Chilled Water System Commissioning: Variable Primary Flow

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Learning Objectives

1. History of chilled water system configurations
2. Variable Primary Flow (VPF) chilled water system configuration
3. Design and Controls Considerations for proper operation of VPF chilled water systems
4. Things to look for when commissioning VPF chilled water systems
Chilled Water System History

Constant Primary Flow\(^1\)

- Constant Primary Flow was used before primary/secondary
- Advent of low delta T problem

![Diagram of chilled water system](image)

- Chiller: 1000 ton, 2 gpm/ton
- Load: 1000 gpm, 12°dT, 10°dT

Loss of capacity and capital investment 916 tons
Primary/Secondary (Balanced) \(^1\)

- Constant Primary Flow / Variable Secondary Flow has been the industry standard for decades.\(^2\)

![Diagram of a chilled water system highlighting the flow rates and temperature differences.](image-url)
Primary/Secondary (Imbalanced) ¹

- Problems propagate when secondary load and flow exceed primary

1000 ton 1000 ton
2 gpm/ton
1000 gpm 2000 gpm
12°dT 10°dT
53 Deg F 53 Deg F
47 Deg F
SCHWS Temp increases

Flow through chiller remains constant

42 Deg F
2000 gpm
54 Deg F Design
53 Deg F
1008 tons

2 gpm/ton
53 Deg F 200 gpm

VF Ramps up

Load
1000 gpm
12°dT

ADDED Load
1200 gpm

2200 gpm 53 Deg F
Chilled Water System History

Primary/Secondary

• Constant Primary Flow / Variable Secondary Flow with check valve, one of many options

Chiller 1000 ton
Chiller 1000 ton

Load 1000 gpm
Load 1200 gpm

2 gpm/ton

Bypass w/Check Valve

12°dT

10°dT

Check valve prevents secondary flow from exceeding primary flow
Variable Primary¹

- Variable Primary Flow with Low Flow Bypass
Why is Variable Primary Flow (VPF) New? (According to survey of chiller manufacturers\textsuperscript{1})

- Always technically feasible
- Practical application limited by on-board controls in use prior to mid-1990s
  - Capacity modulation
  - Freeze protection
  - Flow detection
- Improvements in all areas have increased manufacturer support for variable primary flow
VPF Design Considerations

Design Issues

• Pumps are controlled by load differential pressure (dP), not staged with chillers
• Low Flow Bypass is critical to maintain minimum chilled water flow through the chillers

Flow Rate Range Limits

• Typical 3 – 12 ft/s tube velocity range
  ∴ maximum turn down to ~25%

Rate of change of flow

• Do not exceed rate of change greater than 30% of design flow per minute³
• Older constant speed chillers, do not exceed 10%³
VPF Controls Considerations

Controls Complications with VPF

- Differential Pressure (dP) pumping control
- Low Flow Bypass controls
- Chiller staging effect on flow through chillers
- Chiller modulating flow control valves to balance flow through multiple chillers in operation
Differential Pressure (dP) pumping control

- Common chilled water systems feed multiple loads, air handlers and buildings
- System configurations typically have multiple risers and/or buildings
- Resulting in varying dP requirements throughout the system
- VPF pumps need to satisfy the hydraulically most critical zone, which is the zone furthest below set point
Differential Pressure (dP) pumping control

- Need a sequence to stage pumps
- Pumps can be staged to keep several pumps running at a lower speed
- Don’t let pump speed go below ≈40% or 24Hz, pump will not flow water, look at the pump curve
- Stage up/down at 80%, 60%, 53%
- Put in a dP dead band so pumps don’t hunt!!
Differential Pressure (dP) pumping control

VF D

LOAD dP STPT 16 psi
LOAD dP STPT 12 psi

Chiller
Chiller

Low Flow Bypass
(dP) pumping control 2 zones

Evaluates one zone vs. other zones

Calculate % under setpoint

If both zones are under setpoint, determine which has a greater % under set point
VPF Controls Considerations

Low Flow Bypass controls

• Valve type and actuator must be fast acting
• Bypass control proportional, integral, derivative (PID) loop must be fast acting
• Bypass control loop must be able to handle changes in system operation such as a failure of a load (air handler) which suddenly shuts the CHW control valve
Case Study - Low Flow Bypass

- (3) electric centrifugal 400 ton chillers
- 2 gpm chilled water design flow rate per ton
- 800 gpm per chiller
- Minimum Flow Rate = 210 gpm
- Chilled water header = 10”
- Low Flow Bypass Line Size = 6”

Lesson Learned: size the bypass line appropriately and select a fast acting modulating actuator; controllability of the bypass can be extremely difficult
Case Study – Results

Case Study - Low Flow Bypass

6” Chilled Water Bypass from CHWS Header

10” Chilled Water Bypass Control Valve
Bray Butterfly Valve
Chiller Staging

- Pumps are controlled by system dP’s
- Chillers are staged based on leaving chilled water supply water temperature
- Chiller chilled water flow rates or differential pressure across evaporator

AND
Chiller Staging Problems

• Due to decoupled pumps and chillers
• Load can increase demanding more pumping
• Chillers may be able to still meet the leaving CHW setpoint
• Flow through chiller may exceed the system “allowable” pressure drop and cause loss of pressure in the field
Excess Flow causes increased PD

Cooler Pressure Drop

Pressure Drop, ft wg

Flow Rate, gpm

DESIGN
Chiller Staging Problems

- 1 Chiller operating near full load
- CHWS temperature setpoint may be low 42 °F
Chiller Staging Problems

- Staging on the second chillers
- Valves must be modulating and slow acting
# Chiller Staging Problems

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### Evergreen Chiller Cooler Pressure Drop

**Project Name:** Untitled  
**Sales Office:** Temperature Equipment Corp.  
**Date:** 03/26/2010  
**Time:** 11:59 AM

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<tr>
<td>Cooler Tubing Type</td>
<td>Super E3 (SUPE3), .025 in, Copper</td>
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**Cooler Flow Rate:** 1783.5 gpm  
**Cooler Pressure Drop:** 20.5 ft wg  
**Cooler Fluid Type:** Fresh Water

**Cooler Minimum Flow Rate:** 1021.6 gpm  
**Cooler Maximum Flow Rate:** 4086.3 gpm

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*Note: This does not imply that the chiller can be properly applied over the entire range of condenser water flow rates represented. The chart is to represent pressure drops only.*
Chiller Staging Problems

- Rate of change limit 30%, 2000 gpm = 600 gpm
- Flow drops 1100 gpm, need to take ≈ 2 minutes to open second chillers control valve
Chiller Staging Suggestions

Chiller Staging Sequence Suggestions

• Before staging on next chiller, raise the operating chillers setpoint
• This should be done a few minutes before opening the second chillers evaporator flow control valve
• This will back off how hard the first chiller is working and help prepare it for the sudden drop in chilled water flow
Chiller Staging Sequence Suggestions

- After the second chiller is staged on for a period of several minutes, start resetting the CHWS temp setpoint back down
- LOCK THE PUMPS at their current speed while staging chillers on and off
- You don’t want to pump control sequence to start speeding up pumps due to a drop in system pressure as the second chiller stages on, this will cause faster flow through the chiller
Staging & Hydraulically Most Remote Chiller

Chiller Staging Problems

- Plants consist of both variable speed chillers and constant speed chillers of different capacities
- Need to assess pressure drop across chillers & piping

![Diagram showing chiller staging](image)
Staging & Hydraulically Most Remote Chiller

- Which chiller is hydraulically the most remote?
- Take piping into account when determining this
- How do you select which chiller valves are open and which modulate?

<table>
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<tr>
<th>Chiller Performance Characteristics</th>
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Staging & Hydraulically Most Remote Chiller

FLOW AND PRESSURE DROP TO MATCH OTHER CHILLERS

DESIGN
## Chiller Staging and Pressure Drop Problems

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<th></th>
<th>OA TEMP</th>
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<th>SUMMER ON</th>
<th>SUMMER OFF</th>
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<th>CHW ISO VLV % OPEN</th>
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### Chiller Staging and Pressure Drop Problems

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### CHW Flow GPM

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### RUNNING AMPS

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| STAGE UP SETPOINT | 1900.00 AMPS |
| STAGE DOWN SETPOINT | 1000.00 AMPS |

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<th>15 MIN AVG CHW TEMP</th>
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<tbody>
<tr>
<td>41.13 Deg F</td>
<td>15 MIN AVG CHW TEMP</td>
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</table>
Low Flow Bypass controls

- Review bypass valve size and actuator stroke time
- Hard to Cx without load on the building. Without load the system will operate with bypass open and no load on chillers
- Maximum turn down to 25% is optimistic. Too little water through the evaporator to keep the system stable
- Expect some surging at low flow conditions and *Low Evaporator Temperature* alarm trips
VPF Cx Considerations and Realities

Sequence of Operations

• Request from the design team the chiller plant and pumping staging sequence
• Request a matrix on which chillers AND piping make the hydraulically most remote chillers and how to modulate the CHW flow control valves
Chiller Performance Submittal

- Review chiller minimum and maximum flow rates
- Review chiller rated pressure drop
- Review chiller pressure drop curve
- This may not be provided in a standard chiller submittal and must be requested
- If all this information is not provided, there will be guess work in the field
Controls

- Limit the speed at which the chilled water pump VFD’s can speed up and down
- Limit the time span the chilled water flow control valve actuators can stroke from min to max
- Review the system dP’s and how the pumps track to maintain the lowest from setpoint
- Put in a dead band so the pumps are not always hunting due to system size and complexity
Controls

- **TREND** air handler control valves and bypass valve
- RESET chilled water supply temperature setpoint based on something, valve position
- This will provide chiller electrical savings at the expense of increased pumping
- Condenser water reset still works great!
VPF Cx you can’t make this stuff up!!

Controls

- Johnson Controls buys York, Aug 2005
- May 2010, York startup tech says chilled water reset is not a good idea and disallows JCI from doing chilled water reset
- After a Cx “discussion”, the next days . . .
- York allows JCI access to do CHW reset
- Only to find out – that now you have to control the chillers demand limiting function as well?? Limit to 80% for the first 30 min. 4
References

4. Carrier Corporation – (Project and Chiller Specific, refer to your particular chiller manufacturers details)
5. Johnson Controls Inc./York International Corporation – (Project and Chiller Specific, refer to your particular chiller manufacturers details)
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Questions AND thank you

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