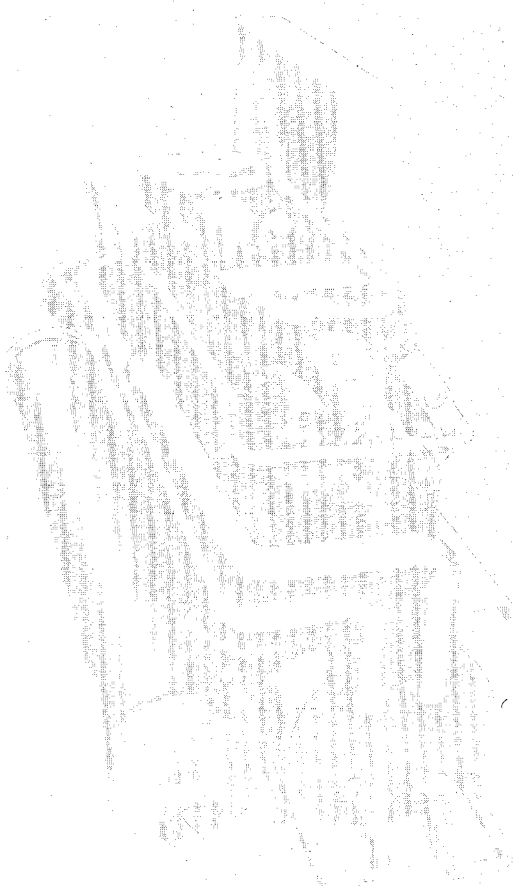

Reciprocating Water Chiller Control

CONTENT

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Introduction

The purpose of this manual is to discuss the performance of the W7900 family of microprocessor-based, chilled water temperature control systems. These systems were developed jointly by the Trane Company and Honeywell for exclusive use with Trane reciprocating water chillers.

Unlike traditional chiller control, that derives control action from return water temperature variation, the W7900 controls from the leaving side or supply water side of the chiller. With this temperature as a component of input, its programmed logic establishes the appropriate control response needed to produce a stable and accurate leaving water temperature condition.

The components of the W7900 family are:

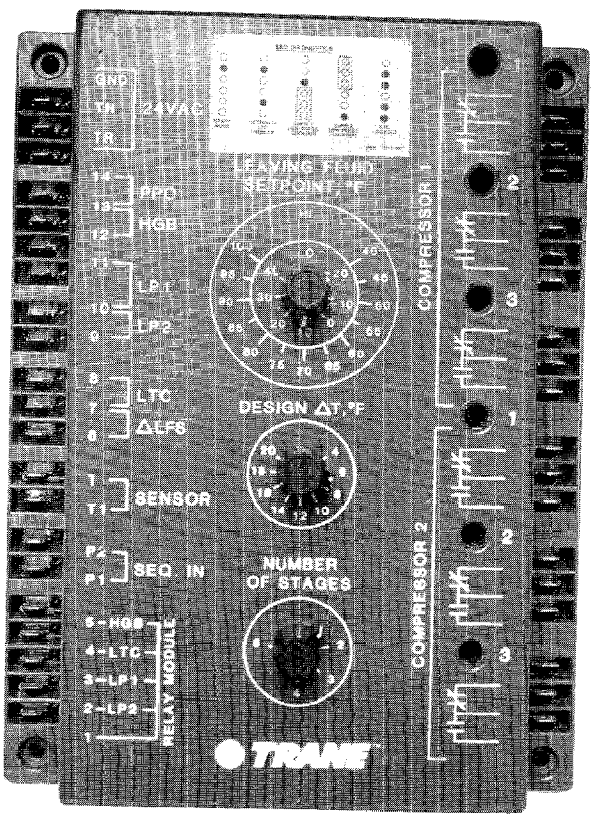

Figure 1

(Figure 1) W7900 Controller...This module performs the central processing functions. It accepts both analog temperature and contact closure inputs as well as user adjusted inputs. It processes them and establishes outputs that operate the chiller functions needed to produce safe, stable and accurate control of the leaving temperature.

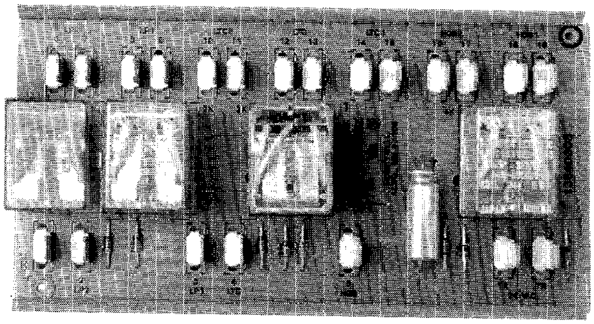

Figure 2

(Figure 2) Q7900 Relay Module...The auxiliary relay module provides the additional relay outputs required to interface the W7900 with the chiller hot gas bypass, low pressure control and low temperature cutout circuitry.

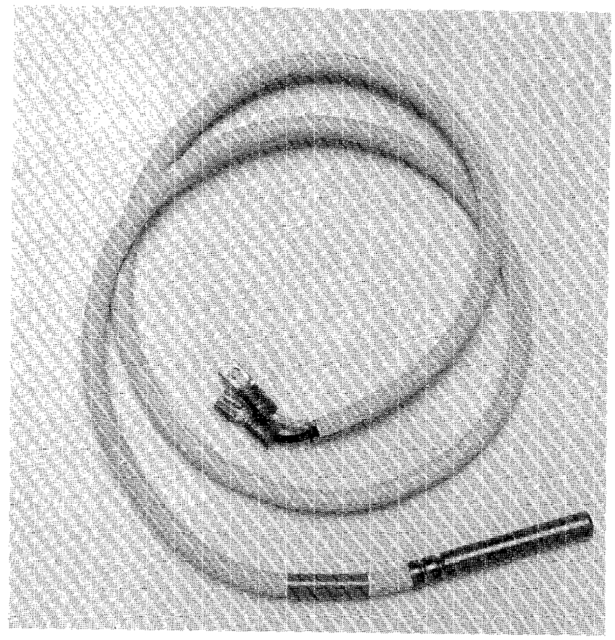

Figure 3

(Figure 3) C7173A Temperature Sensor...This is a positive temperature coefficient (resistance directly proportional to temperature change) thermistor used to sense the chiller leaving water temperature.

The W7900 system of control provides these features:

- Evaporator leaving water temperature control — improves accuracy.
- Anti-recycle timing, based on time between starts — provides operational stability.
- Automatic lead-lag switching — balances compressor starts in dual compressor units.
- Load limiting during high loop temperature starts — prevents nuisance motor overload trips.
- Low temperature cutout, based "degree-minutes" — prevents freezing while avoiding nuisance low temperature trips.
- Low ambient start logic — permits compressor starting without nuisance low pressure trips.
- Low pressure safety lockout — provides loss of charge protection.
- Setpoint overlap — prevents operation when chilled water setpoint is too close to low temperature cutout setting — avoids nuisance low temperature trips.
- Status indicators — provide operating status and trouble shooting information.

In addition, the following features are optionally available:

- Periodic pumpout — avoids liquid slugging on startup.
- Chilled water temperature reset, based on outdoor air temperature or zone temperature — reduces energy consumption.
- "Smart" hot gas bypass control turns off compressor after 30 minutes of continuous hot gas bypass operation — limits non-productive system operation.

(Figure 4) A simplified reciprocating water chiller system is illustrated. The system is composed of a chilled water loop, condenser water loop and a refrigeration loop.

The chilled water loop includes the system cooling load. The magnitude of the load influences the heat gain of the chilled water loop.

The condenser water loop, on the other hand, contains a heat rejector. The rejector, in this example a cooling tower, balances the heat gain with its heat rejection rate. Heat rejection is regulated on the basis of the tower leaving water temperature.

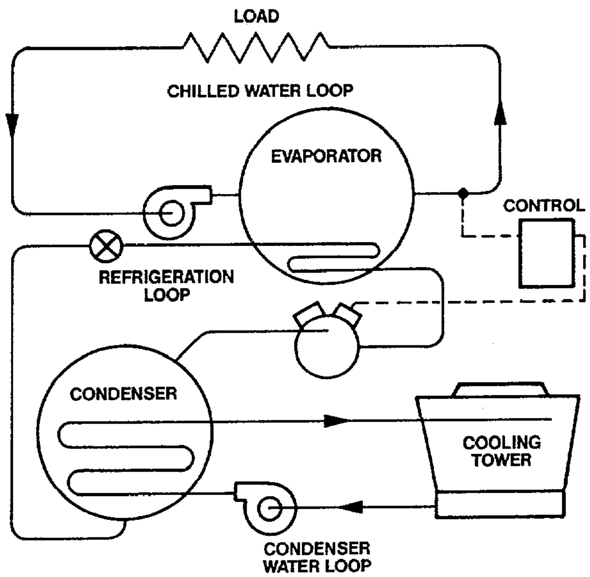

Figure 4

Finally, the refrigeration loop is operated by a system of control that functions to maintain a stable leaving chilled water temperature by varying the capacity performance of the compressor.

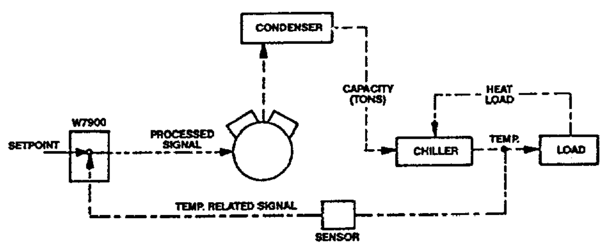

Figure 5

(Figure 5) This illustrates the W7900 control system in block form. The controlled variable is the chiller leaving water temperature and the manipulated variable is the refrigerant flow rate.

The chiller leaving water temperature variations are sensed and translated into load-related signals by the sensor and are transmitted to the W7900 controller.

The controller outputs processed signals that manipulate refrigerant flow, and in turn chiller leaving water temperature, by controlling the compressor and its unloader valves.

The W7900 produces a PID (proportional plus integral plus derivative) control action.

First, proportional control produces a degree of compressor loading or unloading that is

Introduction

proportional to the difference between the leaving water temperature and the setpoint temperature. Proportional control always results in a difference between the current leaving water temperature and setpoint.

This is where integral control action takes over. So long as the temperature difference persists, the controller integrates the error over time and continues to load or unload the compressor, as necessary, in an effort to return the temperature to setpoint. Integral control looks backward in time, therefore, it cannot anticipate the need for future control action.

Finally, the derivative function anticipates future control action by taking into consideration the rate of temperature change or the slope of the change. If the slope is steep, the compressor is loaded or unloaded at a fast rate. If the slope is shallow, the loading and unloading rate is reduced.

PID control produces accurate, responsive control action, eliminating steady state error from the chiller leaving water temperature.

Chiller/Controller Interface

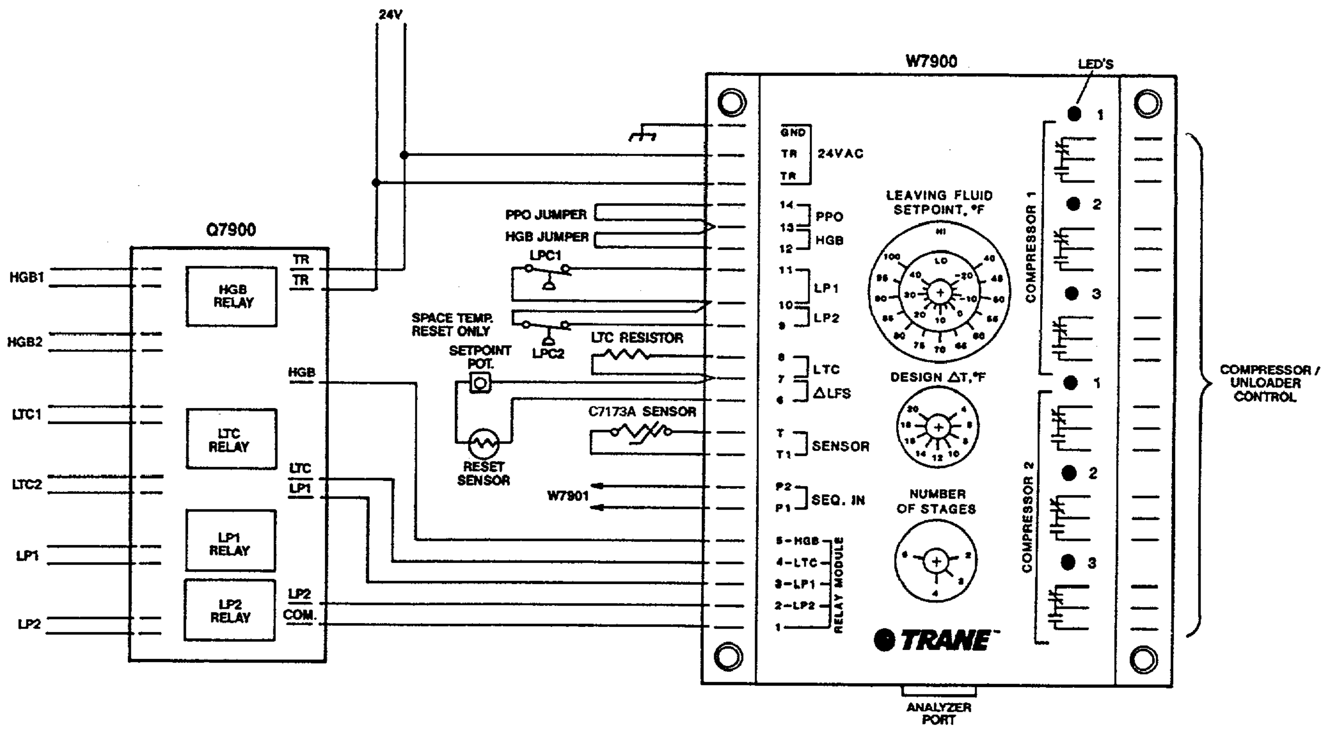

Figure 6

(Figure 6) As discussed, the W7900 is applied with the Q7900 auxiliary relay module. This module provides the added relay functions needed to interface the controller with chiller hot gas bypass, low pressure and low temperature control functions.

The chiller/controller interfacing inputs and corresponding outputs are as follows:

External Control Inputs

- Low Pressure Control...The low pressure control contacts of Compressor 1 and, if used, Compressor 2 are wired to terminals 9, 10 and 11 (LP1, LP2). A contact opening between the terminals of LP1 or LP2 de-energizes the affected compressor.
- Leaving Chilled Water Temperature Sensor...The C7173A sensor, which produces a resistance value that is directly proportional to temperature change, is connected to input terminals T and T1 (SENSOR).
- Optional Chilled Water Temperature Reset...The temperature-related resistance values produced by

a remote reset sensor assembly are input to terminals 6 and 7 (ΔLFS).

- Optional Inputs...Chiller loading and unloading signals, using control logic that is external to the W7900, are input to terminals P1 and P2 (SEQ. IN). Note: Such control is provided by the W7901 sequence controller — to be discussed later.

User Inputs

- Leaving Fluid Setpoint, F...The desired chilled water setpoint can be adjusted from 40 F to 100 F or, when a low temperature resistor is installed for low temperature applications (see Table 1), from -20 F to 40 F.
- Design ΔT, F...The design temperature difference across the chiller must be adjusted in accordance with the application — from 4 F to 20 F.
- Number of Stages...The total number of compressor capacity stages available — from 2 to 6, must be set for the particular chiller being controlled.
- Periodic Pumpout (PPO)...A jumper across terminals 13 and 14 establishes the periodic pumpout control cycle.
- Hot Gas Bypass (HGB)...Jumpering terminals 12 and 13 establishes hot gas bypass control.
- Low Temperature Control (LTC)...The low temperature cutout point is established by selecting an appropriate resistor, see Table 1, and installing it across terminals 7 and 8. The selected low temperature cutout point should be at least 3 F above the freezing temperature of the solution.

Controller Outputs

- Contact closures provide six stages of compressor/unloader control.
- The Q7900 auxiliary module provides the relay functions that control the hot gas bypass valve, low temperature cutout logic and low pressure control logic.
- Analyzer port accommodates the connection of the service-related jumper plug which, when installed, causes the W7900 to enter a pre-programmed test mode.
- LED indicator lights provide operation status and service diagnostic information.

TABLE 1 — LTC Cutout Resistance Values

Resistance (Ohms)	LTC Cutout Temp. (F)
Open or Shorted	35
100	33
200	29
300	25
400	21
500	16
600	9
700	2
800	-5
900	-16
1000	-28

Note:
1. Use metal film resistors, 1 percent tolerance.
2. If terminals 7 and 8 remain open or are shorted, a 35 F cutout temperature results.
3. Once a resistor of 100 ohms or greater is installed, the "Leaving Fluid Setpoint, F" adjustment is shifted to the "LO" or inner scale.

Theory Of Operation

The W7900 controller has the capability of operating in any one of seven modes. The mode is dictated by the current condition.

For example, upon initial power-up, the controller enters the **Start Mode** to check its internal operation.

It then enters the **Run Mode.** In the run mode, the compressor is started, stopped, loaded and unloaded in accordance with the chiller leaving water temperature variations.

Under other conditions, the controller can enter the **Low Ambient Mode, Low Temperature Cutout Mode, Hot Gas Bypass Mode, Load Limit Mode** or the **Periodic Pumpout Mode.**

Start Mode

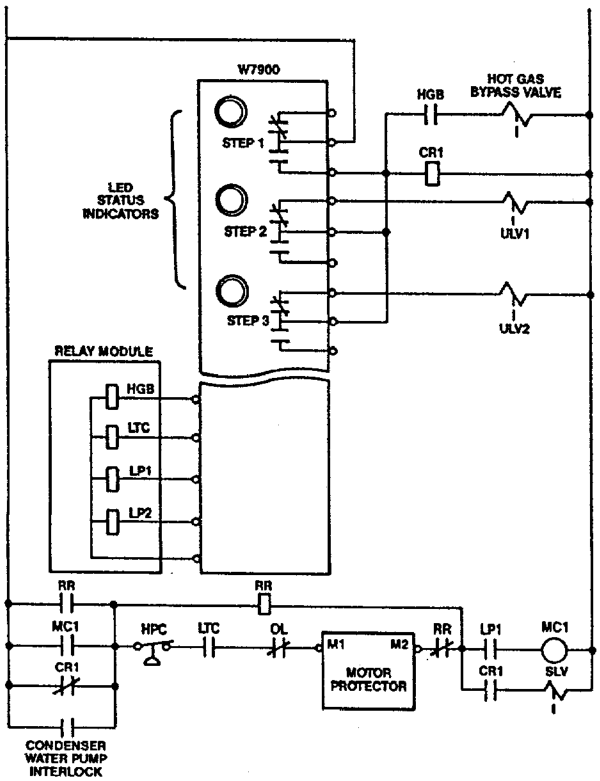

Figure 7

(Figure 7) Note: For simplicity, a single compressor with 2 unloader valves is illustrated.

Upon application of control power, the low temperature cutout (LTC) relay is energized. In turn, its contacts within the compressor starting circuit close. This prevents a false low temperature cutout during the Start Mode.

At the same time, the contacts of the compressor Step 2 relay reverse position, lighting the Step 2 LED. The lighting of the LED indicates the Start Mode is in progress. This phase lasts for four minutes.

The Start Mode allows time for the controller to perform a self-test. In addition, in the event of a power failure during normal operation, the control sequence returns to the Start Mode. This provides four minutes of anti-recycling timing.

After the four minutes have elapsed, the compressor Step 2 relay is de-energized and the controller enters the **Run Mode.**

Run Mode

During the **Run Mode** the compressor and solenoid valves are operated, as required, to maintain the leaving chilled water temperature within close proximity to setpoint as follows:

Compressor Start

If the add/subtract capacity logic (to be discussed later) determines that a compressor start is needed and a low temperature cutout condition does not exist (LTC relay remains energized), a start is initiated by energizing the compressor Step 1 relay and the low pressure control relay (LP) in the relay module.

In addition, the low ambient and compressor on timing functions are initiated. During the low ambient timing period, the low pressure cutout switch is disregarded, permitting the compressor to be started and operated for three minutes without a low pressure cutout. The compressor on timing, on the other hand, keeps track of the compressor on time so that the off time can be calaculated to establish proper recycling rates.

The energizing of the Step 1 relay, in this example, energizes control relay CR1. In turn:

- The normally closed CR1 contacts in the compressor starting circuit open (this function is discussed under "Periodic Pumpout Mode").
- Another set of CR1 contacts (not shown) start the condenser water pump, closing the condenser water pump interlock.
- A third set of CR1 contacts, in series with the liquid line solenoid valve (SLV) close, opening the valve.

The closing of the condenser water pump interlock conducts control power to the low pressure relay contacts (LP1).

As discussed, the low ambient timing function closes the low pressure relay contacts at startup, permitting the compressor motor contactor (MC1) to be energized immediately. Once the contactor is energized, its auxiliary contacts (MC1) in the starting circuit close, locking the contactor into the circuit.

Add/Subtract Logic
The compressor "add" and "subtract" capacity logic operates as follows:

Operator Input —

First, assume these operator adjusted input values.

- Leaving Fluid Setpoint, F...45 F
- Design ΔT, F...10 F

This informs the controller that a 10 F temperature difference is expected across the chiller at design conditions.

- Number of Stages...3

Three stages informs the controller that the chiller has a single compressor with 2 unloaders.

Control Band
Using these input values, the controller calculates a control band (CB) value that is proportional to the Design ΔT (10 F) and the Number of Stages (3).

In this example, the CB is calculated:

$$CB = \frac{\text{Design } \Delta T\text{, F}}{\text{No. of Stages}} = \frac{10\text{ F}}{3} = 3.3\text{ F}$$

The control band is ± 3.3 F. This establishes a dead band of ± 3.3 F or 6.6 F total, in this example, within which no control action is taken.

Composite Temperature
The controller calculates a composite temperature (Tc) that takes into consideration the actual sensed temperature (Ts) and the rate, or slope, of temperature change. The "slope", in terms of degrees/minute, in this relationship gives the controller its derivative control action.

If the sensed temperature is increasing at a fast rate, the calculated composite temperature can be significantly greater than the actual sensed temperature. Conversely, if the sensed temperature is decreasing at a fast rate, the composite temperature can be significantly less than the actual sensed temperature.

For example, assume the sensed temperature to be 48 F and increasing. In this example, the calculated composite temperature can result in a value of 49.5 F.

Error Temperature
Finally, the controller calculates an error temperature (Te), or the deviation from setpoint. The error temperature is the difference between the composite temperature (Tc) and the setpoint temperature (Tsp). Using the values from this example:

$$Te = Tc - Tsp$$
$$Te = 49.5\text{ F} - 45\text{ F} = 4.5\text{ F}$$

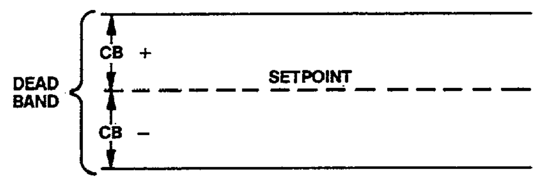

Figure 8

(Figure 8) When the error temperature (Te) is greater than the value of the control band (CB), an add one stage command is generated.

On the other hand, when the error temperature is negative and greater than the control band value, a subtract one stage command is generated.

Finally, when the error temperature falls within the "dead" band, no add or subtract commands are generated.

The addition and subtraction of cooling stages are subject to the following constraints.

Add/Subtract Timing
(Figure 9) Normally, the time lapse between successive add and subtract commands is dependent upon the current value of the composite temperature. This time lapse between successive add and subtract commands produces the integral control action.

As the composite temperature (Tc) moves away from setpoint, the time lapse between each successive add or subtract command is progressively reduced in an attempt to restore stability.

For example, assume the composite temperature has risen above the control band (A). If the

Theory Of Operation

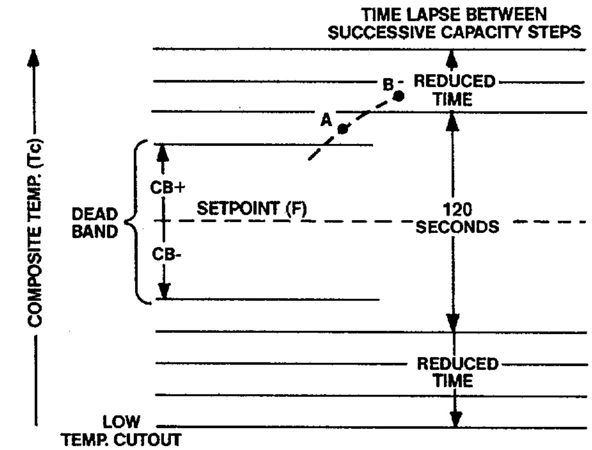

Figure 9

previous add or subtract command occurred more than 120 seconds previously, a stage of capacity is added.

Again, assume that during the following 120 seconds, the Tc rises to B. At this point, a second add command is issued with another possible in something less than 120 seconds, etc.

Similarly, a negative Tc, below the control band value, brings about a reduction in time between successive subtract commands.

Note that, to avoid nuisance trips, the subtract commands are greatly accelerated as Tc approaches low temperature cutout.

The fastest loading rate is 30 seconds between steps while the unloading rate can be reduced to 10 seconds.

Rate Limiting

Even though the error temperature is above the dead band, if the composite temperature is falling at a fast rate, no capacity add command is permitted.

Similarly, if the error temperature is below the dead band and the composite temperature is rising at a fast rate, no capacity subtract command is permitted.

Rate limiting control results in decreased compressor cycling and stability.

Compressor Timing

After a compressor is stopped, an off time of 1 to 5 minutes is computed as follows:

Off Time = 5 Minutes - On Time

This computation limits the time lapse between successive starts to a minimum of 5 minutes and the off time, regardless of the on time, to a minimum of 1 minute.

Staging Order

In a dual compressor system, when adding capacity stages, the lead and lag compressors are started and loaded in sequence.

However, when subtracting capacity stages, the lag compressor is fully unloaded first and then the highest stage of the lead compressor is unloaded. The lag compressor is then stopped followed by the final unloading and stopping of the lead compressor. In this way, excessive compressor cycling at 50 percent load is avoided.

Automatic Compressor Lead/Lag

When the lead compressor of a dual compressor system is stopped, the controller reverses the starting order (lead becomes lag, etc., on the next startup). This results in even compressor wear.

Note: Because the lead-lag sequence is changed each time the unit is shutdown, if hot gas bypass is to be used, it must be applied to both compressors.

Setpoint Overlap

If the leaving chilled water setpoint is too close to the low temperature cutout (setpoint minus the control band is within 2 F of the low temperature cutout, or within 4 F, if hot gas bypass is used), no control activity is permitted. This condition is annunciated by the lighting of the Compressor 1 and Compressor 2, Stage 2 LED's on the face of the W7900 controller.

The setpoint overlap feature avoids nuisance low temperature trips.

Compressor Stop

(Figure 7) When a subtract command stops a compressor, the following events take place.

- Compressor Step 1 relay de-energizes relay CR1.
- Compressor continues to operate through its motor contactor interlock (MC1) and the low pressure relay (LP1) contacts.

Operation continues until either one minute elapses or the low pressure control opens the low pressure relay (LP1).

This limits the pumpdown cycle to one minute.

Remote Reset

The chilled water setpoint temperature can be reset from either space or outdoor air temperature by connecting resistive signals from a remote sensor to controller terminals 6 and 7, "ΔLFS", Figure 6.

For reset from space temperature, a T7047C space sensor is connected in series with an S963B remote setpoint potentiometer. The reset range produced is determined by the "Design ΔT, F" setting of the controller.

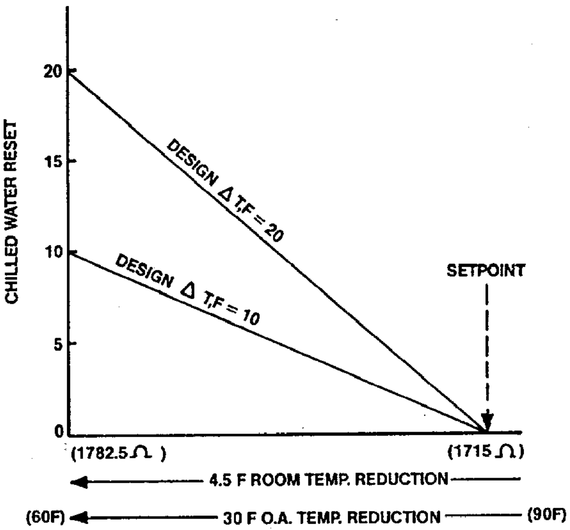

Figure 10

(Figure 10) For example, a 4.5 degree zone or room temperature reduction, below the potentiometer setting, resets the leaving chilled water setpoint upward by 10 degrees for a "Design ΔT, F" setting of 10 degrees, 20 degrees for a 20 degree setting, etc.

On the other hand, reset from outdoor air temperature uses the C7031G outdoor sensor only — the potentiometer is not used. As shown, the same reset range is achieved with a 30 degree change in outdoor temperature (from 90 to 60 F).

The range of ohm resistance input to the "ΔLFS" terminals by the reset sensor (from no reset to full reset) is shown. Note that the sensors have a negative temperature coefficient (resistance is inversely proportional to temperature change).

Note: The controller can be shutdown (all relays exept LTC de-energized) by shorting terminals 6 and 7. Following this, a normal pumpdown occurs. This condition is maintained until the short is removed. The controller then enters the Start Mode without changing the LTC status.

Load Limit Mode

In the Load Limit Mode, the final step of compressor loading is not allowed. This prevents overload trips when starting under high evaporator water temperature conditions.

The Load Limit Mode is entered when the evaporator leaving water temperature is above 64 F (100 F when the leaving water setpoint is above 60 F).

Loading is limited until the leaving water temperature falls below 56 F (94 F when the setpoint is above 60 F).

Periodic Pumpout Mode

When periodic pumpout is selected by jumpering terminals 13 and 14, "PPO", Figure 6, the Periodic Pumpout Mode is entered whenever a compressor is stopped. If at the end of hourly intervals the compressor low pressure cutout switch is closed, the idle compressor is started. The starting circuit is established through the normally closed CR1 contacts and the closing of the low pressure control relay contacts (LP1), Figure 7.

The pumpout cycle is then terminated in one minute, or sooner by the opening of the compressor low pressure cutout switch.

Hot Gas Bypass Mode

When the Hot Gas Bypass option is selected by jumpering terminals 12 and 13, "HGB", Figure 6, the Hot Gas Bypass Mode is entered when only one stage of compressor capacity remains and a subtract capacity command is issued.

Hot gas bypass is initiated by the energizing of the hot gas bypass relay (HGB), Figure 7, to artificially load the compressor and prevent compressor cycling.

If hot gas bypass is not terminated within 30 minutes by an add capacity command, the compressor is turned off.

Low Pressure Cutout Mode

After the compressor has entered the Run Mode and the three minute low ambient time period has elapsed, the low pressure cutout switch input assumes control of the low pressure control relay (LP).

If a low suction pressure condition causes the cutout switch to open, the LP relay opens, stopping the compressor. In turn, the compressor Step 2 and Step 3 capacity relays de-energize while the Step 1 relay remains energized. If the low pressure cutout switch closes within 10 to 50 seconds after the original opening, the compressor restarts.

Theory Of Operation

However, if 50 seconds pass without reclosure of the cutout switch, the compressor Step 1 relay de-energizes, placing the controller in a low pressure lockout condition. Low pressure lockout is annunciated by the lighting of the compressor Step 3 LED. A low pressure cutout can also occur after a single add command results in 5 low pressure restart attempts.

Once a lockout occurs, operation cannot be resumed until the controller is reset and the compressor is restarted via the Start Mode. Reset is accomplished by momentarily interrupting the 24 volt control power circuit to the W7900 controller.

Low Temperature Cutout Mode

The low temperature cutout relay (LTC) remains energized throughout all operating modes.

However, when the chilled water temperature drops below the low temperature cutout limit (established by the LTC resistance value, see Table 1, Page 5), a timer is activated. If the chilled water temperature remains below the low temperature limit for 0.5 degree-minutes (the product of time and temperature), the LTC relay is de-energzied, stopping the compressor.

This condition is annunciated by the lighting of the compressor Step 2 and Step 3 LED's.

Similar to low pressure cutout, operation is resumed by resetting the controller and, in this case, the 115 volt circuit reset relay (RR).

Multiple Unit Control

The coordinated operation of multiple W7900-controlled water chillers in a common water loop requires the service of the W7901 multiple unit control system.

The W7901 control system consists of:

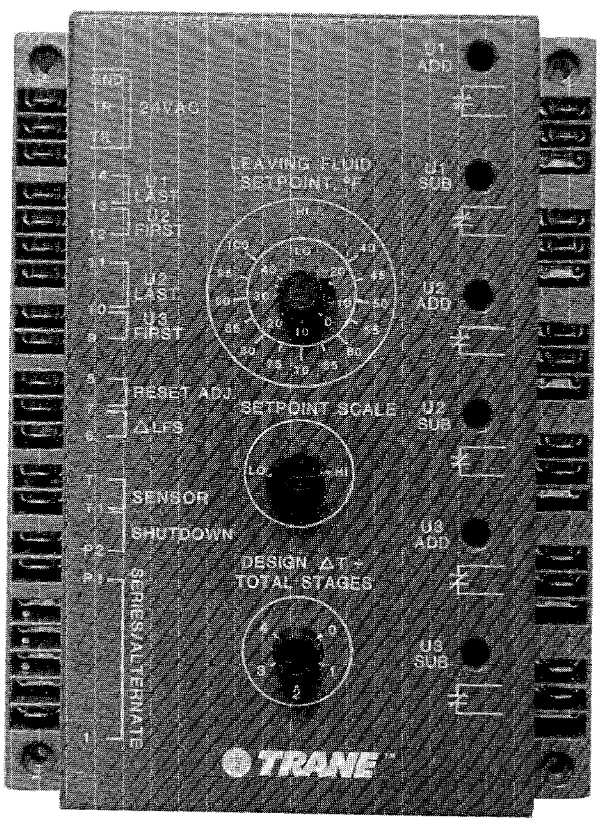

Figure 11

(Figure 11) W7901 Multiple Unit Controller...This device senses common leaving water temperature as well as the individual unit on/off status. It issues add and subtract capacity commands, as needed, to up to three W7900 chiller control modules. The result is stable and coordinated capacity sequencing of the chillers.

Q7901 Auxiliary Module...The relay module provides the relay logic interface between the W7901 and W7900 controllers.

C7173A Temperature Sensor...The sensor is a positive temperature coefficient thermistor used to sense the common evaporator leaving water temperature.

The W7901 system provides these features as standard:

- Common leaving water temperature control for two or three chillers.
- Coordinated capacity staging of the chillers.
- Alternate capacity staging for equal loading, or series staging for base loading of the chillers.
- Common chilled water temperature reset.
- Energy management interface for simultaneous chiller shutdown.

System/Controller Interface

Again, the W7901 is applied with the Q7901 auxiliary relay module to provide interfacing relay logic with the W7900 controllers.

The system/controller interfacing inputs are as follows:

External Control Input (Figure 12)

- Maximum Reset...The maximum leaving water temperature reset advancement is determined by the resistive input from an adjustable S963B1086 potentiometer at terminals 7 and 8 (RESET ADJ.).
- Temperature Reset Setpoint...The resistive input to terminals 6 and 7 (ΔLFS) determines the reset setpoint or reset startpoint.

For reset from space temperature, a T7047C1025 sensor is wired in series with an adjustable S963B1037 setpoint potentiometer.

Reset from outdoor temperature uses a C7031G1016 outdoor air sensor only — a potentiometer is not used.

A 4.5 degree space temperature reduction from setpoint or a 30 degree outdoor temperature reduction, from 90 F to 60 F, resets the chiller leaving water setpoint upward by an amount equal to the maximum reset adjustment (RESET ADJ.).

- Common Leaving Water Temperature Sensor...The T7173A sensor, to be located no more than 50 feet from the W7901 controller, is connected to input terminals T and T1 (SENSOR).
- Status Inputs...The Q7901 Auxiliary Relay Module provides contact closure logic that informs the W7901 of the on-off status of the controlled chillers. The status information is input to terminals 9 through 14 (U1 LAST, U2 FIRST, U2 LAST, U3 FIRST).

U1 LAST or U2 LAST means that, for series loading, the highest stage of chiller 1 has turned on. For alternate loading, it means the lowest stage of chiller 1 has turned off.

U2 FIRST or U3 FIRST means that, for series and alternate loading, the first stage of chiller 2 has turned on.

- Shutdown...A jumper or contact closure across terminals T1 and P2 (SHUTDOWN) causes the W7901 to issue a continuous subtract command to all W7900 controllers. In response, the W7900 controllers subtract stages of 50 second intervals.

User Inputs

- Leaving Fluid Setpoint, F...The range of adjustment is 40 F to 100 F or, for low temperature applications, 40 F to -20 F.

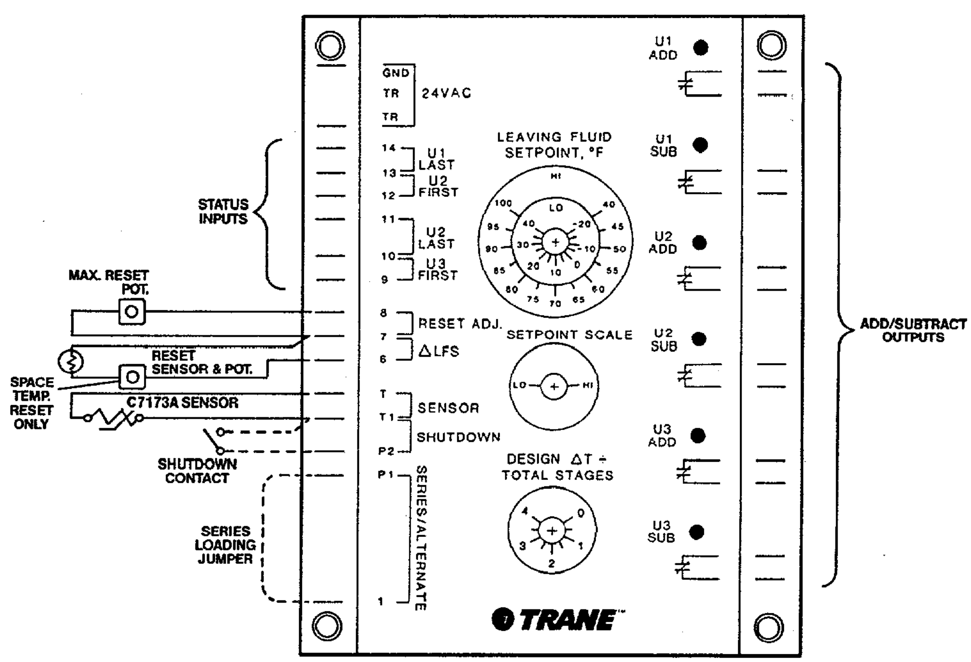

Figure 12

Multiple Unit Control

- Setpoint Scale...The "HI" adjustment informs the controller to use the "HI LEAVING FLUID SETPOINT, F" scale.

  Similarly, "LO" informs the controller to use the "LO" scale.

- Design $\Delta T \div$ Total Stages...The design temperature difference across the chillers (ΔT) divided by the total number of available compressor capacity stages establishes the control band. The adjustment is from 0 to 4 in 0.5 degree per stage increments.

- Series/Alternate...The loading sequence to be used is established by a jumper or the absence of a jumper across terminals P1 and 1 (SERIES/ALTERNATE).

  Series loading is established by the jumper. No jumper, or an open circuit, causes the controller to load the chillers alternately.

Controller Outputs

- The timed opening of three normally closed contacts issue add commands to up to three chillers (U1 ADD, U2 ADD, U3 ADD).

- Similarly, the timed opening of three normally closed contacts issue subtract commands to up to three chillers (U1 SUB, U2 SUB, U3 SUB).

Theory Of Multiple Unit Operation

The W7901 senses common leaving water temperature and controls it by issuing coordinated add and subtract commands to up to three W7900 unit controllers.

The connected W7900 controllers ignore their own internally generated add and subtract commands except when a load limit, low pressure or low temperature condition develops. At this time, the W7900 assumes control of its chiller, performing the functions needed to avoid a safety cutout.

Add/Subtract Logic

The capacity add/subtract logic used by the W7901 is established on the basis of whether the error temperature (Te) is above or below the control band (CB).

Operator Input

Assume these operator adjusted input values.

- Leaving Fluid Setpoint, F...45 F
- Design $\Delta T \div$ Total Stages

In this example, the design temperature drop across the chillers is 10 F (ΔT) and the total number of compressor capacity stages of both chillers is 12 (4 compressors with 3 stages each).

Control Band
Dividing the 10 F (ΔT) by the capacity stages (12), produces the control band (CB) value:

$$CB = \frac{10}{12} = \pm .83 \text{ F}$$

Similar to the W7900, the dead band is twice the control band, $\pm$ .83 F or 1.66 F total, in this example, no add or subtract commands are issued when the error temperature is within the dead band.

Error Temperature

The controller calculates an error temperature, taking into consideration the actual sensed temperature, rate of sensed temperature change and the leaving chilled water setpoint (or current reset) temperature.

If the sensed temperature is increasing or decreasing at a fast rate, the error temperature can be significantly greater than the difference between the actual sensed temperature and the setpoint or reset setpoint temperatures.

For example, assume the current reset setpoint temperature is 47 F and the sensed temperature to be on the negative side of the current setpoint at 43 F and falling. In this example, depending upon the rate of change, the calculated temperature error can result in a value of -5.5 F, instead of the simple error of 4 degrees below setpoint or -4 F.

Since the control band is $\pm$ .83 F, the -5.5 F error temperature places the controller in the subtract capacity mode.

Multiple Unit Operation

The W7901 control band adjustment (Design $\Delta T \div$ Total Stages) reflects the cooling effect addition or subtraction contributed by each stage of compressor loading or unloading.

In the previous example, the control band was calculated:

$$\text{Control Band} = \frac{10\ F\ \Delta T}{12\ \text{Stages}} = \pm .83\ F$$

Therefore, in this example, the addition or subtraction of one compressor stage will lower or raise the leaving water temperature by .83 degrees.

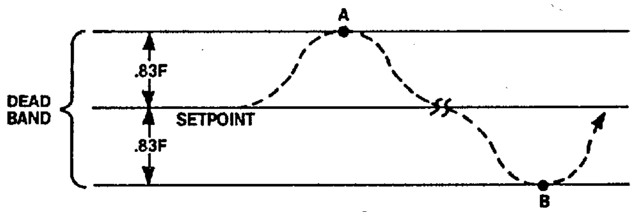

Figure 13

(Figure 13) Assume a rising system load causes the error temperature to exceed the plus side of the control band (A).

In response, the W7901 issues an add command. This results in a .83 F water temperature reduction, returning the control point to the dead band.

Once an add or subtract command has been issued, another command can be issued, if necessary, after 50 seconds.

Again, assume a reducing load produces an error temperature that takes the control point below the minus side of the band (B). This prompts the W7901 to issue a subtract command, returning the control point to the dead band, etc.

In this way, reciprocating compressors that change capacity in steps or stages can be controlled to maintain a stable and accurate leaving water temperature.

(Figure 14) An example W7901 — controlled system is illustrated. In this particular system, the W7901 is coordinating the operation of two W7900 — controlled, parallel-piped, duplex water chillers. A single chilled water pump supplies both units. The chiller flow rates are constant.

In such an application, the W7901 assumes the capacity add and subtract functions plus chilled water reset.

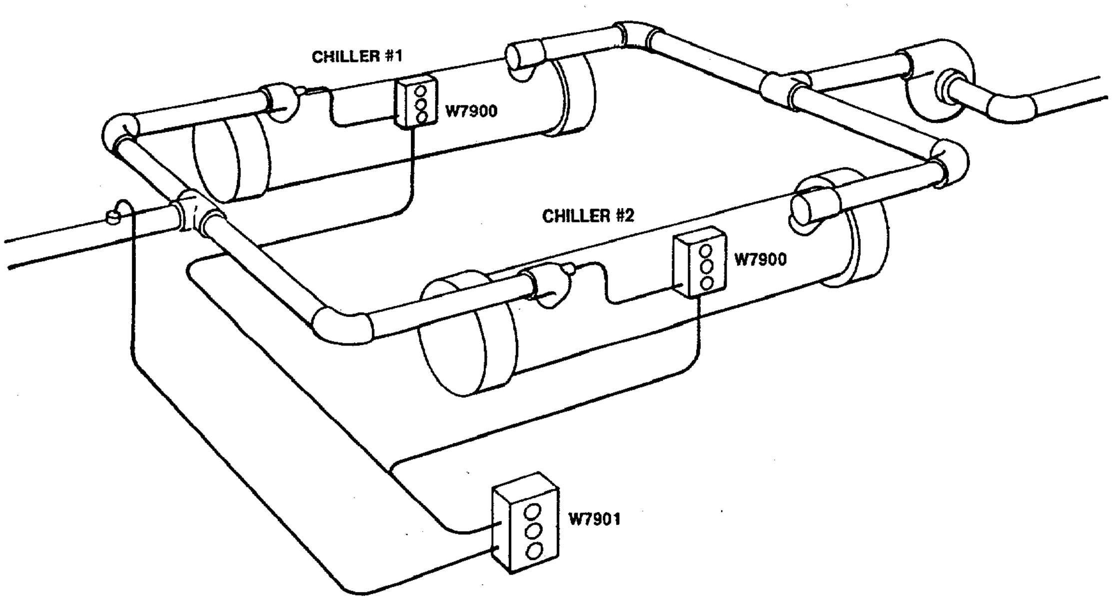

Figure 14

ALTERNATE LOADING

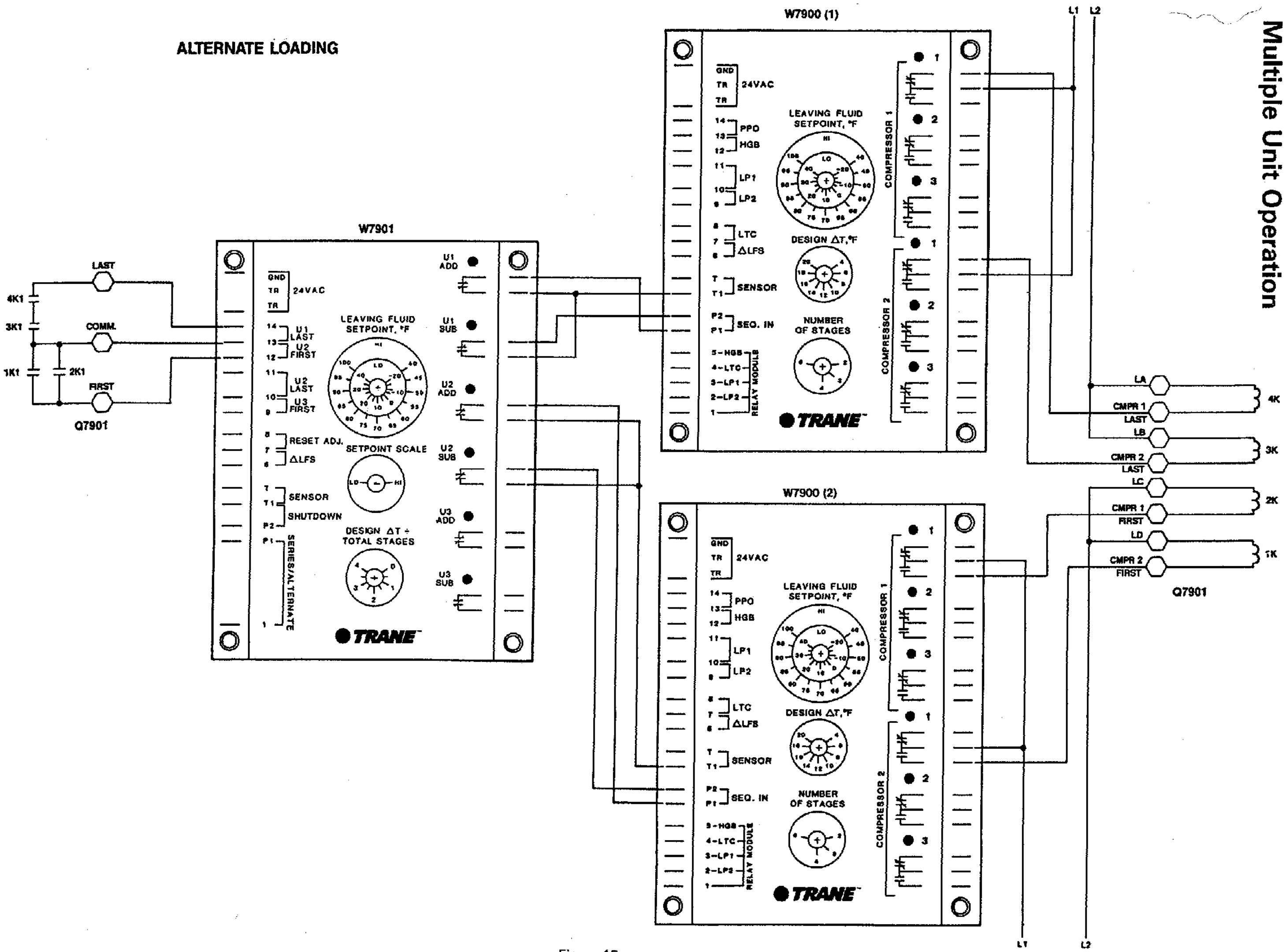

Figure 15

Alternate Loading

(Figure 15) In this example, the chillers are to be started and loaded alternately. That is, control commands are issued alternately to Chiller 1 and then Chiller 2 and back to Chiller 1, etc., until both are loaded fully.

Note that the coils of the Q7901 auxiliary relay module are wired to be operated by the four Compressor Step 1 Contacts on the W7900 controllers.

Sensing a chilled water error temperature that is above the dead band, the W7901 opens its "U1 ADD" contacts, issuing a timed add signal.

Note: This add signal is held for up to 50 seconds. However, if this is the initial startup, the add signal is held for up to 5 minutes, giving the W7900 time to perform its Start Mode diagnostics.

This input to terminal P1 (SEQ. IN) of W7900 (1) is interpreted as an add command. In response, the Step 1 contacts of the lead compressor reverse position. In addition to starting the compressor, it de-energizes relay 4K, in this example, of the Q7901 relay module. This opens the 4K1 contacts, breaking the circuit between terminals 13 and 14 of the W7901, informing the controller that the lead compressor has started.

Once the lead compressor has started, a minimum of 50 seconds is observed before an additional add command can be issued.

After the 50 second time lapse, a 50 second add command can be issued the P1 terminal (SEQ. IN) of W7900 (2) through the opening of the W7901 "U2 ADD" contacts. This causes the Step 1 contacts of the lead compressor of the second chiller to reverse position, starting the compressor. In addition, it energizes 2K of the auxiliary relay module. This closes contacts 2K1, completing the circuit between terminals 12 and 13 of the W7901. Again, this informs the controller that the lead compressor of the second chiller has started.

After an additional 50 seconds, a 50 second add command can be again issued Chiller 1, etc., until both machines are loaded fully.

When the error temperature drops below the dead band, capacity reduction is required. The unloading of the compressor is brought about by the alternate opening and closing of the subtract contacts (U1 SUB and U2 SUB). The same 50 second on and 50 second off timed signals are input to the P2 terminals (SEQ. IN) of the W7900 controllers.

In this sequence, Steps 2 and 3 of the lag compressors are unloaded alternately, followed by Step 3 on the lead compressors. The lag compressors are then stopped followed by the alternate unloading of the remaining steps of the lead compressors.

While the capacity add and subtract and reset functions of the individual W7900 controllers are assumed by the W7901, the W7900's retain all of their safety functions.

For example, if the composite temperature is approaching the low temperature cutout point, the W7900 will refuse all add commands. Instead, it initiates its own subtract commands in an effort to avoid low temperature cutout. Similarly, the W7900 retains the low pressure control and load limiting functions.

Another characteristic that should be noted is, if at startup, a chiller fails to feedback a confirming start signal, the W7901 assumes it to be unpowered and locks it out from future add and subtract commands. When this occurs, the chiller can be returned to the control sequence by momentarily de-energizing the W7901 control power circuit.

However, once a chiller is operating, the failure to feedback a confirming load or unload signal does not cause a lock-out. Instead, the controller reduces the signal duration to 10 seconds and then issues the same command to the alternate unit.

The failure to confirm a command may be caused by the fact that the chiller is in one of its safety modes, such as load limiting.

SERIES LOADING

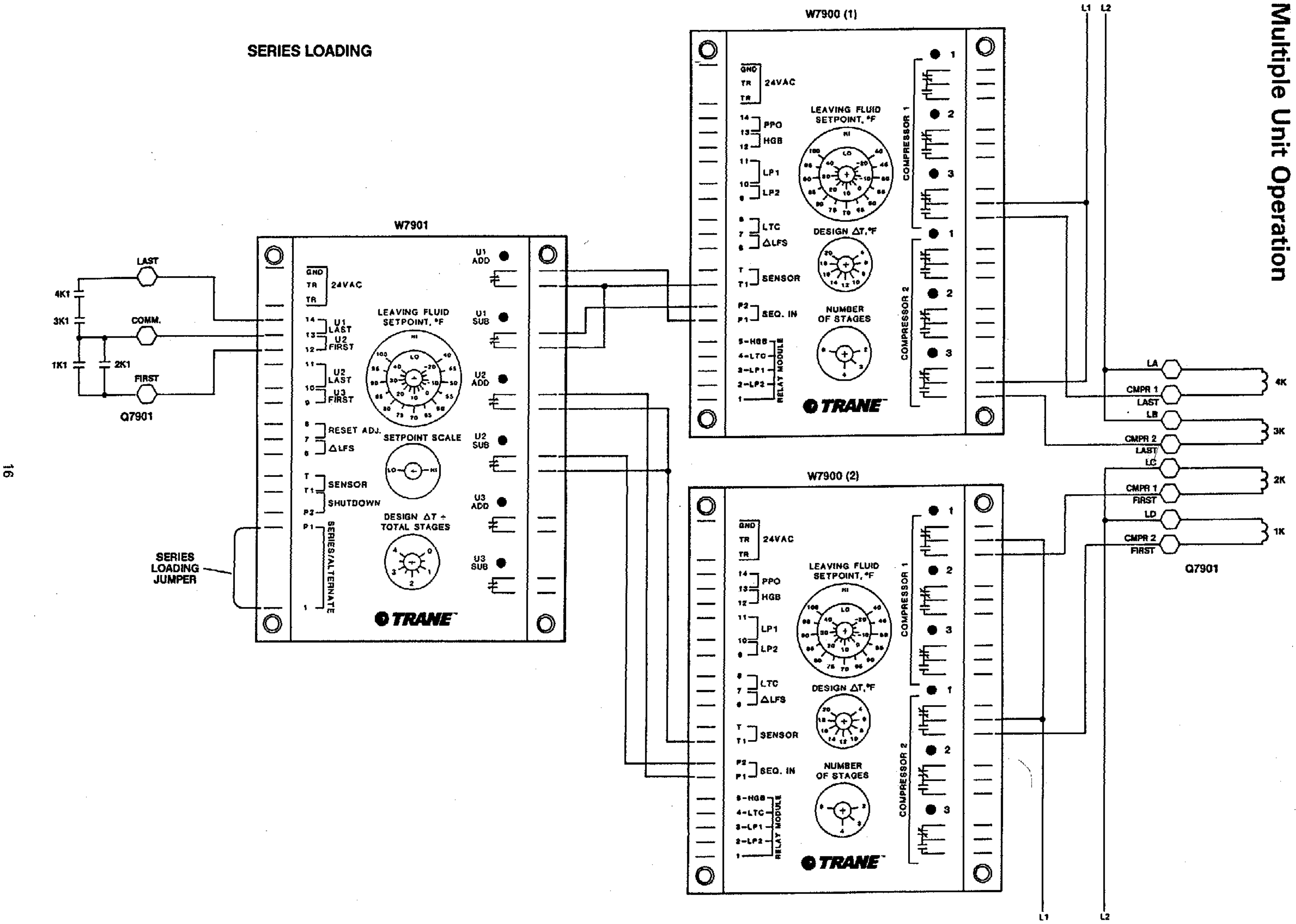

Figure 16

Series Loading

(Figure 16) The series loading sequence is established by installing a jumper across terminals P1 and 1 of the W7901. Series loading activates all capacity stages of the first chiller before the second chiller is started.

Sensing a chilled water error temperature that is above the dead band, the W7901 opens its "U1 ADD" contacts, issuing a timed add signal.

This input to terminal P1 (SEQ. IN) of W7900 (1) is interpreted as an add command. In response, the Step 1 contacts of the lead compressor reverse position, starting the compressor.

Once 50 seconds have elapsed, additional 50 second add commands can be given at 50 second intervals. In this way, add commands are issued to W7900 (1) until all stages are loaded.

Note that the loading of the third stage of each compressor of the first chiller, in series, energizes relays 4K and 3K of the W7901 auxiliary module. In turn, the closing of the 4K1 and 3K1 contacts completes a circuit between terminals 13 and 14 of the W7901. This informs the controller that the first chiller is loaded fully. Once this occurs, no further add commands can be issued for 5 minutes.

When additional capacity is required, a 50 second add command is issued the P1 terminal (SEQ. IN) of W7900 (2) through the opening and closing of the W7901 "U2 ADD" contacts. This causes the Step 1 contacts of the lead compressor of the second chiller to reverse position, starting the compressor. In addition, it energizes relay 2K of the auxiliary module. In turn, contacts 2K1 close, completing the circuit between terminals 12 and 13 of the W7901. This informs the controller that the lead compressor of the second chiller has started.

From this point, the remaining stages of the second chiller are loaded in series, using the 50 second on and 50 second off timing sequence.

When the error temperature drops below the dead band, less capacity is required. The unloading of the compressors is brought about, in the reverse order of loading by issuing timed subtract signals from contacts "U2 SUB" and "U1 SUB" of the W7901. The signals are input to the P2 terminals of the W7900 controllers.

In the unloading sequence, Steps 2 and 3 of the lag compressor are unloaded followed by Step 3 of the lead compressor. The lag compressor is then stopped followed by the unloading of the remaining steps of the lead compressor.

Similar to alternate loading, while the W7901 assumes the add, subtract and reset control, each W7900 retains the low temperature, low pressure and load limiting functions.

Control Application

The application of the W7900 family of controls to multiple chiller systems will be discussed.

The typical chiller piping and pumping configurations to be discussed are:

- Parallel-piped, 1 pump
- Parallel-piped, 2 pumps
- Series-piped
- Parallel-piped, decoupled

Parallel-Piped, 1 Pump

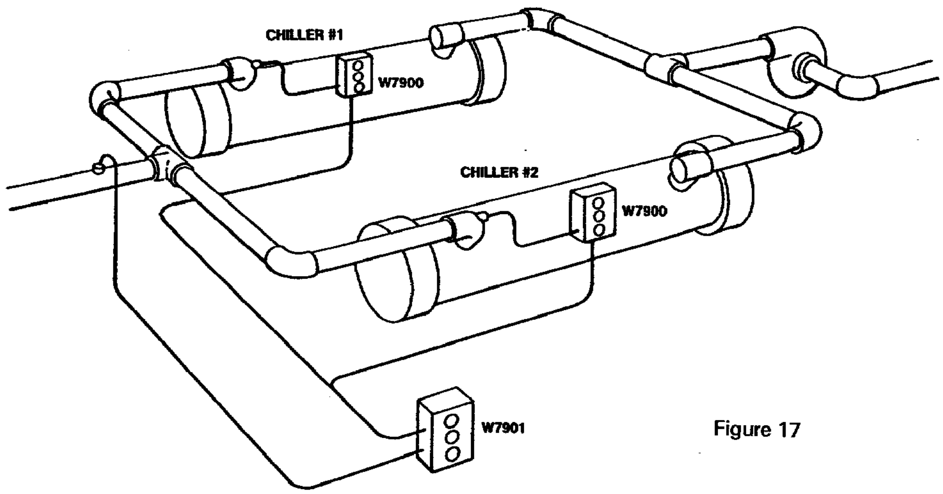

Figure 17

(Figure 17) With the parallel-piped, 1 pump system, a W7901 senses the common leaving water temperature.

In this application, alternate loading is advisable to promote stable control and minimum compressor cycling.

If it is desirable to base load a chiller, series loading is used. When series loaded, each compressor may be equipped with hot gas bypass to avoid compressor cycling at 50 percent system load.

Chiller lead-lag control is not necessary when alternate loading is used. However, when the chillers are series loaded, if lead-lag is required, a sequence panel with switches and the relay logic needed to produce lead-lag operation should be used with the W7901 controller.

Parallel-Piped, 2 Pumps

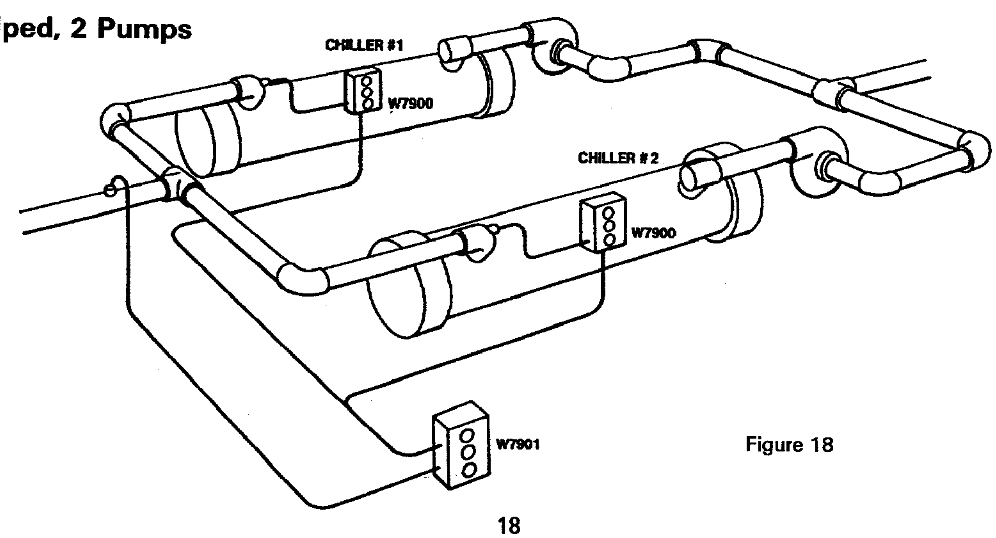

Figure 18

(Figure 18) The parallel-piped, 2 pump system produces two chilled water flow rates. To accommodate this variable flow characteristic, the W7901 is wired to series load the chillers.

In this application, the chilled water pump of the lead chiller is started manually while the chilled water pump of the lag chiller is started when the lead chiller is loaded fully.

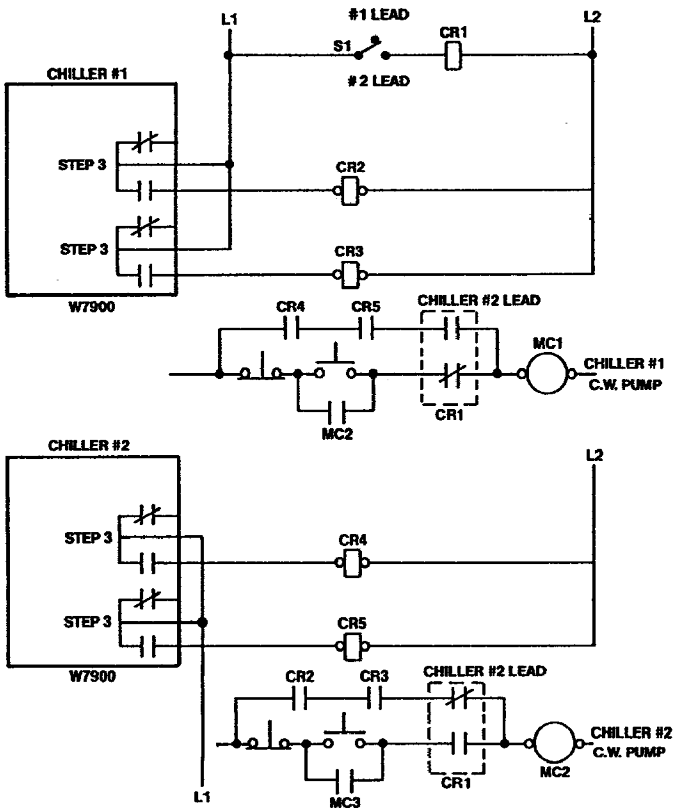

Figure 19

(Figure 19) A suggested control circuit is illustrated. Note that switch S1 provides manual control of the lead-lag relay (CR1). In this example, Chiller #1 is the lead.

When both of the Step 3 contacts for each of the Chiller #1 compressors reverse position, relays CR 2, 3 are energized. In turn, their contacts which are in a series arrangement within the Chiller #2 chilled water pump starting circuit close. The circuit created bypasses the pushbutton station, starting the pump.

Note that when CR1 is energized, its contacts reverse position, changing the lead to Chiller #2.

In the parallel-piped, 2 pump system, each compressor may be equipped with hot gas bypass to avoid compressor cycling at 50 percent system load.

Series-Piped

(Figure 20) The loading sequence of series-piped, constant flow chillers can be either series or alternate, depending upon the designer's preference.

When series loading is used, it is best to base load the upstream chiller. In addition, when calculating the "Design $\Delta T \div$ Total Stages" input for the W7901, use the total temperature drop through both chillers and the total number of compressor stages. For example, if the design temperature drop is 10 F through each chiller and each chiller has 6 stages of capacity, use a 20 F ΔT and 12 stages, or Design ΔT (20 F) $\div$ Total Stages (12) $=$ 1.67 degrees/stage.

Again, to prevent compressor cycling at 50 percent system load, hot gas bypass may be applied to each compressor.

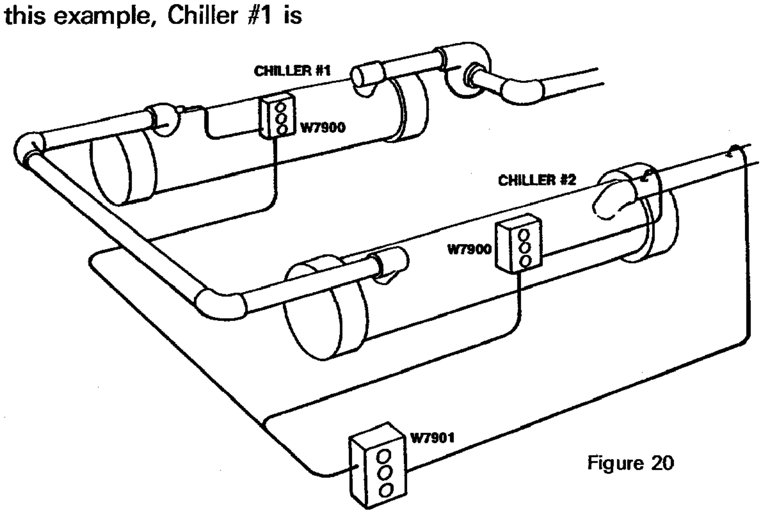

Figure 20

Control Application

Parallel-Piped, Decoupled

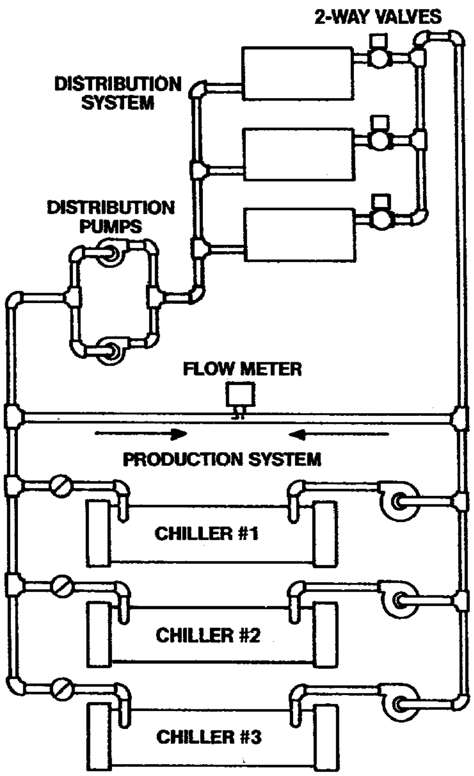

Figure 21

(Figure 21) An alternative multi-chiller, variable flow rate, parallel-piped arrangement is the decoupled system. In this arrangement, each chiller is controlled independently by its own W7900 — the W7901 multiple chiller controller is not required.

The decoupled system uses a piping technique that separates the distribution pumping system from the chilled water production pumping system.

Both systems share a common element — a length of bypass piping that connects the supply and return headers. Taken separately, the variable flow distribution and constant flow production pumping functions form complete, hydraulic systems. The events in one system do not affect pressures or flow in the other. Therefore, the systems are decoupled.

The distribution system consists of multiple chilled water coils that are served by 2-way valves and a water distribution pump(s). With this valving arrangement, load changes cause the flow rate within the distribution piping to vary. This also causes a flow rate change in the bypass. If the distribution system demands greater flow than is being produced by the active chiller-pump combinations, return water is forced through the bypass into the supply header (right-to-left in the illustration). Flow in this direction is an indication of the need for additional chiller capacity.

Sensing this, the flow meter (FM) starts an additional chiller-pump combination. This additional flow causes a flow reversal within the bypass. Flow in this direction satisfies the need of the distribution system.

Over-capacity is also detected by bypass flow — but in the opposite direction (left-to-right in the illustration). When the flow rate in this direction exceeds that produced by one chiller pump by approximately 20 percent, the flow meter stops a pump. Note that this does not result in a flow reversal.

In this manner, bypass flow is used to sense the need for more or fewer chiller-pump combinations.

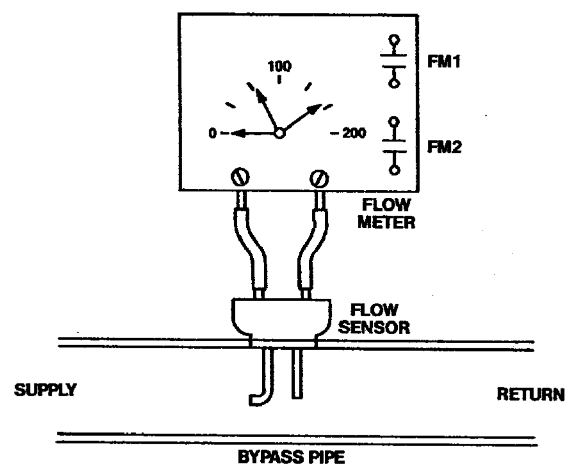

Figure 22

(Figure 22) A suggested control scheme is illustrated. In this example, the devices used to sense and meter the flow within the bypass pipe are an Annubar Flow Sensor plus an Eagle Eye Flow Meter with auxiliary contacts.

The flow sensor is installed to sense the flow rate within the bypass in the direction supply-to-return (left-to-right, Figure 21).

The flow meter is adjusted to close its FM1 contacts when the flow in this direction exceeds approximately 120 percent of the capacity of one chiller pump.

No flow or reverse flow (right-to-left, Figure 21) is seen by the flow sensor as zero flow. The flow meter is adjusted to close its FM2 contacts when a reverse or no flow condition exists.

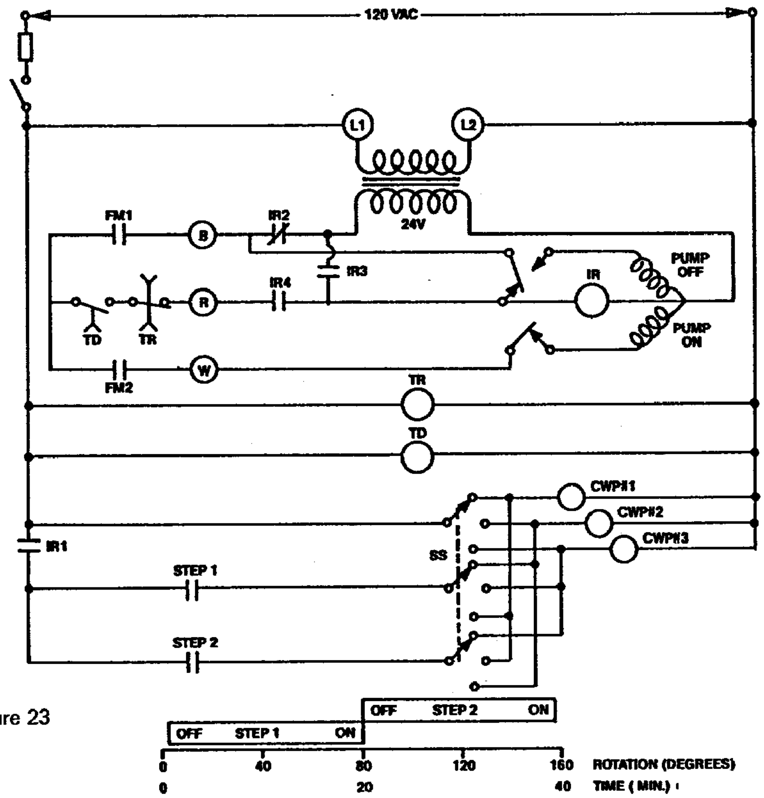

Figure 23

(Figure 23) The pump actuating control scheme uses a Honeywell S684 Step Controller with a 5 minute motor. Note that a normally-open, time to close time delay relay (TD) is used to prevent controller operation for 30 minutes, in this example, after the first chiller is started. This gives the system an opportunity to settle-out before addition chiller capacity is added.

In addition, a repeat cycle timer (TR) is used to slow the movement of the step controller. The reduced travel rate, in this example, produces a 20 minute time lapse between the "on" and "off" of each step of control.

In operation, the lead chiller pump is started manually. After 30 minutes, the time delay relay (TD) closes enabling the step controller.

If, at this time, the distribution system flow rate exceeds that output by the active production pump, a right-to-left flow direction exists in the bypass.

The flow meter sees this as "no flow", closing its FM2 contacts. This closes the circuit R to W of the step controller, energizing the "pump on" motor winding. Under control of the repeat cycle timer (TR), the controller is driven in a direction to close its Step 1 contacts. In this example, the closing of the Step 1 contacts starts chiller water pump #2 (CWP#2).

In the event the added production pumping capacity does not reverse the direction of flow within the bypass, the FM2 contacts remain closed, driving the controller in the direction to close the Step 2 contacts to start the remaining pump.

A reduced flow rate within the distribution system — a flow rate that is less than the combined output of the operating production pumps — causes water to flow from left-to-right in the bypass.

Monitoring the flow rate, the flow meter should be adjusted to close its FM1 contacts when the rate exceeds approximately 120 percent of that produced by one production pump.

The closing of the FM1 contacts energizes the "pump off" motor winding. This drives the controller in a direction that progressively opens the step contacts, stopping the pumps.

The purpose of the sequence switch (SS) is to alternate the starting sequence of the chillers.

In the event of a power interruption, the holding relay (1R) drops out. Upon restoration of power, the motor "pump-off" winding is energized, driving the controller in a direction to open the step contacts.

When the controller reaches zero degrees of rotation, an end switch energizes IR. This closes contacts 1R1, 1R3 and 1R4 and opens 1R2, returning control to the flow sensor. This feature sequences the restarting of the production pumps after a power failure or accidental shutdown.

Energy Management

The far-reaching benefits of building energy management through chiller time-of-day scheduling and electrical demand limiting, via chilled water reset, can be implemented by the Trane Tracer Energy Management Systems.

The Trane EMRA, or "Ernie", reciprocating energy manager is not applied with W7900 based chillers. The W7900 and W7901 controllers provide all of the load/unload logic required.

Energy Management Interface

Time-Of-Day Scheduling
One of the most important functions an energy manager performs is to turn off equipment when it is not needed. This is referred to as time-of-day scheduling.

Operating cost savings can be further improved when time-of-day scheduling is enhanced by optimal start/stop logic.

(Figure 6, Page 4) An energy manager can shutdown a single W7900 controlled chiller by closing a gold contact to short terminals 6 and 7 (Δ LFS). These terminals can be accessed at terminals 1TB3-1 and 1TB3-2 in the Cold Generator control panel.

When a shutdown is initiated, the W7900 de-energizes all compressor capacity steps plus the hot gas bypass relay (HGB). The following pumpdown cycle is terminated by the low pressure controls or after one minute has elapsed.

A normal start is initiated when the short is removed.

(Figure 12, Page 11) An energy manager can shutdown all chillers in a W7901 controlled system by closing a gold contact to short terminals T1 and P2 (SHUTDOWN).

When shutdown is initiated, the W7901 issues subtract commands to all chillers. In response, each W7900 subtracts stages at the rate of 1 every 50 seconds.

If the chillers are equipped with hot gas bypass, the lead compressor of each chiller will operate at its minimum stage of capacity for 30 minutes prior to shutdown.

Normal operation is resumed when the short is removed.

Demand Limiting
Another important function of an energy manager is to minimize electrical demand peaks. It does this by sensing building electrical demand, anticipating demand peaks and turning off selected electrical loads. Depending upon the local utility rate structure, it may be cost effective to shed loads as small as 5 kw. Reciprocating compressors can represent significant electrical loads and are, therefore, good potential candidates for demand limiting. It is important to note, however, that the chiller cooling load can only be deferred by demand limiting — not eliminated — regardless of the demand limiting method used.

Three methods can be used to shed chiller load:

1. Turning chillers off

2. Partially unloading chillers directly

3. Unloading chillers indirectly, via chilled water reset

Method 1 cycles compressors, placing a hardship on the equipment, and is therefore not recommended.

Method 2 requires the addition of relays that control the compressor unloader valves. This method can be difficult to implement because the needed control panel electrical connections are not always easy to make and programming the energy manager can be complicated. However, when used, it has the advantage of shedding electrical load immediately when commanded by the energy manager.

Method 3 is easy to apply and is effective. However, up to 2 minutes time delay may occur between the reset command and the actual decrease in electrical load. Also, this results in only a temporary electrical load reduction. Since the load (10 F ΔT, for example) does not change, the chiller capacity will gradually return to the level needed to maintain a 10 F ΔT load.

The reset of chilled water temperature is implemented by adding resistance between terminals 6 and 7 (ΔLFS) of the W7900 controller or, in a multiple chiller system, the W7901 controller. The reset ratio is established by adding .67 ohms for each percent of design chiller ΔT.

For example, assume the leaving water temperature is to be reset upward by 37 percent of the design chiller ΔT. Using the resistance values from Figure 10, page 9; 37% x .67 ohms/% + 1715 = 1740 ohms

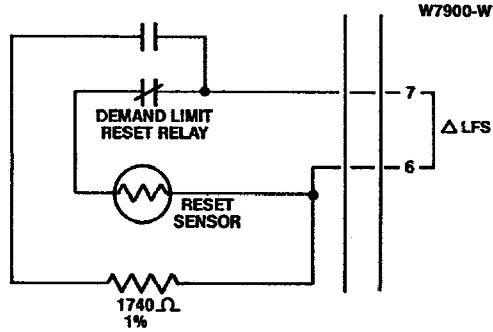

Figure 24

In this example, a 1740 ohm, 1 percent resistor, when placed in the reset circuit, as illustrated in Figure 24, will result in approximately 37 percent reduction in cooling capacity and approximately 37 percent reduction in kw.