Chilled Water System Sequence of Operations

--SAMPLE--

Overview

The chiller system is comprised of three chillers: two larger centrifugals (CH-1 and 2) with good part load efficiency down to 25% and one reciprocating chiller (CH-3) about 1/3 the size of the centrifugals which has excellent part load efficiencies with eight stages of unloading.[1] There is no automatic chiller staging/selection optimization controls. The preferred sequence of chiller staging may vary by season. The primary pumps and condenser pumps run at constant flow. There is a secondary chilled water supply loop with variable speed drives on the pumps controlled from differential pressure, which is reset incrementally to operate at the lowest speed and pressure possible to satisfy the current load. There are three cooling towers, each assigned to one chiller. There is also a heat exchanger in the condenser water loop that rejects heat from ACU-1-10 and CRU-1, which requires the lead cooling tower to operate year-round. The building automation system (BAS) controls many of the chiller functions and setpoints and just enables others, and monitors a number of points through the chiller interface. BAS in brackets denotes where the BAS has control over the setting or parameter, rather than the local chiller packaged control panel.

Note: Sequences 6 and 33 are designed to defer to resetting the chilled water pressure down to its minimum, before the chilled water supply temperature is reset upwards.

[1] Including pump energy, at high loads (75% - 100% of chiller capacity) the centrifugals are more efficient, at 50% the centrifugals and reciprocating chillers are about equal and at 25% load the reciprocating chiller is more efficient. Since 25% load on the small CH-3 is expected to rarely be encountered for any period of time, CH-1 and 2 should primarily be used.

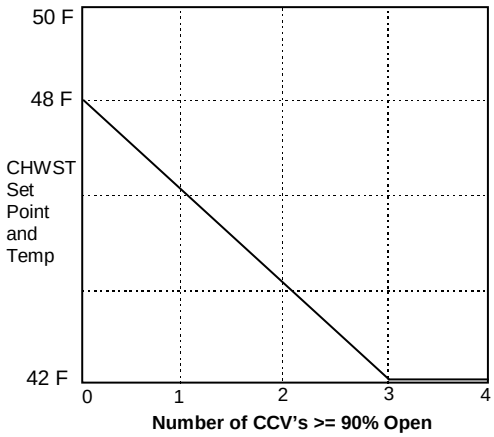
Chillers (CH-1, 2; 3)

1. Software [BAS] lead lag selector to allow any of the chillers to act as the lead machine.
2. Chiller will only be enabled to operate in AUTO upon the following conditions:
   a) Chiller scheduled ON [by BAS]
   b) OSAT > 56F [BAS] (shuts back OFF at OSAT < 54F)
   c) There are no active alarms that initiate a shutdown (reported to BAS and chiller panel)
   d) The cooling tower (CT) sump temperature is above its minimum [BAS and chiller panel]
   e) There is a call for cooling [BAS]
   f) Chilled and condenser water flows are verified [BAS and chiller panel]
3. Upon a call for cooling[2], the lead primary CHW pump starts and the pump status is confirmed ON via a current sensor in the BAS and flow is confirmed through a flow switch . Then the assigned lead chiller oil pump starts, then the lead condenser water pump starts and the pump status is confirmed ON via a current sensor in the BAS and flow is confirmed through a flow switch. There are 30-60 second delays between these pumps, per the chiller integral programmed settings (adjustable). The lead secondary CHWP then starts, ramping up from the minimum speed of 20 Hz via the variable frequency drive (VFD). (20 Hz was determined from performing an amps vs Hz test. 20 Hz is the lowest the motor can go without the amps beginning to increase.)

[2] A call for cooling is when a cooling coil valve (CCV) on one of the ON AHU's (AHU 1, 2, 3 or 4) is at least 15% open for at least 10 minutes. It is noted that the chiller packaged controls designate a call for cooling to be when the CHWST SPt is xx degrees lower than actual CHWT. This is inactive by being set to 0.

4. The lead chiller then starts with the prerotation vanes closed, which begin to open (closed to full open in ~ 3 minutes and full open to closed in ~1 minute).
5. The chiller maintains the CHW supply temperature at the setpoint [BAS] which ranges from 42F to 48F, based on a reset schedule, by modulating chiller capacity. CH-1 and CH-2 utilize prerotation vanes for capacity control, while the reciprocating chiller, CH-3, utilizes 8 stages of unloading.
6. Chilled water supply temperature (CHWST) reset [BAS]. The CHWST will have a default of 44F. The chilled water temperature will be reset upward only when the secondary pumps' speeds are at their minimum (as described in sequence 33). This is because, lowering pump speed with the differential pressure reset strategy (sequence 33) competes with CHWST reset, but DP reset will save more energy than resetting the chilled water temperature up, per ton of cooling.

   When the pump speed is at its minimum allowed, the CHWST reset routine is started and continues until one or more pumps are above their minimum speed, then hold the CHWST setpoint where it is until the pumps are at their minimums. Include a differential or time delay to prevent hunting. Likewise, CHWST setpoint will not lower from current conditions until all secondary pumps are at their maximum speed. This deference to the pressure reset is accomplished by starting the pressure reset downward when all CCVs are less than 90% open and not starting the CHWST reset upward until all CCVs are less than 80% open. When enabled, the CHWST reset sequence is: when all CCV's are less than 80% open, the CHWST setpoint (SPt) is at its highest value of a proportional range (48F). When three or more CCVs are 80% or more open, the CHWS SPt is at its lowest value (42F).



7. The CHWST reset will not increase when the return air relative humidity rises above 50% [BAS].
8. Chiller Staging. [All in BAS] There is no automatic chiller staging/selection optimization controls. The first lag chiller will be called for whenever the secondary CHW flow exceeds the primary CHW flow for 20 minutes (adjustable) as determined by flow meters AND the lead chiller is 95% loaded (by % of rated current).[1] For reference, each secondary CHW pump is design rated at 765 gpm. After a call has been maintained for the 20 minutes, the first lag chiller and pump sequence start as described above for the lead chiller. The second lag chiller will start under the same conditions and sequences. Whenever a lag chiller starts, all running chillers load and unload as necessary to be running within 5% of the same % load (based on rated current).

[1]This 95% load parameter will allow CH-3 to operate as the lead chiller, if desired, up to its full load before the much larger chillers (CH-1 and 2) start, since there is such a difference in primary CHW flow between CH-1 or 2 and CH-3, but no difference in the secondary CHW pump flows for the different chillers.

9. The last selected lag chiller and associated pumps stage OFF when the total primary CHW flow exceeds the total secondary CHW flow by the capacity (flow) of the last selected chiller's primary CHW pump for a 20 minute duration (adjustable).
10. All chillers and pumps will turn OFF when OSAT is < 55°F for _____ minutes [BAS], OR when all CCV's are less than 15% open for 10 minutes [BAS], OR when all air handlers are OFF [BAS], OR when an unoccupied schedule occurs (subject to night low limit conditions not being met) [BAS], OR when failure alarms are registered (BAS and chiller controls).

Misc. Chiller Features

11. Chillers will not cycle ON and OFF more than three times in a one hour period (chiller controls).
12. Alarm on chiller failure. Failure alarms must be manually reset. See other alarm modes in chiller operator's manual [alarms created by chiller controls, shutdown by chiller controls, message sent to BAS].
13. Demand limiting. [BAS] Demand limiting setpoint adjustment may be made through building automation system [BAS]. The demand limit (in sum of all chillers kW), when met will delay the start of the next chiller for one hour (adjustable). This sequence is different than the disabled stock sequence in the chiller packaged controls.
14. The BAS will monitor kW and calculate the load on the chiller using evaporator CHW flow and temperature differentials [BAS].
15. Provide emergency stop switch located adjacent to chiller room mandoor exit to stop all equipment in chiller room, except ventilation system. Ventilation fan to automatically operate on purge mode with activation of emergency stop switch.

Primary Chilled Water Pumps (CHWP 1`, 2, 3 for CH-1 & 2 and CHWP 4; 5 for CH-3)

16. Each primary CHW pump is assigned to one chiller [BAS]. Lead primary CHW pump starts upon a call for cooling per above chiller sequences. Lag primary CHW pump starts upon a call for the lag chiller per above chiller sequences [BAS]
17. Primary CHW pumps to operate continuously when their associated chiller is running. Primary CHW pumps provide constant flow through the chiller according to the manufacturer's recommendations: 675 gpm for CH-1 and CH-2 and 180 gpm for CH-3. Check balancing report for finals.
18. A standby (redundant) primary CHW pump is provided for CH-1 and 2 together and can be operated as active pumps after opening manual valves. A standby primary CHW pump for CH-3 will automatically change over [detected by BAS and chiller controller; pump control by BAS].
19. a) CHWP 1, 2; 3: Alarm on pump failure detected via a motor current switch and flow switch. Upon failure of lead pump, chiller shuts down and lag chiller should start automatically to meet load [BAS].
    b) CHWP 4; 5: Alarm on pump failure detected via a motor current switch and flow switch. Upon failure of lead pump, standby pump automatically starts [detected by BAS and chiller controller; pump control by BAS].

Chiller Condenser Water Pumps (CDP 1, 2, 3, 4; 5)

20. CD pumps CDP 1, 2, 3 for CH-1 and CH-2 and CDP 4, and 5 for CH-3 to operate continuously when their associated chiller is running. CD pumps provide constant flow through the chiller condenser

according to the manufacturer's recommendations: 1350 gpm for CH-1 and CH-2 and 360 gpm for CH-3.

21. A standby (redundant) CD pump is provided for CH-1 and 2 together. The pump can be operated as an active pump after opening and closing appropriate manual valves. A standby pump is provided for CH-3 and will automatically changeover [BAS].

22. a) CDP 1, 2; 3 (CH-1; 2): Alarm on pump failure detected via a motor current switch and flow switch. Upon failure of lead pump, chiller shuts down and lag chiller should start automatically to meet load [detected by BAS and chiller controller; pump control by BAS].
    b) CDP 4; 5 (CH-3): Alarm on pump failure detected via a motor current switch and flow switch. Upon failure of lead pump, standby pump automatically starts [detected by BAS and chiller controller; pump control by BAS].

Cooling Tower (CT-1, 2; 3)

21. Cooling towers operate with operation of their associated condenser water pump or with the operation of the ACU condenser pump (see Seq. 41). With operation of a pump, open selected tower supply (isolation) valve and allow tower temperature control to function [BAS].

22. Software selector to allow any tower to be the lead tower, second tower or third tower [BAS].

23. a. CT Sequences. [All BAS] The CT during the normal cooling season rejects heat from the chillers and returns as cool of water as can be efficiently achieved to the chiller's condenser. A reset schedule is used: ECDWT setpoint equals the outside air wet bulb temperature plus 7°F, but not lower than 65°F, nor higher than 83°F.

    The CT will try and maintain the ECDWT setpoint temperature by first modulating the normally open bypass valve, with no water going over the top of the tower. When the valve is in full bypass AND the ECDWT is greater than the ECDWT setpoint, the bypass valve begins to close and the normally closed CT control valve associated with the respective CT and CDW pump, opens 100% and water goes over the respective CT. (See (b.) for additional details). The bypass valve continues to modulate open to try and maintain the ECDWT setpoint without the CT fans.

    When the bypass valve is fully closed and the ECDWT reaches 2°F above the setpoint, the setpoint is achieved by successive cooling tower stages. There are six CT stages:

CT Stage	CT1 Low Fan	CT2 Low Fan	CT3 Low Fan	CT1 High Fan	CT2 High Fan	CT3 High Fan
0						
1	X					
2	X	X				
3	X	X	X			
4			X	X		
5				X	X	
6				X	X	X

    Every four minutes the ECDWT is polled. When the ECDWT reaches 2°F above the setpoint, the tower stage is increased by one. If the ECDWT is more than 1°F below setpoint, the CT stage is lowered by one.

    b. If only CH-3 is ON, only the CT cell fan currently ON will run. (One CT is always ON to serve HE-1). Upon CH-3 AND CH-1 or CH-2 being ON together, then another CT cell will come ON.

With only CH-1 OR CH-2 ON, two CT cells will be ON. The intent of these sequences is to not waste CT fan energy when not very much water is flowing over the tower.
c. The lead CT isolation valve modulates with the bypass valve inversely proportional. This is required to 1) provide warmer water, faster to CH at startup, 2) to prevent excess water from overflowing the CT basin, and 3) even with the small heat exchanger (HE-1) running, some water still goes over the top of the tower resulting in freeze potential. This strategy will prevent water from going over the tower during these conditions.

24. When a lag chiller comes on line, its condenser water pump and associated CT come on line [BAS].

25. A multiple position CT sump or basin level sensor provides the following information to the BAS:
    a) High water alarm
    b) Low water alarm
    c) Open make up water valve
    d) Closed make up water valve
    e) System shutdown
    Alarm on heater stage failure detected via current sensing switch.

26. Cooling tower sump two stage heaters shall be controlled to maintain a sump temperature of 45°F with the following schedule [BAS]:

	ON (°F)	OFF (°F)
Stage 1	48	50
Stage 2	45	48

    CT1 and CT2 have a sump temperature sensor. Each CT area in the sump has a 2 stage heater. All heaters of all CTs of a given stage act together on indication by any of the two sensors of low temp.

27. Cooling tower makeup valve (one for all three CT's) to maintain sump water level. Upon sensing a drop in water level, slowly open makeup valve in industrial cold water line [level sensor by BAS].

28. Alarm on pony and main motor upon motor failure detected via current sensing relay. Upon failure of fan motor, lag CT starts automatically [BAS].

29. Alarm on excessive vibration detected via vibration limit switch. Upon failure of fan, lag CT starts automatically [BAS].

30. The lead cooling tower operate during periods, when the chillers are OFF (even during winter) to maintain a heat rejection source for the heat exchanger HE-1, which serves approximately 40 tons of cooling from ACU-1 thru 10 and CRU-1. See sequences for CDP 6, 7, 8; 9.

Secondary Chilled Water Pumps (CHWP 6, 7; 8)

31. Software lead/lag function allows any of the secondary pumps to act as the lead pump [BAS].

32. Lead secondary CHW pump starts upon a call for cooling per above chiller sequences. Lag secondary CHW pump starts upon a call for the lag chiller per above chiller sequences [BAS].

33. Differential pressure control. [All BAS] The objective is to always have one CCV 90% open so the pumps operate at the lowest speed and pressure possible to satisfy the current load. Every 5 minutes the CCV's are polled. A PI loop that changes the secondary pump discharge differential pressure setpoint to maintain the remote (local on 8th floor) DP setpoint to maintain the most open CCV at 90% open (with a deadband of +/-_____). For example: When the most open CCV is more than 90% open, a PI signal is calculated and changes the local DP setpoint upward. When the local DP setpoint is not being met, a PI signal is calculated and sent to the pump discharge pressure setpoint and it is raised accordingly. Through another PI loop, the variable speed (frequency) drive (VFD) increases the pump motor speed to meet the raised pump differential (discharge) pressure setpoint.

The remote DP setpoint will be maintained between maximum and minimum pressures. The maximum pressure limit is the pressure required to provide full flow to all CCV's simultaneously (per TAB). The minimum pressure limit is the pressure correlating to the lowest speed the pump motor is allowed to be operated at (per motor manuf. and TAB). Maximum pressure limit:_____psi.
Mininum pressure limit:_____psi.
The VFD internal settings will allow the VFD to run the pumps to their minimums.
Number of remote DP sensors: _____. Locations: _____
_____

**Differential Control and CHWST Reset. The DP reset and CHWST reset compete with each other for control of the building. Seq. 6; 33 have the net effect of deferring to the pressure reset over the CHWST reset. The CHWST reset won't come into play until all the CCV's are less than 80% open, which won't occur until the pressure reset is at its minimum.

34. Pump Staging. [BAS] With one secondary CHW pump running, when the total secondary CHW gpm exceeds the lead secondary CHW pump design gpm for 10 minutes (all adjustable), start the first lag pump. Both pumps converge and run at similar speeds and gpm to maintain the common discharge pressure differential setpoint and the remote DP setpoints. If the total secondary gpm exceeds the total design gpm of the running pumps (lead and 1st lag) for 10 minutes, start the second lag pump. All three pumps converge and run at similar speeds and gpm to maintain the common discharge pressure differential setpoint and the remote DP setpoints.
35. During reducing load as the DP increases: when the total secondary CHW gpm has reduced to be equal to or less than the sum of the first two selected pumps' gpm for 10 minutes (adjustable), the second lag secondary CHW pump shuts OFF. Similarly, when the total secondary CHW gpm, with two pumps ON, has reduced to be equal to or less than the gpm of the lead CHW pump for 10 minutes, the first lag pump shuts OFF.
36. The controller shall monitor rpm and gpm of the pumps and shall not allow operation of the pumps at or beyond their published "End of Curve" [BAS]. Upon sensing an end of curve condition, via a pump curve equation, the next pump will be staged ON.
37. Alarm on pump failure detected via current sensing switch. Upon failure of pump, next lag pump starts automatically (BAS and chiller controller).
38. Alarm on failure of VFD [BAS].
39. The rpm of secondary CHW pumps to be monitored by BAS.
40. For coil freeze protection during smoke exhaust system operation, pumps CHWP-6, 7; 8 to run under NORMAL control and all cooling coil valves to open with operation of respective AHU when smoke exhaust system (EF-10) is in operation AND outside air temperature is below 40°F [BAS].

41. **ACU Condenser Water Pumps (CDP 6, 7 and 8; 9) and HE-1**

42. The lead cooling tower operates during periods, when the chillers are OFF (even during winter) to maintain a heat rejection source for the heat exchanger HE-1, which serves approximately 40 tons of cooling from ACU-1 thru 10 and CRU-1. CDP 6 or 7 (one is redundant) provides water from the heat exchanger to the cooling towers. CDP 8 or 9 (one is redundant) services the ACU's and CRU-1 from HE-1. The selected CD pump for each loop (CDP 6 or 7 AND 8 or 9) operate continuously [BAS].

43. During chiller OFF periods, the ECDWT setpoint and CT bypass valve and fan staging parameters remain the same as during chiller ON periods (see above).

44. Alarm on pump failure detected via current sensing switch. Upon failure of any pump, standby pump automatically starts [BAS].

General Chiller Operation During Unoccupied Periods

45. Unoccupied Operation. During scheduled unoccupied hours at night or weekends, the chiller system is in standby, except the cooling tower operates as required to maintain 65°F condenser water to the heat exchanger HE-1 for heat rejection of ACU-1 thru 10 and CRU-1.

46. Winter Operation. During winter, the chiller system is in standby, except the cooling tower operates as required to maintain 65°F condenser water to the heat exchanger HE-1 for heat rejection of ACU-1 thru 10 and CRU-1.