Variable Speed Pumping

Presented by:
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Key Learning Objectives:

#1: Discuss the key design differences between Primary/Secondary and Variable Flow Primary large chilled water pumping systems. Discuss the benefits and concerns related to each of these key differences.

#2: Provide an overview and fundamental understanding of how large chilled water variable speed pumping systems operate and reduce energy consumption. Discuss the theory behind the control curve and the operation of the system within a control area.

#3: Compare expected energy savings based on alternative locations for the sensors as well as sensorless control. Also show how sensor location may result in underflow conditions in zones without sensors.
Large Chilled Water Design Seminar
Primary-Secondary Pumping
Pump Selection – Worst Case Situation

Pump is selected for:
- Sum of all terminal flow requirements
- Highest head loss circuit

Very high head loss
Another Problem – Variable Volume Systems

If all the control valves close, flow through the source becomes too low or changes too quickly.
How can we separate a large system into “flow independent” sub-systems?
Primary – Secondary Pumping

Fundamental Idea

Secondary Pump

Primary Pump

Tee “A”

Tee “B”

Low pressure drop in the “common pipe”
If Primary Flow = Secondary Flow

No flow in the common
Primary Supply Temp = Secondary Supply Temp
Primary Return Temp = Secondary Return Temp

If Primary Flow > Secondary Flow

“Forward” flow in the common
Primary Supply Temp = Secondary Supply Temp
Primary Return Temp ≠ Secondary Return Temp

If Primary Flow < Secondary Flow

“Backward” flow in the common
Primary Supply ≠ Secondary Supply
Primary Return = Secondary Return
Primary-Secondary Pumping

Secondary Loop Distribution

Primary Loop Production

Supply

Pump Controller

Return

Adjustable Freq. Drives

Primary-Secondary Common Pipe

Chiller

Chiller

Chiller

Primary Loop Production

Secondary Loop Distribution
Secondary System Curve

Control Valves
- Closing
- Opening

Valve Throttling

System Curve

Flow: F1, F2, F3

Head: H1, H2, H3
Large Chilled Water Design Seminar
Variable Speed Pumping
Why variable speed?

1. How does it work?
2. When should I use it?
3. What about variable primary flow?
Adjustable Frequency Drives

• Rectifier section
  – converts AC to DC

• Inverter section
  – forms a synthetic sine wave
  – maintains a controlled frequency/voltage ratio

• Requires an automatic control system

• Adds to the initial cost of the system
Affinity Laws

1. Capacity varies as the RPM change ratio:
   \[ \text{FLOW}_2 = \text{FLOW}_1 \left( \frac{\text{SPEED}_2}{\text{SPEED}_1} \right) \]

2. Head varies as the square of the RPM change ratio:
   \[ \text{HEAD}_2 = \text{HEAD}_1 \left( \frac{\text{SPEED}_2}{\text{SPEED}_1} \right)^2 \]

3. Brake horsepower varies as the cube of the RPM change ratio:
   \[ \text{BHP}_2 = \text{BHP}_1 \left( \frac{\text{SPEED}_2}{\text{SPEED}_1} \right)^3 \]
Required Differential Pressure

\[ \Delta P \text{ Sensor/Transmitter} \]

25 Ft. Head
System Curve
& V/S Control System

25 FT Differential Head
Maintained Across Load
(Set Point)

Overall
system curve

Distribution piping head
loss curve

Set Point

Pump TDH
Effect of Constant* Set Point

As the valve closes, the pump slows down

Control curve
Overall system curve
Distribution piping head loss curve

Set point, 25 FT
Pump TDH

*What’s Constant?
Decrease in Heat Load Results in $T_{room} < T_{set \text{ point}}$
Causes Two Way Valves to Throttle Flow
Decrease in Pump Speed Reduces Flow, Reduces Error
System Operation on Control Curve at Lower Speed

- **Q1 Flow, Q (gpm)**
- **Head, (ft)**
- **Pipe, Fitting Friction Loss**

Control Curve

- **Speed 1**
- **Final Speed**

A, B, C

Q4, Q1

**System Operation on Control Curve at Lower Speed**
Variable vs Constant Head Loss

Variable Head Loss

Constant Differential Head Loss

Supply

Pump Controller

Adjustable Freqy. Drives

Return
Variable Head Loss Ratio

- C/S, Constant Flow System
- C/S, Variable Flow

- V/S, 0% Variable Hd Loss, 100% Constant $\Delta$ Hd
- V/S, 25% Variable Hd Loss, 75% Constant $\Delta$ Hd
- V/S, 50% Variable Hd Loss, 50% Constant $\Delta$ Hd
- V/S, 75% Variable Hd Loss, 25% Constant $\Delta$ Hd
- V/S, 100% Variable Hd Loss, 0% Constant $\Delta$ Hd

Pump Head Matched to System at Design Flow
V/S Curves

% Efficiency Curve

Head, Feet

GPM

% Speed Curves

Constant Efficiency Curve
Efficiency Changes

% Speed Curves

Constant Efficiency Curve

Head, Feet

GPM
Minimum Drive Speed

% Efficiency Curves

Head, Feet

% Speed Curves

Constant Efficiency Curve

GPM
Multiple Pump System

Constant Differential Head Loss

Variable Head Loss

Supply

Pump Controller

Adjustable Freqy. Drives

Return

Multiple Pump System

Variable Head Loss

Constant Differential Head Loss

Supply

Pump Controller

Adjustable Freqy. Drives

Return
Parallel V/S Operation

Graph showing the performance characteristics of pumps in parallel operation. The graph includes curves for Pump 1, Pumps 1 & 2, and Pumps 1, 2 & 3 at different RPMs (600, 900, 1150, 1450, 1770 RPM). The control curve is highlighted, with a set point of 25 ft. (4500 GPM, 100 ft). The graph illustrates the capacity in U.S. GPM versus head for different series configurations.
Variable Flow Through The Evaporator
Variable Primary Flow

Two-position Control Valves

Flow Meter, option

Modulating Valve

Controller

AFD

CHILLER

DP Sensor
What’s different?

• Primary pumps only
• Flow meters or Δp sensors at each chiller to monitor flow.
• Two-position isolation valves at each chiller
• Minimum flow bypass with a modulating control valve.
• “Smarter” controller.
Alternative #1

• Minimum Flow Bypass at Chillers
  – Minimum Chiller Flow
  – Minimum Pump flow

• Headered Pumps
NOTE:
ALL SENSOR SIGNALS WIRED TO TECHNOLOGIC 5500

BYPASS:
FOR SYSTEMS WITH EXTENDED LIGHT LOADS/WEEKEND SHUTDOWNS. SET BALANCE VALVE FOR LOW FLOW TO REDUCE THERMAL STRATIFICATION AND ALLOW QUICK START UP AFTER SHUT DOWN.
Controller

- Initial programming is crucial.
- Must use accurate data from the chiller manufacturer.
- Start-up coordination should include the BMS too.
Key Control Variables

1. Monitor zone differential pressure sensors, compare actual values to the required set points.
   
   • Pump speed is modulated to maintain set point.
   
   • Pump staging will occur as required to meet set point.

Control sequence is exactly as described earlier.
Key Control Variables

2. Determine if the minimum flow requirements are being met for all working chillers.

Prevents freeze-up or chiller low-flow trips

If chiller flow is too low, controller opens minimum flow bypass valve in programmed increments. Size the valve for system $\Delta p$.

“Requests” de-staging action from the chiller control system or BMS.

- Allows for operator intervention, decision making.
- Required by code in some areas.

Headered pumps allow operation of two chillers with one pump.
Key Control Variables

3. Monitors chiller flow rate to prevent operation above the maximum flow for the chillers and the pumps.

   Excess chiller flow generates a request to stage on an additional chiller. Minimum flow bypass valve is closed.

   Operator or BMS intervention required.

   Headered pumps allow operation of one chiller, two pumps.

   Optional system flow meter provides end-of-curve protection for the pumps
Alternative #2

• Bypass at End of System
  • Minimum chiller flow
  • Minimum pump flow
• Headered Pumps
Alternative #2

- Minimum flow bypass valve is controlled to protect both the pumps and the chillers.
  - Pump requires >25% BEP flow
  - Minimum flow of largest chiller
- Size the bypass valve using the zone $\Delta p$.
- Best for systems with extended light loads or weekend shut-down.
Alternative #3

- Primary pumps piped directly to chillers.
- More common in retrofit systems.
- Easier for applying un-equally sized chillers in parallel.
NOTE
ALL SENSOR SIGNALS WIRED TO TECHNOLOGIC 5500

NOTE
FOR SYSTEMS WITH EXTENDED LIGHT LOADS/WEEKEND SHUTDOWNS. SET BALANCE VALVE FOR LOW FLOW TO REDUCE THERMAL STRATIFICATION AND ALLOW QUICK START UP AFTER SHUT DOWN.
Consider this design if:

- System flow can be reduced by 30%.
- System can tolerate modest changes in water temperature.
- Operators are well trained.
- Demonstrates a greater cost savings.
- High proportion of operating hours at:
  - Part load.
  - Full load with low entering condenser water.
Turn-down Ratio

• Chiller manufacturers publish 3 - 11 fps evaporator velocity range (typically).
• Nominal base of 7 fps desirable.
• You may have to increase your “acceptable head loss” targets, use more pump head.
• Variation of ±1 to 2 fps.
• Work with the chiller manufacturer.
Operator Ability

• Within operator’s ability?.
  – Commercial buildings may not have well qualified operators.

• Training is mandatory.
  – Initial
  – Periodic, in view of operator turnover.
Sensor Calibration

• Multiple sensors control:
  – Flow
  – Temperature
  – Delta P
• Maintenance
• Calibration
• Location
Large Chilled Water System Design Seminar

Variable Speed Sensor Location
What if?

ΔP Sensor here

Zone A

Zone B

Zone C

Supply

Controller

CHILLER

CHILLER

CHILLER

AFDs

Pump Controller

Return
Sensor Across Mains At Pump

• What’s the set point?
  – It’s the greatest branch and distribution piping head loss calculated at design flow. In other words…design head.
Differential Pressure Sensor at the Pump
Maximizing Variable Head Loss
Control Area

- Zone 1: 20 ft
- Zone 2: 20 ft
- AFDs
- Pump Controller
- DP Sensor
- CHILLER
- CHILLER
- CHILLER
- CHILLER

Nodes: A, B, C, D, E, F
Pressure Drops in Piping

\[ \Delta P_{AB+EF} \quad \Delta P_{Zone\ 1} \quad \Delta P_{BC+DE} \quad \Delta P_{Zone\ 2} \]

\[ 20\text{FT} \quad 20\text{FT} \quad 20\text{FT} \quad 20\text{FT} \]

\[ TDH = \Delta P_{AB\ +\ EF\ +\ BC\ +\ DE\ +\ \Delta} \quad P\ ZONE\ 2 = 60\ FT \]
Control Area Calculation

<table>
<thead>
<tr>
<th>Flow Zone 1</th>
<th>Flow Zone 2</th>
<th>Friction Loss AB+EF</th>
<th>Friction Loss Zone 1</th>
<th>ΔP Zone 1</th>
<th>Friction Loss BC+DE</th>
<th>Friction Loss Zone 2</th>
<th>ΔP Zone 2</th>
<th>TDH</th>
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</thead>
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<td>20</td>
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</tr>
<tr>
<td>0 gpm</td>
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<td>40</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>60</td>
</tr>
</tbody>
</table>

What pump head is required at:
- zero flow?
- full flow?
- less than full flow?
Control Area

The diagram shows the relationship between flow (gpm) and head (FT) for different control areas. The lines represent:

- Lower Limit
- Upper Limit
- Single Point

The graph indicates how the head changes with flow for each control area.
Single Sensor, Including Balance Valve Pressure Drop

Zone 1
25 ft

Zone 2
20 ft

A
B (50)

C

D

E (10)
What do you mean...?

- The head loss across the coil and the wide open valve in zone 1 is 25 feet at full flow.
- If that’s true, then we need to add an extra 15 feet of head loss in the balance valve to insure adequate flow out to Zone 2 when the Zone 1 valve is wide open.
Set Point, Zone 1, 40 ft

<table>
<thead>
<tr>
<th>Flow Zone 1</th>
<th>Flow Zone 2</th>
<th>Friction Loss AB+EF</th>
<th>Friction Loss BC+DE</th>
<th>Head Required Zone 2</th>
<th>Setpoint - Friction Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 gpm</td>
<td>600 gpm</td>
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<td>20</td>
<td>20</td>
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<td>600 gpm</td>
<td>0 gpm</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>

Excess head means wasted energy
Sensor Location

Zone 1

Zone 2

AFDs

DP Sensor

Pump Controller

Sensor Location
Single Sensor in Zone 2

Zone 1 requires 600 gpm at 25 ft
Zone 2 requires 600 gpm at 20 ft

<table>
<thead>
<tr>
<th>Flow Zone 1</th>
<th>Flow Zone 2</th>
<th>Friction Loss AB+EF</th>
<th>Friction Loss Zone 1</th>
<th>Friction Loss BC+DE</th>
<th>ΔP Zone1, Available</th>
<th>ΔP Avail - Friction Loss Zone 1</th>
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</thead>
<tbody>
<tr>
<td>0 gpm</td>
<td>600 gpm</td>
<td>5</td>
<td>0</td>
<td>20</td>
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<td>40</td>
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<td>5</td>
<td>25</td>
<td>0</td>
<td>20</td>
<td>-5</td>
</tr>
</tbody>
</table>

Inadequate head for Zone 1
Sensor in Zone 1

Zone 1 requires 600 gpm at 25 ft
Zone 2 requires 600 gpm at 20 ft

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<td>0 gpm</td>
<td>600 gpm</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>300 gpm</td>
<td>300 gpm</td>
<td>5</td>
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<td>20</td>
</tr>
<tr>
<td>600 gpm</td>
<td>0 gpm</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>25</td>
</tr>
</tbody>
</table>

Inadequate flow in Zone 2
What can we do...?

In this system:

• Single sensor in Zone 2 at 20 ft fails to provide adequate flow only when
  – load in Zone 2 < 50% and
  – load in Zone 1 > 75%

• Is this a predictable, recurring situation?
  – manual adjustment
  – programming

• Add a second sensor
Applying Multiple Sensors

Supply

Zone A
Zone B
Zone C

Pump Controller

AFDs

DP Sensors

Return
Use Multiple Sensors?

• Load
  – Similarity
  – Priority
  – Diversity

• One building or several

• Redundancy

• First cost vs operating cost
Summary

• Give priority to the needs of the branch.
• The rule of sensor location is simple and easy to apply:
  – If you have to use a single sensor, put it across the critical branch.
  – What’s the “critical branch”?
  – It’s the same one that determined the pump head.
• As we’ve seen, the analysis is more important than the “rule”.
Questions?

Variable Speed Pumping

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