Commissioning Chilled Water Systems
From Design to Occupancy

Anthony Avendano – Horizon Engineering Associates LLP

31/03/2016 – Fortaleza, CE
OUR COMPANY

Who We Are

Established in 1995
20 years of building commissioning

10 offices; 75+ employees

Professional certifications and registrations

90% of business is commissioning

Expert Knowledge of LEED
450+ LEED projects

Strong Operational Background
Objective

• What types of Equipment is part of the Chilled Water System
• What are the advantages of commissioning a chilled water system
• What is the commissioning process of chilled water systems
• What is required to effectively commission a chilled water system
Chilled Water Systems

• Central Plant CHW
  – CHW distributed to constituents

• Equipment Served
  – AHUs
  – FCUs
  – Secondary Loops
  – Tertiary loop
CHW Generation

[Diagram showing the process of CHW generation, including hot water supply, compressor, electricity, condenser, evaporator, expansion valve, and water flow.]
CHW System Overview
Types of CHW System Flow

• There are two basic types of CHW flow systems
  1. Constant flow CHW
  2. Variable Flow CHW

• Constant flow for smaller systems, not used much today due to energy

• Variable flow for larger systems
  – Can be primary secondary loop
  – Good for green design
Primary Secondary Loop
Connected Loads - Dual Temperature

- Different types of systems when the heating and cooling distribution systems are combined
  1. Two pipe system
  2. Four pipe systems
Two Pipe System

Fig. 24  Simplified Diagram of Two-Pipe System
Four Pipe System

Fig. 26 Four-Pipe Independent Load System
Chiller Types

• Reciprocating Liquid Chillers

• Centrifugal Chillers

• Modular Chillers (scroll, screw, magnetic bearing)
Reciprocating Chiller
Centrifugal Liquid Chillers
Modular Chillers

Bank of Chillers

Compressor Types
Condenser Water

• Used to remove heat from chiller and reject to another location

• Examples:
  o Air Cooled
  o Cooling Tower
  o Natural Water Source
Cooling Tower - Installed
Heat Exchangers

 Courtesy: Asea Brown Boveri Limited
Free Cooling
The United Nations (UN) complex spans over 17 acres and includes 6 buildings totaling 2.7 million sf, originally built in 1950.

UN’s problems were associated with aging building system and not the basic construction, a renovation of the complex was the most cost-effective way of replacing inefficient equipment.

UN’s chiller plant utilizes condenser water by two methods: a river water system and a cooling tower condenser water system.

Under normal operation, river water is used directly as condenser water utilizing a water side economizer mode.
Why Commission your Chilled Water System?

• **System Integration**
  – Individual pieces of equipment are not the whole system, e.g., chillers, cooling towers, pumps, heat exchangers, thermal storage tanks, etc.

• **Efficiency**
  – Design conditions

• **Safety**
  – Personnel and property protection
Commissioning Definitions

- Definition - “The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.”
  - ASHRAE Guideline 0

- Sets clear measurable goals for everyone
  - Verifies that the owner’s requirements are being met throughout the design and construction phases

- Establishes accountability
  - Changes the way people perform
  - Allows designers and contractors to measure success as well as deficiency
Value to Property Owners

- Training of operations staff
- Maximizing energy usage (utilities)
- Higher value of rentable SF
- Reduction in common deficiencies for typical design / install programs
- Peer review of existing operating protocols
Value of Commissioning

1. Identify potential issues during design
2. Identify/resolve issues during construction
3. Successful Day 1 operations. Confirm building equipment and systems operate and perform properly
4. O&M documentation is complete
Value of Commissioning

5. Operating staff is trained properly

6. Reduces operating and maintenance costs

7. Improves IAQ, occupant comfort and productivity

8. Reduces project closeout issues
What is the Commissioning Process for a Chilled Water System?

• Phases
  – Pre-Design Phase CX
  – Design Phase CX
  – Construction Phase CX
  – Post-Construction Phase CX
Commissioning Pre-Design Phase

- Document/review owner’s project requirements
- Scope and budget for commissioning
- Select CxA
- Create commissioning plan
- Working with the owner to select design strategies and goals
User Requirements

• Design Intent Document is the place to document the performance requirements of the central systems as defined to meet the needs of the users.
Installation Types

• New Installation
  – All components are new installation

• Existing
  – Repurposing existing equipment of spaces for a new design
Design Intent

- The chiller plant is useless as a stand-alone monument. It needs to meet the needs of the building users in order to be considered successful.
Common Design Issues

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

- 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
Controls

• Limit the speed at which the chilled water pump VFDs 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 dPs 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
Commissioning - Design Phase

- Document/review basis of design
- Refine the scope of commissioning
- Perform design review
- Update the commissioning plan
- Include commissioning requirements in construction documents
  - Including pre-functional checklists and functional performance test procedures
Design Review

- Review of the design must be in conjunction of the OPR.
- The review should be done with the mindset of an operator and not a designer. We need to bring a completely different perspective to the table. We don’t want to duplicate efforts.
Design Review

- “It’s cheaper to change it on paper than after it’s built”
- Should be completed before CD’s are issued
- Otherwise will lead to contractor change orders
- “Remember, we want Cx to save the project money not cause it to cost more”!
Submittals and Documentation

• Submittals - CxA requests all necessary documentation required to properly commission the project through the CM
  – May include: manufacturer installation, O&Ms, performance data, control drawings

• Pre-functional and Functional Checklists
  – Provides a full range of checks to determine that individual components, equipment and systems operate in accordance with the plans and specifications
Commissioning - Construction Phase

- Update commissioning plan and schedule
- Review submittals against commissioning plan, OPR, and BOD
- Review control sequences
- Update test procedures
- Document construction observations
- Develop systems/O&M manuals
Factory Testing

• Review controls
• Gather information
• Simulate conditions that may not be possible in field installation
• Ask questions
Simulated Controls Testing
Representing a Bank of Modular Chillers
**Sample Test Procedure**

- Simulate testing conditions not possible/safe in field

<table>
<thead>
<tr>
<th>Compressor High Current</th>
<th>Bank #1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TP/ER.14</strong></td>
<td>If Compressor Current increases above Cut-out Forced Setpoint, Forced Capacity condition occurs and compressor is forced to run at MIN capacity (settable).</td>
</tr>
<tr>
<td><strong>TP/ER.16</strong></td>
<td>If Compressor Current drops below Cut-in Forced Setpoint, meaning Forced Capacity condition is gone. Compressor keeps running at forced capacity for another Forced Capacity Off-Delay time before it gets back to normal operation.</td>
</tr>
<tr>
<td><strong>TP.16</strong></td>
<td>Simulate condition with high current reading above alarm set point for 30 seconds (adj)</td>
</tr>
<tr>
<td><strong>ER.16</strong></td>
<td>Compressor shuts down. Next compressor with least run hours starts. Manual acknowledgment of alarm required to reset unit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compressor High Pressure Sensor</th>
<th>Bank #1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TP/ER.16</strong></td>
<td>If Compressor High Pressure increases above Cut-out Forced Setpoint, Forced Capacity condition occurs and compressor is forced to run at MIN capacity (settable).</td>
</tr>
<tr>
<td><strong>TP/ER.17</strong></td>
<td>If Compressor High Pressure drops below Cut-in Forced Setpoint, meaning Forced Capacity condition is gone. Compressor keeps running at forced capacity for another Forced Capacity Off-Delay time before it gets back to normal operation.</td>
</tr>
<tr>
<td><strong>TP.18</strong></td>
<td>With compressor in operation, simulate condition with high pressure reading remains above high pressure cut out setting beyond accounted delay of — seconds (adj)</td>
</tr>
<tr>
<td><strong>ER.18b</strong></td>
<td>Compressor shuts down, alarm annunciated. Next compressor with least run hours starts. Manual acknowledgment of alarm required to reset unit</td>
</tr>
</tbody>
</table>
Checklists

• The components of the checklist:
  – Installation
  – Pre-functional
  – Functional and performance testing
  – Acceptance testing
Checklists

- Developing Cx Checklists
  - Checklists should document the entire history of a piece of equipment as it should have installation, pre-functional and functional checks within its fields.
Electrical Considerations

- Plant Operations - Emergency Power, critical systems etc. (i.e. server rooms)
- Uninterrupted Power Supplies
- Plant Safety - Lighting / Exit signs
Installation Review

- Design Details
- Specifications
- Submittal Requirements
- IOMs
- Code Compliance
- Mock-ups
- Good Practice (recommendations)
# Installation Comments

<table>
<thead>
<tr>
<th>#</th>
<th>Tag</th>
<th>Floor / Coordinate</th>
<th>Trade</th>
<th>Found By</th>
<th>Date Found</th>
<th>Applicable Spec</th>
<th>Issue / Impact / Recommendation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HX-402B-4</td>
<td>MR-50</td>
<td>Mechanical</td>
<td>AA</td>
<td>02/26/15</td>
<td>Drawing M501 detail 6</td>
<td>Vent not installed at high point as specified</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of heat exchanger piping detail](image)
Pre-Functional

- Static Testing
- Testing and Balancing (TAB)
- Vendor check-out sheets
- Point to Point
Functional

• Sequence of Operations (SoO)
• Safeties
• Performance
• User Interface
Sequence of Operations

**CHILLER PLANT CONTROL AND MODE DETERMINATION – PAGE 1 of 7**

**GENERAL PLANT CONTROL**

The Central Chilled Water Plant will be manually operated by the plant personnel from the BMS console, with the exception of certain emergency operations that will occur automatically. The BMS will provide advisory messages to the plant personnel as follows:

1. **CHILLED AND CONDENSER WATER PUMPS**
   - For detailed pump control sequences see section CHP-2.06 through CHP-2.13.
   - The operator will pre-select the pump stage order via the BMS console. The BMS will display pump status.
   - The operator will have the ability to remove a pump from rotation via the BMS by commanding the pump off. The BMS will ensure that the pump is not automatically returned to rotation unless requested.
   - Only one pump is allowed to be commanded off by the BMS. The BMS will automatically start the next pump and control the necessary fresh makeup water to maintain the chilled water temperature at the required setpoint.

2. **RIVER WATER PUMPS**
   - For detailed pump control sequences see page CHP-2.29.
   - River water pumps will be manually started from the BMS console by the Plant Operator. River water makeup water will be added to the BMS console for display.
   - The BMS will display pump status.
   - Once a pump has been manually commanded off by the plant operator the BMS will slowly ramp up the pump speed and modulate in unison with the active pumps to control river water flow at the required setpoint.

3. **RIVER WATER INTAKE SYSTEM**
   - For detailed pump control sequences see page CHP-2.29.
   - The river water intake gates are normally open at all times.
   - The following systems are normally shut down and are start and stop by a local controller based on differential pressure or time.
   - Screen and pumps are controlled by associated screen controllers.
   - Well suction pumps are manually controlled by the plant operator via local switches.

4. **CHILLERS**
   - For detailed chiller control sequences see sections CHP-2.23 through CHP-2.27.
   - The plant operator will manually control each chiller control system as desired based on current system demand parameters.
   - Chiller control system is enabled at the BMS will automatically control only active chillers and open the respective chilled water and hot water valves. CHW and HW pumps will automatically control to maintain minimum fluid flow through each active chiller.
   - Upon confirmation of disabled and base water flow the BMS will advise the plant operator to manually shut down the BMS. The BMS will advise the plant operator to enable the BMS.
   - Chilled water production will be regulated during periods when river water is inadequate. Chilled water production will be regulated during periods when river water is inadequate. Chilled water production will be regulated during periods when river water is inadequate. Chilled water production will be regulated during periods when river water is inadequate. Chilled water production will be regulated during periods when river water is inadequate.
**Mode Flow Schedule**

### Mode 1

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Chiller #2</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Chiller #3</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Chiller #4</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td></td>
</tr>
</tbody>
</table>

### Mode 2

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 3

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 4

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 5

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 6

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
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</table>

### Mode 7

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 8

<table>
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<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
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### Mode 9

<table>
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<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>

### Mode 10

<table>
<thead>
<tr>
<th>#</th>
<th>Equipment</th>
<th>RW Flow (GPM)</th>
<th>SCW Flow (GPM)</th>
<th>PCW Flow (GPM)</th>
<th>SCH Flow (GPM)</th>
<th>Differential Pressure (PSID)</th>
</tr>
</thead>
</table>
Control Valve Schedule
Automatic Control Valve
# CHW System Sample Checklist

<table>
<thead>
<tr>
<th>TP.2</th>
<th>Mode #4 shall be activated automatically whenever Chiller plant is operating on river water, normal power is lost and Steam Chiller is operating.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i. The following shall take place automatically when Mode #4 is enabled by the operator at the BMS workstation.</td>
</tr>
<tr>
<td></td>
<td>h. Once emergency power is available, Advisory message shall be displayed on the BMS workstation advising the operator to enable Mode #4.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ER.2.0</th>
<th>(1) River water (RWP-2 or RWP-3 as pre-selected) and chilled water pumps (CHWP-3 or CHWP-4 and CHWP-5 or CHWP-7 as pre-selected) shall start and operate on emergency power based on operator selection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER.2.1</td>
<td>CV-113 100% OPEN</td>
</tr>
<tr>
<td>ER.2.2</td>
<td>CV-101 100% OPEN</td>
</tr>
<tr>
<td>ER.2.3</td>
<td>CV-114 100% OPEN</td>
</tr>
<tr>
<td>ER.2.4</td>
<td>CV-119 Modulating CHW bypass valve CV-119 will modulate to maintain DP set point (adjustable)</td>
</tr>
<tr>
<td>ER.2.5</td>
<td>CV-103 100% CLOSED</td>
</tr>
<tr>
<td>ER.2.6</td>
<td>CV-104 100% CLOSED</td>
</tr>
<tr>
<td>ER.2.7</td>
<td>CV-105 100% CLOSED</td>
</tr>
<tr>
<td>ER.2.8</td>
<td>CV-115 100% CLOSED</td>
</tr>
<tr>
<td>ER.2.9</td>
<td>CV-116 100% CLOSED</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Result</th>
<th>05/20/15</th>
</tr>
</thead>
</table>

PASS
Cx Reports

• Field Observation Report (FOR) or Site Inspection Report
  – Documents each visit
  – Filled out each time the site is visited

• Deficiency Sheet
  – Must be completed with each deficiency
  – All data should be filled
On Site

• Communication - Team leader/PC/Owners Rep
• Scheduling your site visit
• Pre-planning precautions
  – Is a shut down required?
  – Disruption of service
• Notify CM/owner of your presence
• Report any issues found to appropriate PIC
• Note deficiencies
• Complete field report
Required Resources to Commission

- Team Participation and cooperation
- Checklist-Detailed bases of field visits
- Testing Equipment
  - Panametric
  - HDM
  - Data Loggers
  - Sensors
Panametrics
-Verify Flow Readings
Hydro Data Meter (HDM)

- Pressure readings and the performance curve:
Hydro Data Meter (HDM)

- Pressure readings and the performance curve:
Hydro Data Meter (HDM)

- Circuit Setters
Data Logging

• Utilized for the following Cx activities:
  – Trending of relative humidity and temperature of individual VAVs, AHU, RTU, AC Units, etc.
  – Verify motor operation (typically condensate pumps, air compressors, fuel oil pumps, etc.)
Additional Test Equipment in Cx Agents toolbox

- Sound meters
- Multi-meters
- Infrared Thermometer
- UE2000 Ultraprobe
Commissioning - Occupancy and Operations Phase

- Assist with maintenance management program
- Adjust for occupancy/warranty period
- Off-season testing
- Optional: lessons-learned meeting
- Optional: periodic re-commissioning
Acceptance

- The process of turnover and accepting the equipment. It is permissible to accept equipment provided that the items left to complete are identified and required to be completed.
- When is system complete?
- Who signs-off?
  - Construction Manager
  - Installing Contractor
  - Design Professional
  - CxA
As-Built Review

• Prior to completion of the project, HEA should review the as-built documentation for thoroughness and completion prior to going to the design team for final approval
  – How should this be performed?
Occupancy Phase

- Post occupancy
- Seasonal testing
- Warranty
- Training
- Ongoing Cx efforts
Warranty Management

• Warranty management is broken into two stages
  1. The 10 month back check and interview process that is required by LEED to ensure the building is working correctly
  2. The second part is if in fact there was a issue after the building was in operation, we would go back to verify the issue
Warranty Phase

• CxA role
• Deliverables
• Specification
• Extended warranty items
• Documentation of warranty periods
• Equipment and systems acceptance
• Warranty issues and review
Seasonal Testing

- Seasonal testing should be done on heating and cooling systems. This test is done on the system within its season of operation. Cooling tests in summer and heating tests in the winter. Try to use “design days”.
- There is the issue of fan coil units and heat pumps operating in the shoulder season. These units should also be checked during these off seasons.
Training

• Training Requirements
• Training Documents
• Syllabus Creating
• Documenting Training Sessions
Training

• Gives building operators chance to walkthrough operations and maintenance with the construction team to relay all applicable knowledge
Conclusions

• Proper commissioning of your chilled water system is essential to verify:
  – System operates per design intent
  – System run/performes efficiently
  – The staff are properly trained for turnover
  – To minimize call back for arising issues
QUESTIONS?

THANK YOU

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- New York, NY
- Long Island, NY
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