4.32 MASTER/SLAVE CONTROL FOR TWO CHILLERS

4.32.1 General

This function shall allow to perform master/slave plant control between two chillers linked by the CCN network. Master and slave chiller need to operate on the same bus. Master/slave operations shall operate in cooling or heating mode.

To operate properly, the master and the slave chillers must have an additional CHWS sensor located on the common chilled leaving piping when the water control is done on the outlet side. This CHWS sensor shall be connected on each chiller basic board. When the water system control is done on the inlet side no additional CHWS sensor is required.

Parallel chiller control with dedicated pumps is recommended. Chiller must start and stop its own water pump located on its own piping. If pumps are not dedicated for each chiller pimping, chiller isolation valves are required: each chiller must open and close its own isolation valve through the control (valve shall be connected to the pump outputs).

Water system control with no individual chiller pump control is feasible. It is not recommended when the water control is done on the outlet particularly if the system load is low or if the control point is close from the freeze water tripping point (because of system instability that can be caused by the freeze protection override). System flow is constant even if the master or the slave chiller is stopped. In that case, the system pump shall be controlled by the master chiller.

Series chillers with dedicated primary pumping and constant flow shall be feasible but not recommended (because of plate heat exchanger risks) on single circuit units. Series configuration shall not be allowed for dual circuit units. Pump start/stop must be controlled externally. Each series chiller must control its own isolation and bypass valves: stopped chiller must be isolated from water flow (chiller pump command shall be used for valves control. Each chiller must open and close its own chilled isolation valve).

The master chiller shall monitor all external commands as start/stop, demand limiting or setpoint select. It needs to be started in *Master* operating type. The slave chiller must operate in CCN mode. If the master chiller is turned off while the master/slave function is active then, the slave chiller shall be stopped.

The master/slave linkage shall not be allowed to operate if any one of the slave chiller CTRL_PNT, DEM_LIM, LAG_LIM, CTRL_PNT HC_SEL or LCW_STPT variables has a force priority higher than a control force. In that case, the master slave operations shall not be allowed or shall be disabled.

The control of the slave chiller shall be done through commands emitted by the master chiller. The slave chiller has no action in the master/slave operations: it shall only verify that CCN communication with its master is correct.

The master function shall provide the ability to select a lead chiller among the master and the slave. Selection shall be based on the delta between the master and the slave run hours and shall try to optimize the runtime hours. If this function is unused then, the lead chiller shall always the master. Lead/lag changeover between the master and the slave due to hour balance shall occur during chiller operations odd days at 12:00 a.m.

The lead chiller shall always be started first and the lag chiller shall be maintained at zero percent capacity through master forcing the lag demand limit value (LAG_LIM) to 0%. The lag water pump shall be maintained off. When the lead chiller cannot be loaded anymore (because it is loaded at its full available capacity or at the master demand limit value) then the lag start timer is started. When the lag start timer is elapsed, if the error on the master controlled setpoint is greater than 3^F and if the pulldown time is elapsed then, the lag chiller water pump shall be turned on (if required by configuration) and the lag chiller shall be allowed to start through master forcing the lag chiller demand limit value (LAG_LIM) to its own demand limit value. To ensure that the lag chiller will be unloaded first in case of water load decrease then, the lead chiller setpoint error shall be reset downwards of 4^F provided that the lag capacity is not zero.

When capacity lead/lag capacity balance is not selected, to ensure that the lag chiller will be unloaded first in case of water load decrease then, the master shall force the lead chiller setpoint error shall be reset downwards of 4^F provided that the lag capacity is not zero.

If lead/lag capacity balance is selected, once the lag chiller has started, the master shall try to keep the difference in capacity between lead and lag less than 20%. The master shall then be responsible for water loop capacity calculation,

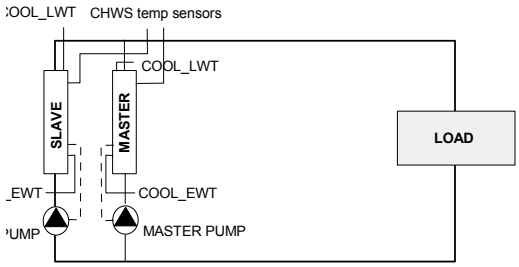
and shall determine which one between lead and lag to increase or decrease capacity by writing the STAGE_DT variable.

The lead pulldown time tells how long after starting the lead chiller (one time after the master chiller status has been manually started) before checking whether to start an additional chiller. This time delay gives the lead chiller a chance to remove the heat (in cooling) or to add heat (in heating) that the chilled water loop picked up while being stagnant during an unoccupied period. Thus, the routine is giving the lead chiller an opportunity to pull down the loop temperature before starting another chiller.

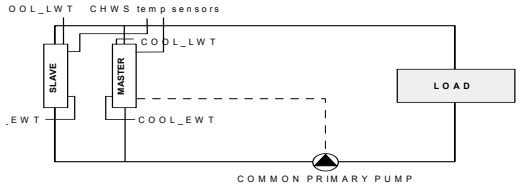
If a communication failure is detected between the master and the slave then, all master/slave functions shall be disabled and chillers shall return to standalone operations until communication is reestablished.

Note: to ensure that no compressor is started before the flow rate is correctly established then, the water flow control is absolutely required on the lag chiller for master slave operations.

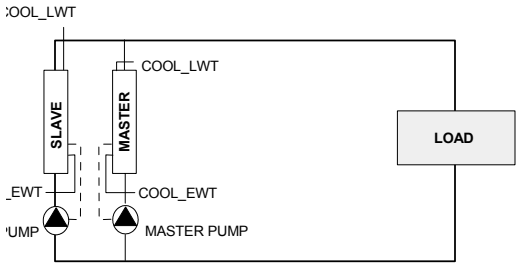
The figures below illustrate master/slave application for the most common plant layouts. Those figures are not exhaustive.



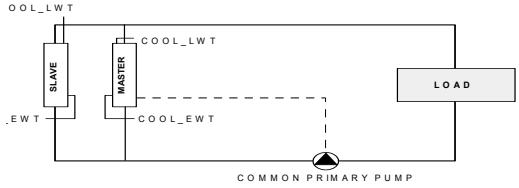
Typical parallel Master/slave chillers, dedicated primary pumping, variable flow Leaving water control



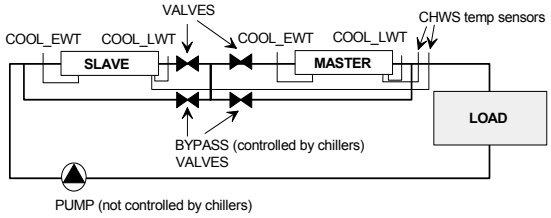
Typical parallel Master/slave chillers, common primary pumping, constant flow Leaving water control



Typical parallel Master/slave chillers, dedicated primary pumping, variable flow Entering water control



Typical parallel Master/slave chillers, common primary pumping, variable flow Entering water control



Typical series Master/slave chillers, dedicated primary pumping, constant flow Leaving water control option

4.32.2 Process

Inputs

ms_sel	Master/Slave select
slv_addr	Slave chiller address
str_tim	Lag start timer
ll_bal	Lead/lag balance
ll_bal_d	Lead/lag balance delta
lag_pump	Lag pump control select
heatcool	Unit current heat/cool mode
master_status	master status
cap_dt	Master error on control point
CHIL_S_S	CCN chiller start/stop

CTRL_PNT	Control point
DEM_LIM	Master demand limit
LCW_STPT	CCN leaving Chiller water setpoint
lwt_opt	Master and slave LWT option
CPOC table 621H	SM equipment table

Outputs

CHIL_S_S	CCN chiller start/stop
CTRL_PNT	Control point
DEM_LIM	Demand limit
LAG_LIM	Lag limit
LCW_STPT	CCN leaving Chiller water setpoint
CPOC table 621H	SM equipment table
mstslv	Unit Master/Slave type
slv_stat	Slave chiller chilstat value
slv_capt	Slave chiller total capacity
master_enabled	Master control status
slave_enabled	Slave control status
ms_activ	Master/Slave control active
l_strt_d	Lag start delay
ll_hr_d	Master/slave run hours delta
ll_state	Master lead/lag current state
lead_select	Master/slave lead select
ll_chang	lead/lag changeover status
llcap_eq	Master/slave capacity balance control select
ms_error	Master/slave error
mode[27]	Master/Slave control active

Process

The following variables will be used below:

master_oper_typ	Master operating type
master_heatcool	Master heatcool status
master_ctrl_pnt	Master control point
slave_chilstat	Slave chilstat value in table 621H
master_t_cap_t	Master candidate additional capacity
master_dem_lim	Master current demand limit
lead_cap	Lead chiller current capacity
avail_lead_cap	Lead chiller available capacity
lag_cap	Lag chiller current capacity
master_cap_max_flag	master chiller cap_max_flag
slave_cap_max_flag	slave chiller cap_max_flag (in slave table 621H)
master_cap_max_flag	master chiller cap_max_flag
master_next_add_cap	master next added capacity in percent(in slave table 621H)
master _next_decr_cap	master next decreased capacity in percent (in slave table 621H)
slave_cap_max_flag	slave chiller cap_max_flag (in slave table 621H)
slave_next_add_cap	slave chiller next added capacity in percent (in slave table 621H)
slave_next_decr_cap	slave chiller next decreased capacity in percent (in slave table 621H)
lag_start_timer	Timer for lag start delay
master_ontime	Master hr_mach
slave_ontime	Slave hr_mach (in slave table 621H)

Both chiller configured for master ahe lead chiller (one time after the master chiller status has been manually started) before checking whether to start an additional chiller.

If the master was switched manually from off to on then start the pulldown timer.

Process for the master unit

if ms_sel = master then, all the following routines shall be executed by the master unit every 15 seconds.

General

All commands shall be emitted by the master chiller even if it is currently the lag. It shall control operations on itself and on the slave by utilizing forces on three points with a force **priority of 7** (control force):

LAG_LIM	Lag demand limit variable
DEM_LIM	Demand limit
HC_SEL	Heat Cool select
CTRL_PNT	Control point (slave)
LCW_STPT	Leaving chilled water setpoint (used for master/slave, SM or CSM III control)
STAGE_DT	Lead/lag balance capacity control variable

The master shall use the Write variable command with a PID of 4AH to force the Slave. This shall allow the slave chiller application to know when the variable is written to. The slave chiller applications shall use a force priority of 7 to force its variables excepted the CHIL_S_S variable that shall keep the Slave under control even if the communication is important in the bus (no force done within 2 mn will cause a loss of communication). The Slave shall also use force priority 7 (controlling POC force) when disabling master control.

The slave CHIL_S_S variable will be updated periodically (every 30 seconds). This will allow the slave to detect when the master is operational.

- The master shall read the slave table 621H (see section 4.20.6.3) such as to get slave operating information:
- chilstat provides the slave chiller status (off, local, CCN, shutdown)
- lagstat provides slave configuration parameters
- cap_t slave capacity running
- hr_mach slave runtime hours
- cap_max_flag slave max. capacity flag
- if cap_t_av slave available capacity running
- next_add_cap slave next added capacity run in percent
- next_decr_cap slave next decreased capacity run in percent

In addition, the master shall detect communication failure with the slave through the table 621H reading command.

Master error detection

If the unit is a master (ms_sel = master) and any one of the following conditions is verified then, an error (ms_error) shall be issued:

- The master water pump is not configured (pump_seq = 0) while the control of the lag unit pump is required (lag_pump = 0) [ms_error = 1].
- Master (element #) and slave (slv_addr) have the same network address. Only address element number shall be verified since both units must be located on the same CCN bus [ms_error = 2].
- There is no slave configured at the slave address: lagstat = 0 in slave table 621H [ms_error = 3].
- Slave pump_seq incorrect configuration shall be detected through lagstat (lagstat = 1) in table 621H [ms_error = 4].
- There is a conflict between the master and the slave ewt option: the master is configured for ewt control while the slave is configured for lwt control. Slave lwt_opt configuration shall be detected through lagstat in table 621H [ms_error = 5].
- There is a conflict between the master and the slave ewt option: the master is configured for lwt control while the slave is configured for ewt control. Slave ewt_opt configuration shall be detected through lagstat in table 621H [ms_error = 6].
- There is a conflict between the master and the slave pump option: the master is configured for lag pump control while the slave is not configured lag pump control. Slave lag_pump configuration shall be detected through lagstat in table 621H [ms_error = 7].
- There is a conflict between the master and the slave pump option: the master is not configured for lag pump control while the slave is configured for lag pump control. Slave lag_pump configuration shall be detected through lagstat in table 621H [ms_error = 8].

- The slave chiller is in local or remote control (ctrl_typ = local or ctrl_typ = remote): chilstat = 3 in table 621H [ms_error = 9].
- The slave chiller is down due to fault: chilstat = 5 in table 621H [ms_error = 10].
- The master chiller operating type is not Master: master_oper_typ ≠ master [ms_error = 11].
- No communication with slave [ms_error = 12].
- Master and slave heatcool status not consistent in operation (see description below) [ms_error = 13].

Master chiller state determination

The master unit shall be the chiller being configured in the MST_SLV table as master. When the master operating type is *Master* then, it shall monitor all external commands as start/stop, demand limiting, setpoint select, or setpoint reset even if it is not the current lead chiller (see below the description of lead chiller). Those commands shall always be applied to both master and slave chillers (i.e. a stop command shall stop both master and slave chillers). Master/slave control shall not operate if the slave chiller is not in CCN or if the slave is controlled through network by a device with higher priority. In addition, master/slave function shall not be allowed in case of master error (see above).

If ms_sel = master and
ms_error = 0 and (no master/slave error is active)
(slave_chilstat = 0 or slave_chilstat = 1) (see chilstat update in section 4.26.6)
then,
master_enabled = true (master chiller function is enabled)
mode[27] = on
ms_activ = true (to be displayed in the master M_MSTSLV Maintenance table)

else,
master_enabled = false
mode[27] = off
ms_activ = false

Lead/lag chiller determination

This function shall determine whether master or slave chiller is the lead. The lead is always started and loaded first. It is unloaded last. The lag is started and loaded last (when the lead is already at full load). It is unloaded first. If the lead lag balance select has not been enabled then, the lead chiller shall always be the master chiller. If the lead lag balance select has been enabled then, the lead chiller shall be determined upon unit operating hours: if the hours delta between the master and slave chiller is greater than the configured lead/lag balance delta then the chiller with the smallest operating hours shall be the lead (calculation once per day).

This function shall be executed by the master if master_enabled = true.

Master/slave hours delta calculation

ll_hr_d = master_ontime - slave_ontime

Lead and lag determination

Lead/lag determination upon master/slave operating hours shall be executed every odd day at 12 a.m. or every time the master chiller is started. If the lead/lag balance function is not configured then, the lead unit shall be always the master. If balance is selected then, the lead chiller shall be changed if the unit on time delta is greater than the configured balance delta value.

if ll_bal = no then, lead_select = master
else,
if master has just switched from the off to the delay state or (time = 12 a.m. and day is odd) then,
if ll_hr_d > ll_bal_d then, lead_select = slave
else, lead_select = master

Master chiller start and setpoint commands

Start commands shall be emitted if the master chiller status is on (see the master status update in section 4.5.2). When the master status is active then, the master shall force the slave *CCN Chiller Start/Stop* variable to enable and shall force

the slave *Control Point* variable to its own control point value. When the master status is off then, the master shall force the slave *CCN Chiller Start/Stop* variable to disable until the slave chiller is off.

```
if master_enabled = true then,
   if master_status = on then,
      force slave CHIL_S_S = enable
      force slave HC_SEL = master_heatcool
      force slave CTRL_PNT = master_ctrl_pnt (master control point) every 30 seconds
   else, force slave CHIL_S_S = disable
else,
   if slave_chilstat = 1 then, force slave CHIL_S_S = disable
```

Lead chiller pulldown timer initiation

The lead pulldown time tells how long after starting the lead chiller (one time after the master chiller status has been manually started) before checking whether to start an additional chiller.

If the master was switched manually from off to on then start the pulldown timer.

Slave heatcool mode control

The lead/lag control shall be disabled if the master and slave heatcool status are not consistent.

If lead_cap > 1% and slave_heatcool ≠ master_heatcool then, ms_error = 13

Leader max. capacity flag determination

This flag means that the lead capacity cannot be increased anymore because the lead is loaded at its available capacity or because the capacity cannot be increased because of demand limit value (see section 4.15.2).

```
If lead_select = master then, lead_cap_max_flag = master_cap_max_flag
else, lead_cap_max_flag = slave_cap_max_flag
```

Lag start timer initiation

The timer for starting lag shall be counted down when the lead chiller capacity cannot be increased anymore (lead_cap_max flag is active). The timer shall be disabled and reset if the above condition is no more satisfied. If the lead lag changeover is active, then the lag start timer shall be ignored.

```
if lead_cap_max_flag = true then,
   count down lag_start_timer
else, disable lag_start_timer, lag_start_timer = lstr_tim

if ll_chang = yes then deactivate Lag Start Timer (lstr_tim)
```

Master error calculation

The error on the master control point shall be the value computed in the master capacity control function excepted when the water control is done on the inlet with no flow on the master unit (pump halted): in that case, the entering temperature value provided by the master is not consistent and the error shall be computed using the entering water of the slave unit (through table 621H).

```
if (lwt_opt = yes or lag_pump = 1 or lead_select = master) then, master_dt = cap_dt
else,
   if heatcool = cool then, master_dt = ewt - ctrl_pnt        (ewt value in table 621H)
   else, master_dt = ctrl_pnt - ewt                           (ewt value in table 621H)
```

Master and slave capacity limitation control

The lead chiller capacity shall be forced to the master demand limit. The lag chiller capacity shall be limited to 0% (through lag_lim variable) while the lead capacity can be increased. When the lead capacity cannot be increased anymore (lead_cap_max flag is active) then, the lag capacity shall be limited to the master demand limit provided that the lag start timer is elapsed and that the error on the master control point is greater than 3^F and that the master pulldown time is elapsed. If the lead chiller is shutdown, then the lag start timer shall be ignored. This routine shall not run if the lead lag changeover is active.

lead LAG_LIM = master_dem_lim
if ll_chang = no then,
  if [lstr_tim elapsed or lead shutdown] and lead_cap_max_flag = true then,
    if [lag_cap < 1% and master_dt > 3^F and master pulldown time elapsed] then,
      force lag LAG_LIM = master_dem_lim
  else,
    force lag LAG_LIM = 0%

Lead chiller setpoint offset:

To ensure that the lag chiller will be unloaded first then, the lead chiller setpoint error will be reset downwards when the lag capacity is not zero and the lead lag changeover is not active. See dt calculation in capacity control function (section 4.13.2).

if [lag_cap > 1% and ll_chang = no] then, force lead LCW_STPT = 200°F
else,
  force master LCW_STPT = master_ctrl_pnt
  force slave LCW_STPT = master_ctrl_pnt

Lead and lag changeover initiation

The lead lag changeover shall become active during operations if any one of the following condition is satisfied:
If the lead unit has been changed.
The lag chiller capacity is not zero while the lead chiller capacity can still be increased (lead_cap_max_flag = false).

ll_chang = no
if old_lead_select ≠ lead_select then, ll_chang = yes
if lag_cap > 1% and lead_cap_max_flag = false then, ll_chang = yes

Changeover session

When the changeover has been activated then, the new lag chiller capacity shall be decreased until the new lead chiller is loaded at its full available capacity or at the master demand limit.

if ll_chang = yes then,
  lead_select = [1- lead_select] (the old lead is now the lag and the old lag is now the lead)
  the following steps shall be executed successively:
Step #1: the master shall force lag chiller LAG_LIM value to the smallest of lag chiller current capacity or master_dem_lim values.

if lag_cap > master_dem_lim then, force lag LAG_LIM = master_dem_lim
else, force lag LAG_LIM = lag_cap

Step #2: when step #1 is completed then, master shall decrease the lag chiller demand limit of -25% every 5 minutes. This shall allow a slow transition between the lead and the lag.

-
- loop until: lag LAG_LIM value < 1% or lead_cap_max_flag = true
- force lag LAG_LIM = [lag_cap - 25%] every 5 minutes
- end loop
-
- Step #3: when step #2 is completed then, the master shall deactivate the lead lag changeover flag.
- ll_chang = no

Master communication failure

If the communication is lost between the master and the slave then, the master shall return to its native control: master_enabled = false

if ms_error = 2 then,
  force LCW_STPT = master_ctrl_pnt
  master LAG_LIM = auto (priority 7)
  alarm[69] shall be tripped

Process for the slave unit

Slave error

If the unit is a slave (ms_sel = slave) and any one of the following conditions is verified then, an error (ms_error) shall be issued:

- The slave water pump is not configured (pump_seq = 0) while the control of the lag unit pump is required (lag_pump = 0) [ms_error = 1]. Set lagstat = 1 in table 621H.
- The slave chiller is in local or remote control (ctrl_typ = local or ctrl_typ = remote) [ms_error = 10]. Set chilstat = 3 in table 621H.
- The slave chiller is down due to fault [ms_error = 10]. Set chilstat = 5 in table 621H.
- Communication was enabled with master and is lost [ms_error = 12].

Slave capacity command

if slave_enabled = true and llcap _eq= true then,
 if STAGE_DT = 1 then stage_delta = ADD_STAGE
else,
 if STAGE_DT = 2 then stage_delta = REMOVE_STAGE
  else if STAGE_DT = 0 then stage_delta = 0

Slave chiller state

The slave unit shall be the chiller being configured in the MST_SLV table as slave. It shall receive commands from the master unit.

If ms_sel = slave and
- ms_error = 0 (slave error is active)
- slave_chilstat = 0 or slave_chilstat = 1 (see chilstat update in section 4.26.6)
- dem_lim = 100% (no external demand limit is applied to the slave)

then,
  slave_enabled = true (slave chiller function is enabled)
  mode[26] = on
  ms_activ = true (to be displayed in the slave M_MSTSLV Maintenance table)
else,
  slave_enabled = false
  mode[26] = off
  ms_activ = false

Slave demand limit command

if slave_enabled = true then,
 force slave DEM_LIM = 100%
else,
 slave DEM_LIM = auto
 slave LAG_LIM = 100%, LAG_LIM = auto

Slave water pump control

See the slave chiller water pump control in section 4.7.

Slave communication failure

The slave shall check communications with master by detecting a write variable command on CHIL_S_S. This command is emitted every 15 seconds by the master. If communication has not been received from the master during 120 seconds then, the slave unit shall return to its native control.

if ms_error = 2 then,
  slave_enabled = false
  force LCW_STPT = slave_ctrl_pnt
  slave CTRL_PNT = auto (priority 7)
  slave DEM_LIM = auto (priority 7)
  slave LAG_LIM = auto (priority 7)
  alarm[69] shall be tripped

Master/Slave Error

The following error shall be updated in the M_MSTSLV Maintenance table (priority order):

Master/Slave alarm code			
Error code	**Master**	**Slave**	**Description**
0	x	x	Normal
1	x	x	The master or slave water pump is not configured while the control of the lag unit pump is required (lag_pump = 1)
2	x		Master and slave units have the same network address.
3	x		There is no slave configured at the slave address
4	x		Slave pump_seq incorrect configuration
5	x		There is a conflict between the master and the slave lwt option: the master is configured for ewt control while the slave is configured for lwt control.
6	x		There is a conflict between the master and the slave lwt option: the master is configured for lwt control while the slave is configured for ewt control.
7	x		There is a conflict between the master and the slave pump option: the master is configured for lag pump control while the slave is not configured for lag pump control.
8	x		There is a conflict between the master and the slave pump option: the master is not configured for lag pump control while the slave is configured for lag pump control.
9	x	x	The slave chiller is in local or remote control (chilstat = 3)
10	x	x	The slave chiller is down due to fault (chilstat = 5)
11	x		The master chiller operating type is not Master: master_oper_typ ≠ master
12	x	x	No communication with slave.
13	x		master and slave heatcool status are not the same.

Note: see section 4.24.5.4 for master and slave alarm 54