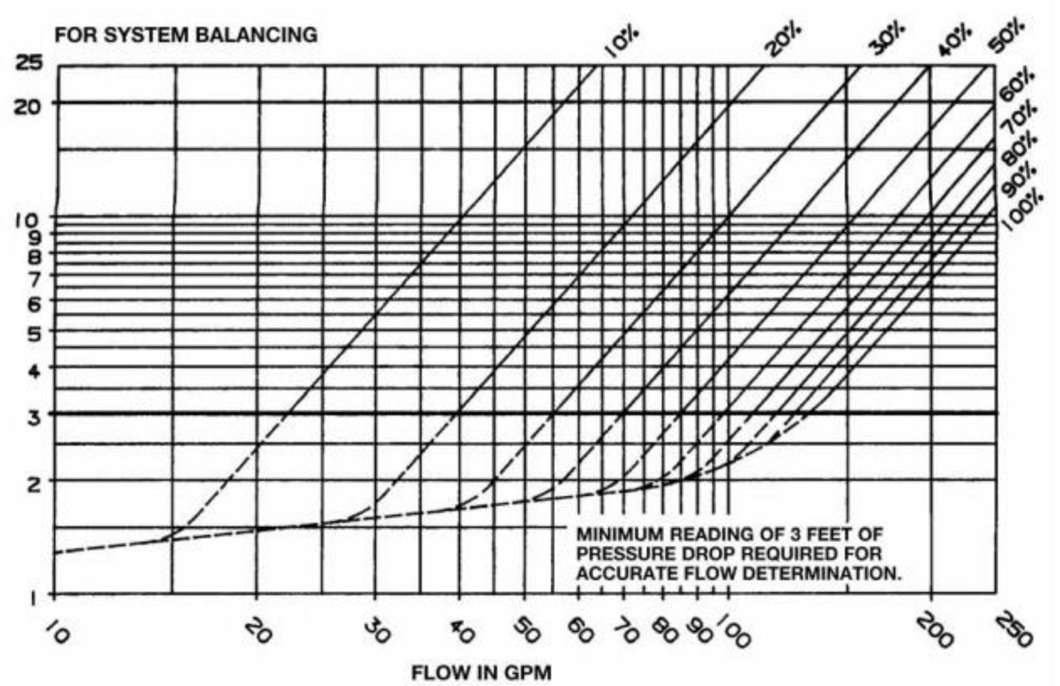


Pumps & Water Flow Measurement

- Options if pump curve is flat
  - Provide a flow measuring device at the pump (Always a good idea).
    - Fixed orifice type device is preferred (sized properly).
    - Multi-Purpose Valves use with caution (sized properly).
  - Summation of the water flows at the terminal devices
  - Water pressure drop measurement across a heat exchanger, chiller barrel, etc. Need to make sure that the system is clean.

Water Flow Measuring Stations - Sizing

- The use of Multi-Purpose Valves for total pump flow measurement
  - Typically sized line size and not for flow quantity (oversized)
  - Location is not ideal, need 5 pipe diameters before and after the valve.



Water Flow Measuring Stations - Sizing

Flow measuring stations need to be sized to allow for a measurable and useful pressure drop.

- Size the FS for **water flow quantity** and not **pipe size**

Most manufacturers of Flow Measuring Stations (**fixed orifice or venturi**) are sizing their products for water flow. They provide multiple options for flow quantity per same line size.

SIZE (INCHES)	CV (MODEL TAG)	FC
1/2, 3/4	0.39	0.067
1/2, 3/4	1.1	0.14
1/2, 3/4	2.5	0.28
1/2, 3/4	4.2	0.54
3/4 L	0.9	0.14
3/4 L	1.9	0.28
3/4 L	3.9	0.56
3/4 L	7.0	1.15
1.0	1.8	0.28
1.0	3.8	0.56
1.0	7.6	1.15
1.0	12.2	1.73

	DIFFERENTIAL PRESSURE: INCHES W.C.				
GPM	½" LB ¾" UB	½" HB ¾" LB	¾" HB	1" HB	1¼" HB
0.3	7				
0.4	13				
0.5	19				
0.6	27				
0.7	36				
0.8	46	10			
0.9	57	11			
1	69	14			
1.1	83	17			
1.2	97	19			
1.3	113	22			
1.4	129	26			
1.5	147	29			
1.6	165	33			
1.7	185	37			
1.8	206	41	10		

Water Flow Measuring Stations – Types

Variable Orifice

- Two pieces of information are required to determine water flow – Valve handle position which determines size of orifice and the differential pressure
- Inexpensive
- Most accurate at full open; Low accuracy at less than full open
- Poor flow characteristics
- Tendency to clog at low flows; “Strainer Effect”

Water Flow Measuring Stations – Types

Fixed Orifice Plate

- Inexpensive
- High permanent pressure loss
- Lower range of flow signal

Water Flow Measuring Stations – Types

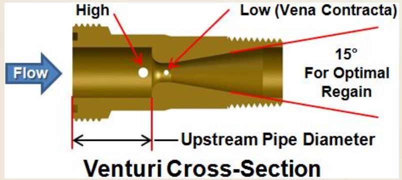
Fixed Venturi

True Venturi

- More expensive
- Most accurate
- Lowest permanent pressure loss
- Wide range of flow signal
- Longer body design

Truncated Venturi

- Less expensive than True Venturi
- Loss of accuracy compared to True Venturi
- Higher permanent pressure loss
- Sensitive to upstream pressure disruptions



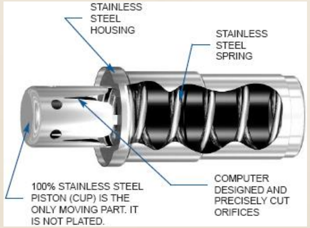
Water Flow Measuring Stations – Strainer Effect

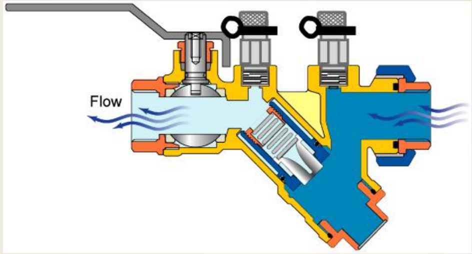
¾” Balancing Valve 50% Open

¾” Balancing Valve 25% Open

Water Flow Measuring Stations – Types
Automatic Flow Limiting Device (AFLD)

- These devices **limit** water flow, they do **not BALANCE** water flow.
- Various manufacturers with a variety of options:
  - Stainless steel or plastic cartridge, static or variable orifice design, pressure ranges, allow for **actual** flow measurement, etc.
- Need to review system and equipment for proper application of AFLDs.
  - VAV reheat systems, heat pump loops, systems with DIVERSITY, systems sized for future, etc.





Water Flow Measuring Stations – Types

Pressure Independent Control Valve (PICV)

A PICV is a device that **maintains a constant differential pressure across the control valve**. This allows for the PICV to **maintain a constant flow for a given control valve position regardless of changes in the system pressure**.

Standard **PICVs are NOT a flow measuring station** – some have the option. In addition, **PICVs are NOT balancing devices**.

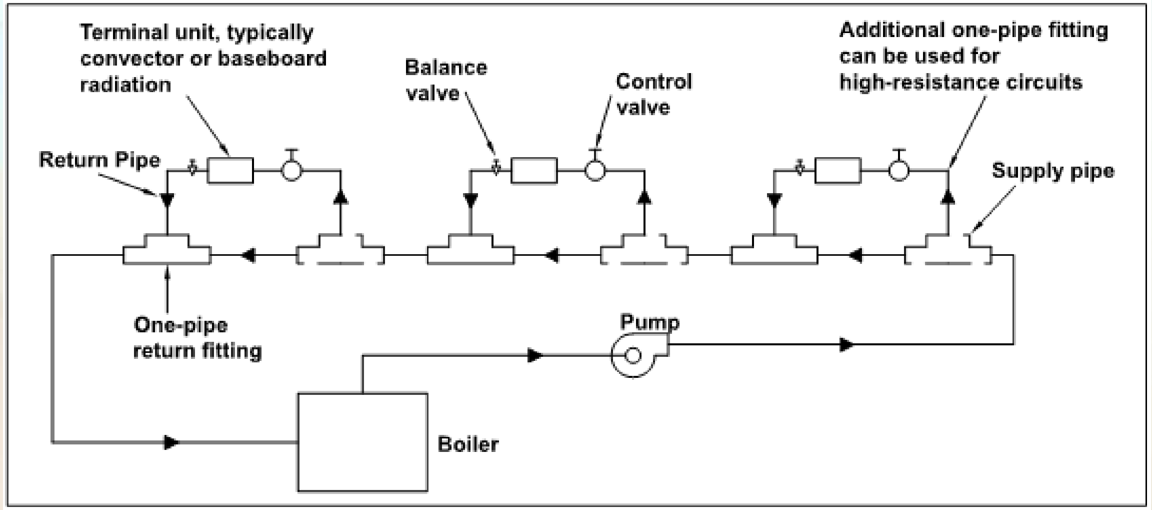
- Expensive
- Large permanent pressure loss (requires more pump energy)

Hydronic TAB Approach

Main goal of today is to try to provide an understanding of the overall approach to the hydronic system TAB process for different types of piping/pumping systems.

Refer to Chapter 15 of the AABC National Standards 7th Edition for detailed procedures and data requirements for each piping/pumping system discussed.

Types of Piping Systems
One-Pipe Main

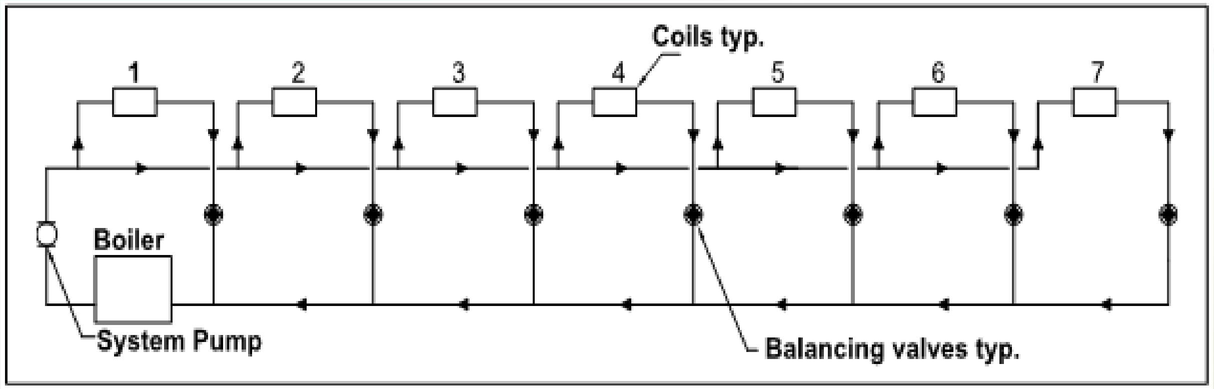


TAB Approach Summary

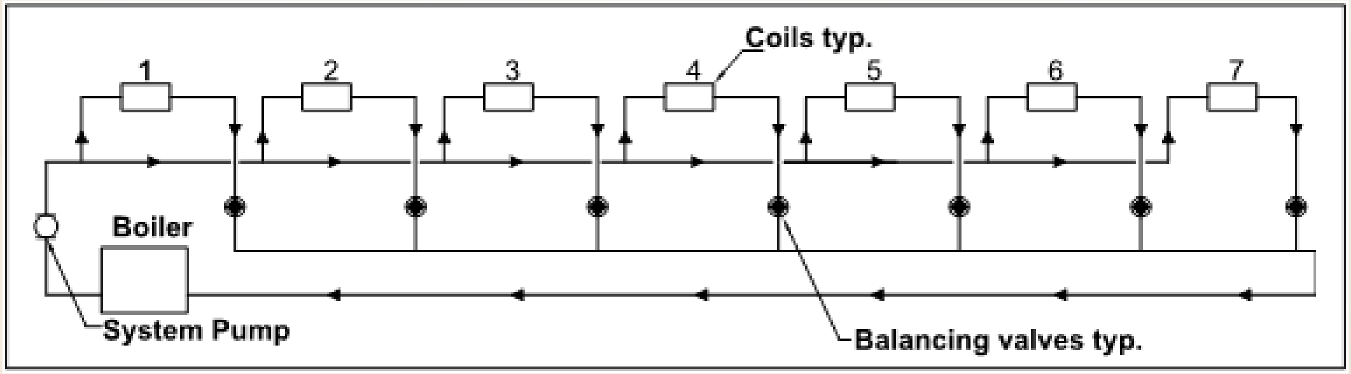
- Assume
  - Constant volume water flow
  - No system diversity
- AFLD vs Settable
- Index system 100% open
- Test pump flow
- Proportionally balance elements
- Retest pump flow

Types of Piping Systems
Two-Pipe

Direct Return



Reverse Return



Types of Piping Systems
Two-Pipe

TAB Approach Summary **Direct Return**

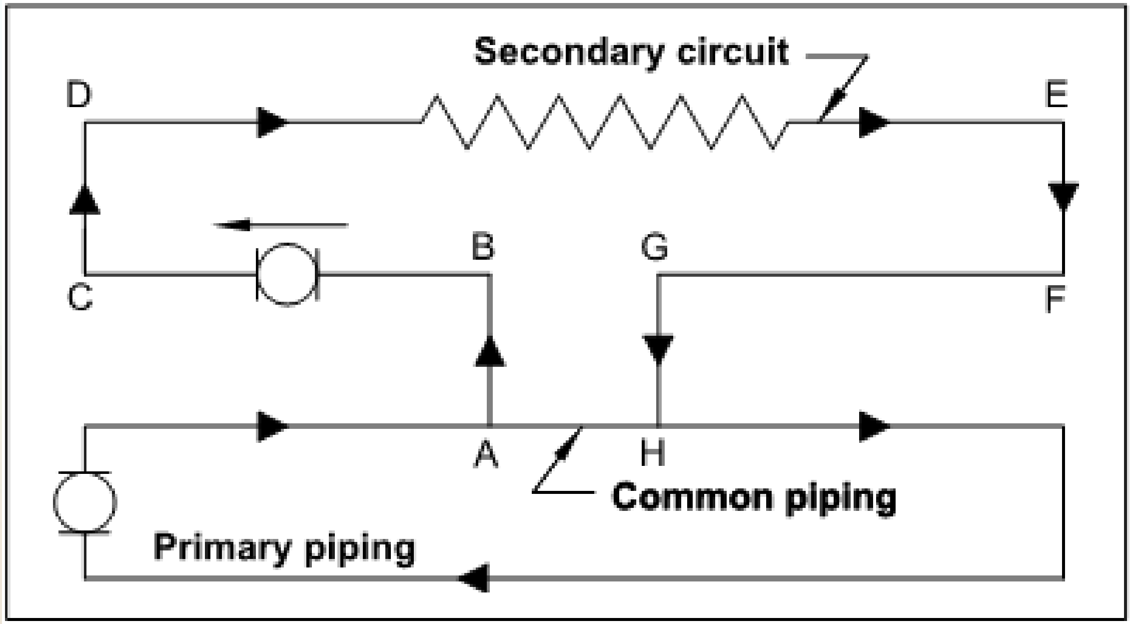
- Assume
  - Constant volume water flow
  - No system diversity
- AFLD vs Settable
- Index system 100% open
- Test pump flow
- Proportionally balance elements
  - Will require multiple iterations with settable devices
- Retest pump flow

TAB Approach Summary **Reverse Return**

- Assume
  - Constant volume water flow
  - No system diversity
- AFLD vs Settable
- Index system 100% open
- Test pump flow
- Proportionally balance elements
  - Will require less iterations with settable devices
- Retest pump flow

Types of Hydronic Systems

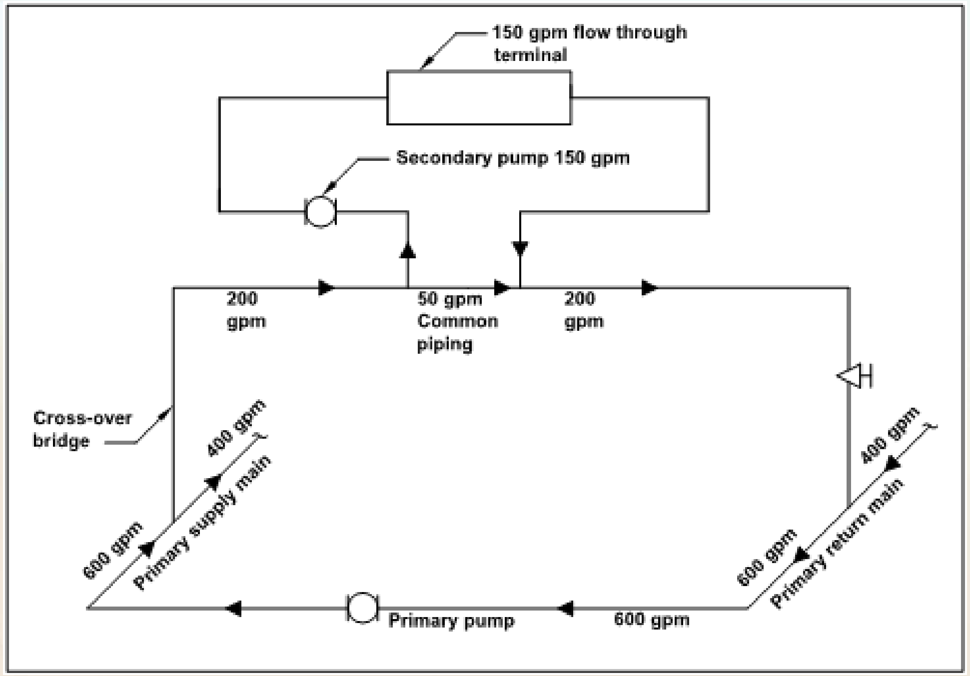
Primary-Secondary



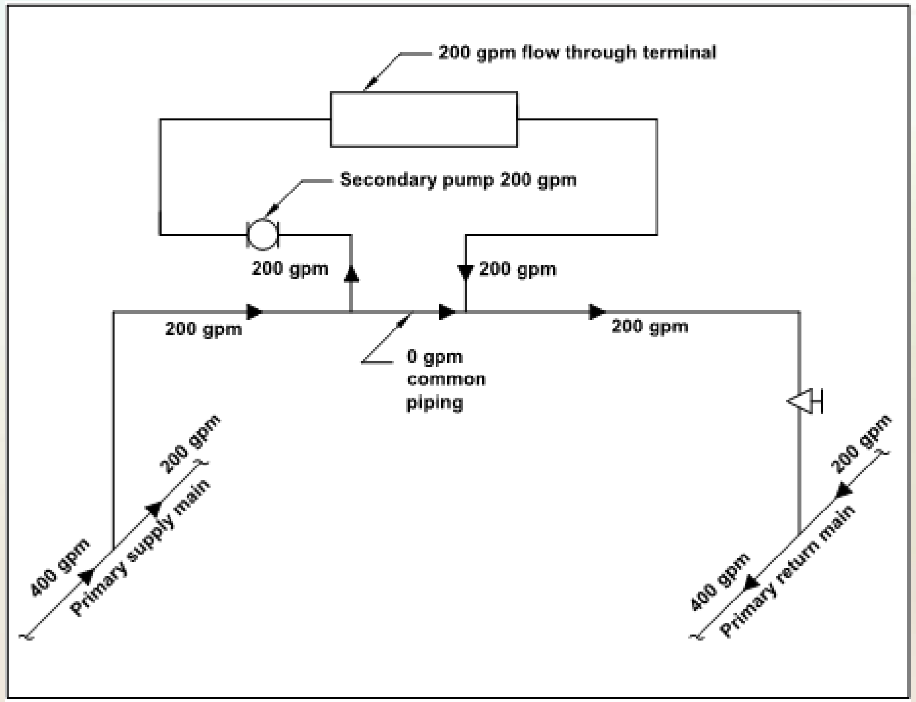
Types of Hydronic Systems

Primary-Secondary

Secondary Flow less than Primary Flow



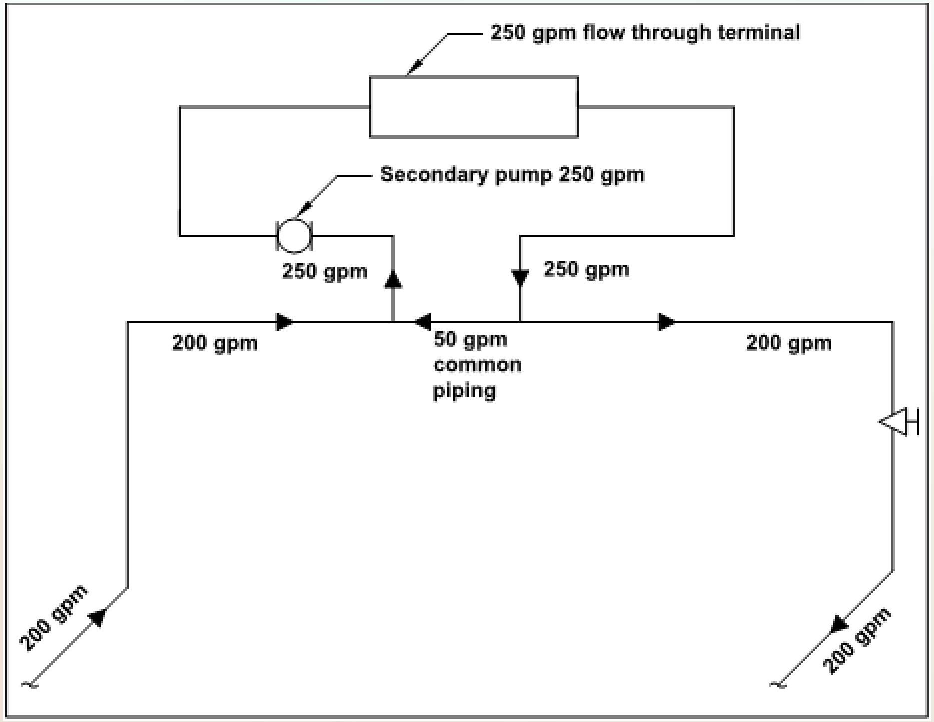
Secondary Flow equal to Primary Flow



Types of Hydronic Systems

Primary-Secondary

Secondary Flow greater than Primary Flow



Types of Hydronic Systems
Primary-Secondary

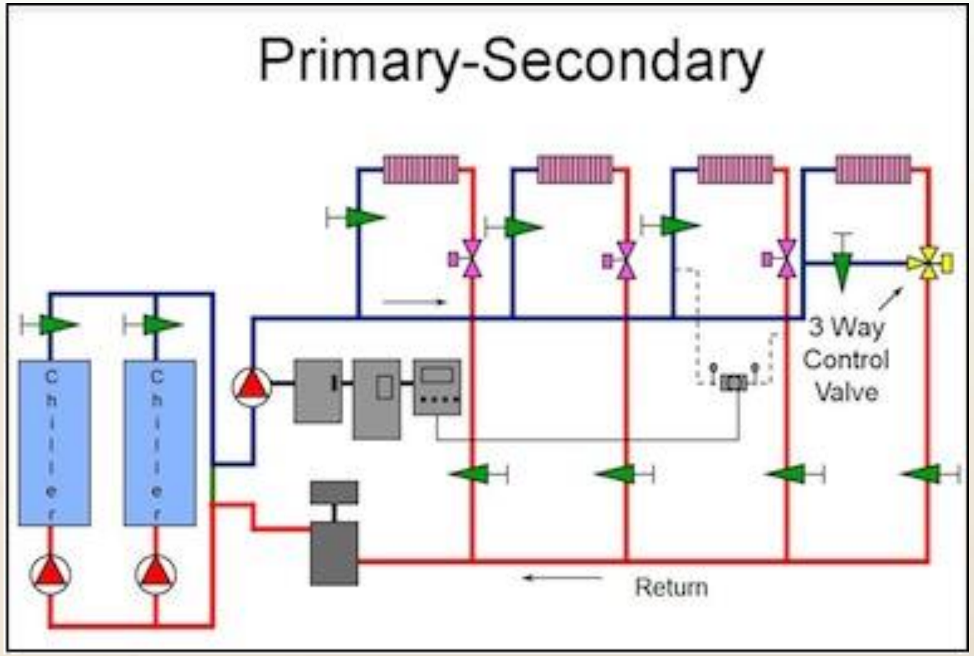
TAB Approach Summary

- Assume
  - Constant volume water flow
  - No system diversity
- AFLD vs Settable
- Index system 100% open
- Test primary pump flow
- Test secondary pump flow
- Proportionally balance elements
  - Will require multiple iterations with settable devices
- If possible, verify water flow in common/decouple pipe
- Retest primary and secondary pump flow

Types of Pumping Systems

Variable Volume

Typical variable volume pumping system has the pump VFD controlling to system DIFFERENTIAL pressure sensor. The system differential pressure varies as the elements' 2-way control valves vary position based on load conditions.



TAB Approach Summary

- Assume
  - No system diversity
- AFLD vs Settable
- Index system 100% open
- Test pump flow at 60 Hz
- Proportionally balance elements
  - Will require multiple iterations with settable devices
- Establish DP setpoint
- Retest pump flow at 60 Hz

Types of Hydronic Systems

Systems with Diversity

- **Diversity** in an HVAC water system is defined as the percentage difference in the pump capacity versus the connected load.

- Pump is sized for 300 GPM and the total connected load at all terminal units is 450 GPM.

  Diversity = [(450-300)/450] x 100 = 33.33%

- How is the system diversity calculated during the design phase of the project?

Types of Hydronic Systems

Systems with Diversity

Diversity in a hydronic system creates challenges and a systematic thought process for the TAB scope of work.

- One must understand a pressure dependent vs pressure independent system.
- Can diversity be simulated for the TAB process?
- How will all elements be satisfied if they are all indexed 100% open?

There is enough information for discussion for a technical session on Testing Hydronic Systems with Diversity, not enough time today

Types of Hydronic Systems

Systems with Diversity

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TESTING HVAC WATER SYSTEMS WITH DIVERSITY

Clarify the difference between pressure dependent and pressure independent systems, and then make a deep dive into this TAB process. There's a lot of science involved, but in the end, steering and tweaking the process may seem more like an art.

By James E. Hall, P.E., TBE, CxA

There are several types of HVAC water systems that are designed with diversity. It could be a chilled water system, heat pump loop water system, heating water system, or (most commonly) a reheat water system. When diversity exists in an HVAC water system, the TAB of this system requires a system review and careful consideration of the approach to the TAB process.

The HVAC water system diversity is defined as the percentage difference in the pump capacity versus the connected load. For example, if the pump is sized for 300 gpm and the total connected load to all elements is 450 gpm, then the diversity of the HVAC water system is as follows:

Diversity = [(450-300)/450] x 100 = 33.33%

Keep in mind that diversity is not a calculated value in the design process. Diversity is a byproduct of the calculated block load of the building and the calculated individual loads within the building (individual space load requirements). In addition, the water coil selection process can affect the amount of diversity in a system as the manufacturers' selections do not always match the design water flow quantity (gpm) requirements.

To properly address the TAB process in a system with diversity, an understanding of a pressure independent system and pressure dependent system is required.

Pressure dependent devices have their water flow (airflow) vary with the system pressure. As the system pressure increases the flow increases at the device and as the system pressure decreases the flow decreases at the device.

Pressure independent devices have their water flow (airflow) stay at the required flow regardless of the system pressure (as long as the system is operating within its capacity limitations). The pressure independent device monitors the flow (pressure) to the device and adjusts the devices' control valve (damper) to maintain the required flow.

A comparison of an airside VAV system to a waterside variable water volume system can help clarify the difference between pressure dependent systems and pressure independent systems.

Airside

- In a variable volume air system, the fan modulates speed to maintain the static pressure set point as the VAV boxes modulate damper position to maintain the required airflow to the space. The VAV box is controlling an airflow setpoint/requirement to maintain space conditions. The VAV box reports the airflow quantity to the BAS/DDC system.
- When one VAV box or multiple VAV boxes change damper position, airflow does not change at the other VAV boxes (as long as the system static pressure setpoint is maintained) since they are pressure independent.

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Types of Pumping Systems

Variety of other types of Systems

Variable Primary Flow

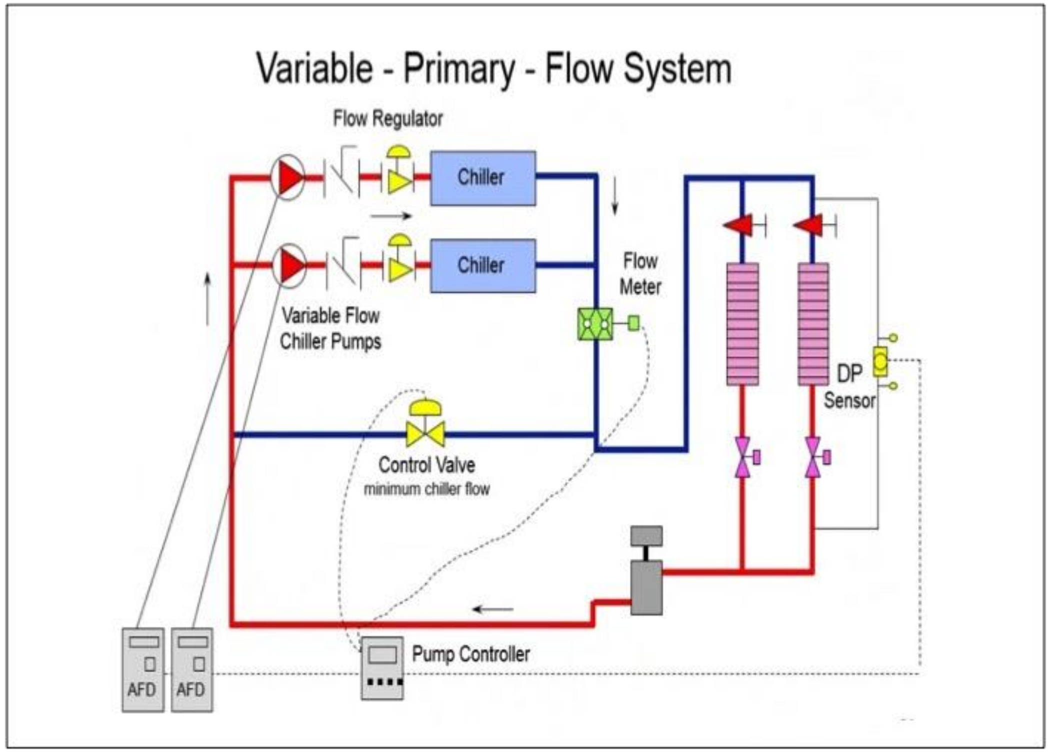
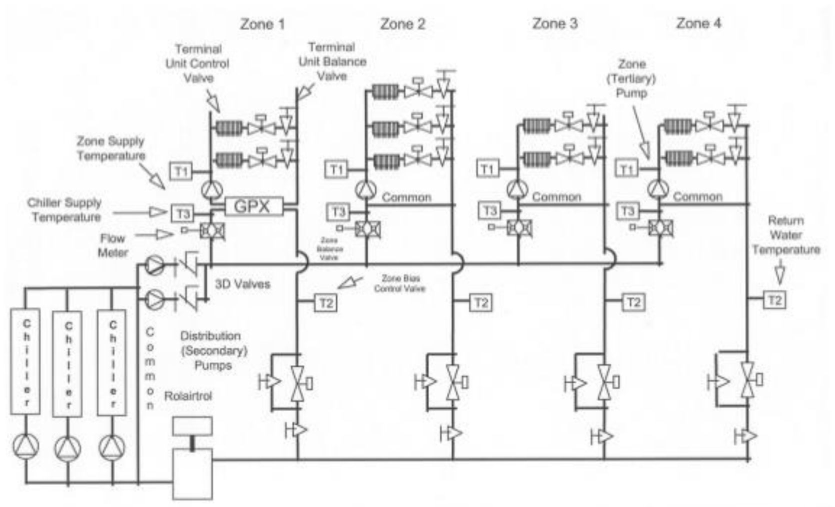


Figure 5

Campus Pumping Systems

System Examples

Campus / District – Primary – Secondary - Tertiary



Hydronic System the TAB Approach Summary

- The system design, equipment selection (Flow Measuring Stations), installation and operation of the system will determine the TAB data obtained (a byproduct of the system).
- The approach to the TAB process must be thought out and documented.
  - It starts with a review of the system including an understanding of the sequence of operation.
  - It should include how the system was set up for testing, what valves were open or closed, etc.

Hydronic System the TAB Approach Review

1. System Service: Chilled Water, Condenser Water, Heating Water
2. Piping system: 2-pipe, reverse return, etc.
3. System FMS: Settable or AFLD
4. Control Valves: 2-way, 3-way
5. Variable or Constant Flow – Location of DP Sensor
6. Open Loop System or Closed Loop System
7. Any bypasses in the system?
8. Is there Diversity? How much?
9. Additional Report Data Notes:
   a) What is operating under control at time of test?
   b) What is indexed open and closed at time of test?
   c) How was the system set up for testing?
   d) What is outdoor air temperature at time of test?

Hydronic System Troubleshooting Tips

- Expansion tank location – Locate it on the suction side of the pump.
- Start up strainers on the pumps are removed.
- Pump rotation is correct.
- All of the air is removed from the system, this could take weeks if the system is large in volume (closed system vs open system).
- Fill pressure for the system is correct.
- Pressure relief valves are sized properly.
- There are test ports and/or flow measuring stations installed at key locations; major piping branches, all coils/elements, pumps, etc.
- Project schedule and phasing can create hydronic TAB challenges

This concludes The American Institute of Architects Continuing Education Systems Course

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