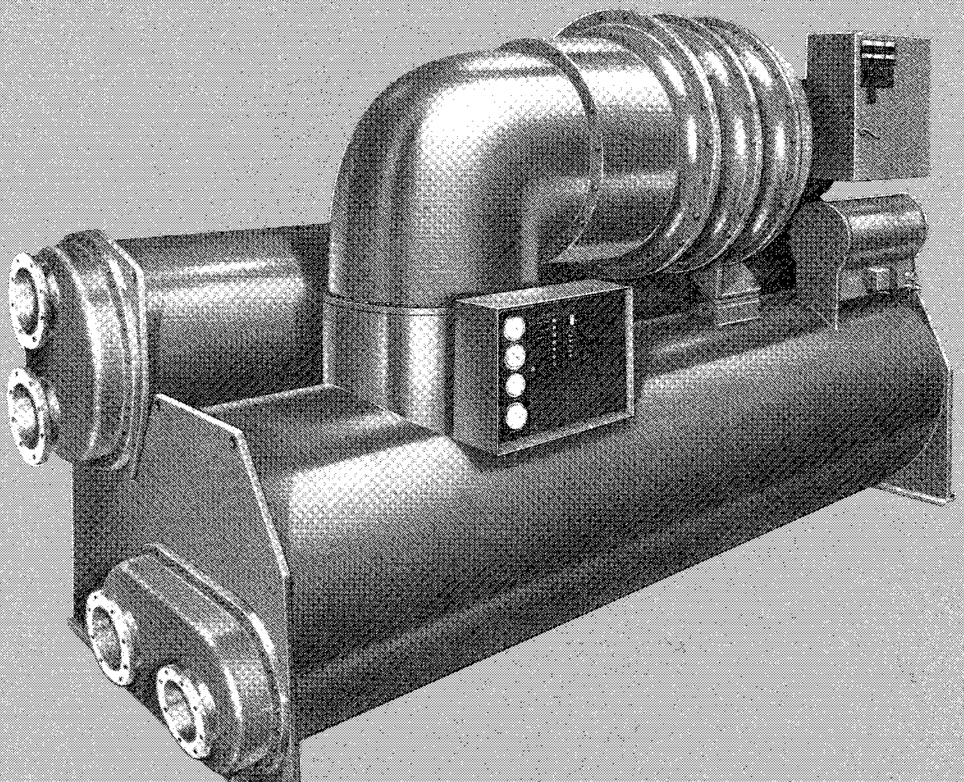
TRANE™

Applications Engineering Manual

Control Of Model CVHE CenTraVacs



Control Of Model CVHE CenTraVacs

Purpose

This manual describes the control and application of Model CVHE CenTraVacs in single and multiple chiller installations. Overall system descriptions provide the fundamentals. In addition, functions of major control elements are detailed. Primarily, the intent is to provide adequate information to apply Model CVHE CenTraVacs to conventional chilled water systems.

Content

The CenTraVac System

The Model CVHE CenTraVac is a state-of-the-art, water cooled hermetic centrifugal water chiller. Cooling capacities nominally range from 140 to 1250 tons of refrigeration. Three stages of centrifugal compression are used to meet the thermodynamic requirement of a conventional Refrigerant-11 vapor compression cycle. Two economizers (interstage flash cooling chambers) are used to provide maximum thermodynamic cycle efficiency.

The CVHE CenTraVac is driven directly by a hermetic, 2-pole, low slip 3600 rpm AC induction motor. Because R-11 is a low pressure refrigerant, operating pressures are below 15 psig for conventional air conditioning applications.

Chilled water is produced in a shell-and-tube evaporator of the flooded design. Refrigerant evaporates on the outside surface of the tubes, chilling water as it passes through the tubes. Water surfaces (tube internal diameter) can be cleaned mechanically or chemically by accessing the tubes at either end.

All heat is rejected through a shell-and-tube condenser. Like the evaporator, condenser water is circulated internally through the tubes. Therefore, they too may be mechanically or chemically cleaned.

The Model CVHE CenTraVac is a one-piece, completely factory assembled package. Field connections to the machine are made to four elements:

1. Main compressor power
2. Control system interlocking
3. Chilled water piping
4. Condenser water piping

Main compressor power is taken from standard 3 phase, 60 Hz utility grids. Voltages may vary from 200 to 4160, depending on the specific electrical service provided.

Proper application of the CenTraVac requires an understanding of the functions of the complete system and its components.

First, control system interlocking ties capacity control functions and CenTraVac safety devices to the chilled water system.

Chilled water is circulated by one or more pumps through a piping system to air conditioning terminals. Ordinarily, these terminals employ an extended surface heat transfer coil. One of two basic concepts can be used to control the air conditioning effect.

Modulated Flow	Constant Flow
2-way valve	3-way valve

Traditionally, water chillers are rated as constant flow devices. The reasons for this are beyond this brief overview and are discussed in Trane Engineer's Newsletter Vol. 9, No. 1. Some form of interlocking must be provided to prove chilled water flow before the chiller is permitted to operate. Operation of the CenTraVac without adequate chilled water flow has serious consequences and must be avoided.

The CenTraVac control system maintains a constant temperature, chilled water supply. The assumption is that a constant supply water temperature will satisfy the continuous cooling needs of the terminal units. In this way, chiller capacity is matched with the system's demand for cooling.

Condenser water is usually pumped from a cooling water source. Several sources re commonly available:

- Open cooling tower
- Closed circuit cooling tower (evaporative cooler)
- Cooling pond
- River or lake water (with or without heat exchanger)
- City water

Condenser water interlocking is also required. However, the physical consequences of an interrupted supply of condenser water, while important, are not as damaging as the loss of chilled water flow.

Condenser water also requires temperature control. If the water is too warm, the CenTraVac may not be able to meet the cooling load. If it is too cool, other operational problems can occur. This control system is completely separate and usually not interlocked with the CenTraVac itself.

Control Panel

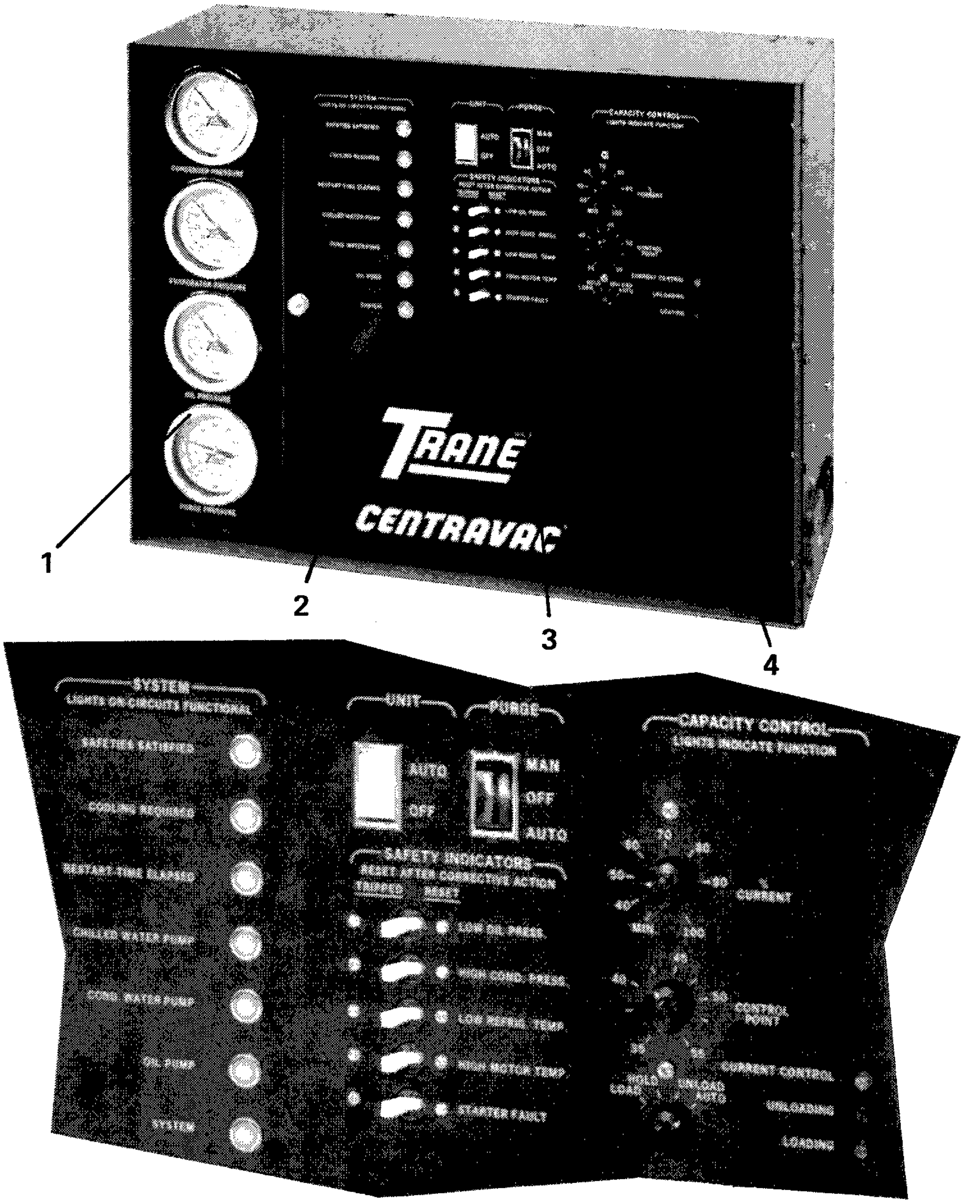


Figure 1

(Figure 1) All safety and operating controls are housed in the CenTraVac control panel. The panel functions are divided into four categories, as indicated by the external panel layout:

1. Pressure indicating gauges have no operating function. They are used only to provide condenser, evaporator, lubricating oil and purge drum pressures.

2. System sequence status lights perform an important diagnostic function. A series of seven lights shows the progress of the CenTraVac starting sequence. As each of the seven circuit interlocks is verified, its individual pilot light comes on. Therefore, the reason for an aborted start can be determined by observing the pilot lights and determining the point at which the sequence was breached.

3. Five fault trip indicators display the status of each safety cutout control. Circuit interrupters are used to open the circuit instead of relays because they will hold their position in the event of power interruption. Therefore, power failure does not require the manual resetting of all safeties. Additional alarm contacts on each of the fault trip indicators are brought to a terminal strip for external connection.

4. The electronic capacity control system consists of three elements:

- Chilled water temperature control
- Demand limiter
- Manual inlet vane control

Chilled Water Temperature Control

The chilled water temperature control module uses a transistorized sensing element to measure the supply water temperature. The controller has an adjustable dead band that spans the plus and minus sides of the setpoint temperature. The dead band adjustments are ±.25, ±.50, ±1.0 and ±1.5 F. Within this dead band no control action is taken.

The control module loads and unloads the chiller using variable duration control pulses. The time lapse between each successive load/unload pulse is adjustable between 10 and 310 seconds. This, coupled with the dead band adjustment, provides the latitude of control sensitivity needed to produce stable system performance over a broad range of application conditions.

Loading...When loading, the control pulse duration is a function of the chilled water temperature deviation from the plus side of the dead band versus the motor current, as a percentage of the "% Current" setting of the demand limiter.

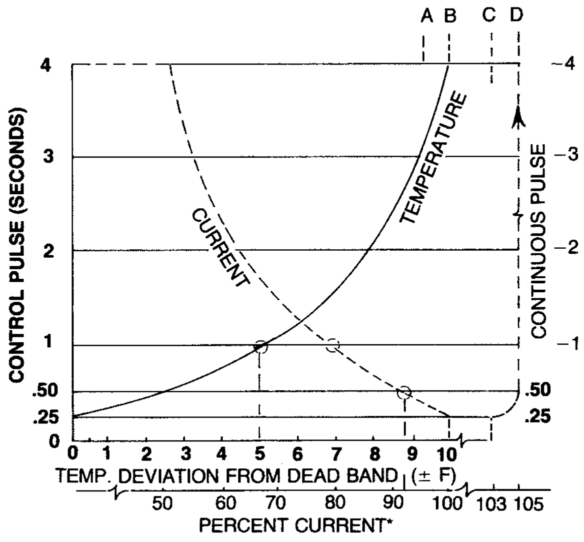


Figure 2

(Figure 2) For example, assume the supply water temperature is 5 F above the plus, or upper, dead band limit and the overload is generating a signal that is proportional to 93 percent of its "% Current" setting.

Since the module recognizes the more critical of the two conditions, instead of the one second, the lesser .5 second load pulse is used. In this example, current limiting takes precedence over temperature control. Had the current been 80 percent, or less, of the "% Current" setting, the temperature related 1 second pulse would have been used. In other words, in this example, to maintain stability, the module selects the lesser of the two pulse signals. Again, the selected 10 to 310 second time lapse is observed between successive load pulses.

Unloading...Unlike loading, the unloading mode is solely a temperature related function. Since chiller unloading provides motor current relief, motor current is not a consideration. Therefore, the unloading pulse duration is a function of the chilled water temperature deviation from the minus side of the dead band.

Demand Limiter

The demand limiter control setting is continuously variable from 40 to 100 percent of the motor full load current. Any particular setting pre-loads the device, as required, to limit the motor current to that value.

Motor current is sensed by three current transformers and is processed into a proportional DC voltage by the CenTraVac electronic overload. This output voltage is monitored by the demand limiter which transforms it into a signal that is related to its "% Current" setting.

As discussed, throughout the temperature controller modulating range, the chilled water temperature deviation from the dead band and the "% Current" signals are compared. And, the "% Current" signal is used to establish the load pulse duration when current limiting becomes the critical condition.

When in the current limiting mode, the load pulse duration is reduced until 100 percent of the demand limiter "% Current" setting is reached (point B). At this point, the control pulse duration drops from .25 seconds to zero—vane movement stops.

At 103 percent of the load limiter setting (point C), an unload sequence is initiated. This sequence consists of .25 second unloading pulses, each followed by the 10 to 310 second null period. This sequence is repeated in an attempt to return the chiller to 100 percent of the "% Current" setting.

Finally, should the current exceed 105 percent of its setting (point D), a continuous unloading pulse is established. This pulse is terminated when the motor current is reduced to 95 percent of the limiter setting (point A). At this point, the chiller is free to again accept load.

Manual Inlet Vane Control

A four-position switch provides manual override of the automatic capacity control system. In addition to "automatic" control, the inlet vanes can be made to "load", "hold" or "unload". This permits the operator to check vane motor and linkage operation.

Note: While the chilled water temperature control system is overridden, the demand limiter and low refrigerant temperature systems remain in control to limit vane travel.

Sequence Of Operation

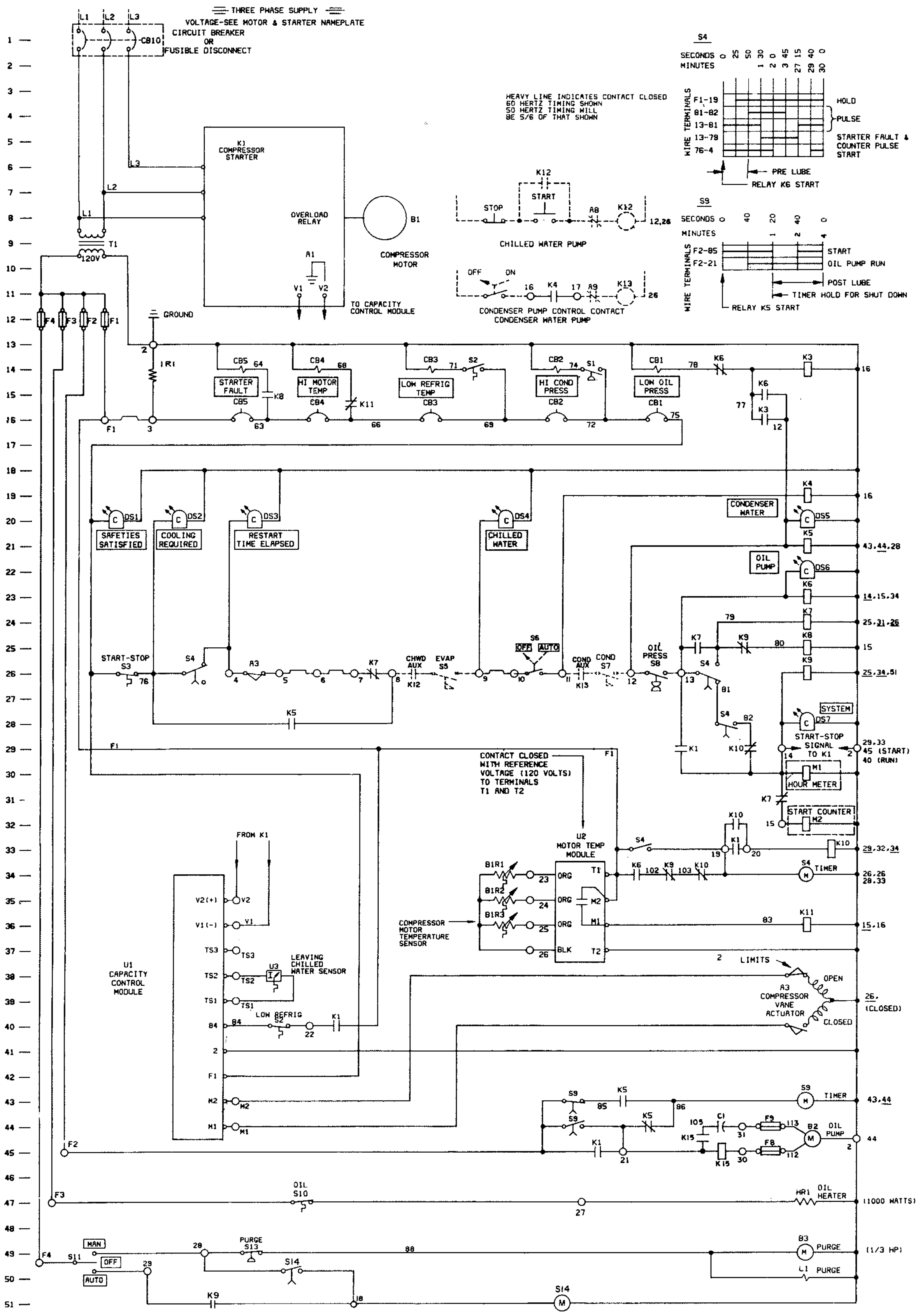


Figure 3

(Figure 3) The sequence of operation can be described using this schematic line diagram.

A start is initiated by performing three manual operations:

1. Energize the chilled water pump starter, K12 (line 8).
2. Close the main circuit breaker, CB10 (1).

Immediately, the motor temperature module, U2 (34), closes its contacts, energizing relay K11 (36). In turn, the K11 contacts (15) open, preventing circuit interrupter CB4 (16), "Hi Motor Temp.", from opening.

Note: The action of the circuit interrupters is delayed approximately 1 second. This avoids nuisance trip-out at initial start-up, when the relay logic needed to arm the interrupters is being established.

3. Set the "Off-Auto." switch, S6 (26), to "Auto.".

Once these procedures have been performed, control power is conducted through the safety control interrupter contacts (16). If all interrupter contacts are closed, Pilot light DS1 (20), "Safeties Satisfied", will light and power will be fed to the F1 terminal of the capacity control module, U1 (42). This drives the vane actuator, A3 (39), to the closed position.

Next, when the return water temperature indicates that a load exists, the cooling demand switch, S3 (26), closes. This lights DS2 (20), "Cooling Required", and conducts control power to timer contact S4 (26). Provided 30 minutes have elapsed since the previous start, S4 is closed, lighting DS3 (20), "Restart Time Elapsed".

Assuming the compressor is not running and its inlet vanes have been driven to the closed position, the inlet vane actuator end switch, A3 (26), is closed. This conducts control power through the normally closed contacts of K7 (26) to the auxiliary contacts, "CHWD AUX." (26), of the chilled water pump starter, K12 (8). Once the starter is engaged and chilled water flow is established, the contacts and the flow sensor, S5 (26) close, lighting DS4 (20), "Chilled Water". Proceeding through switch S6 (26), relay K4 (19) is energized. The normally open contacts of K4 (11) close, energizing the condenser water pump starter, K13. This closes both the starter auxiliary contacts, "COND. AUX." (26), and, once flow is established, the flow sensor S7 (26). In turn, pilot light DS5 (20), "Condenser Water", lights and relay K5 (21) is energized. Contacts K5 (43 and 44) reverse positions, energizing the oil pump timer, S9. Approximately 40 seconds later, the S9 contacts (44) close, energizing the oil pump motor, B2, through a current sensing relay, K15. Relay K15, in turn, closes, placing the start capacitor, C1, into the circuit. Once the motor assumes running load current, K15 drops-out, de-energizing C1. Another set of K5 contacts (28) close to maintain the control circuit by forming a parallel path with the start inhibitor functions.

When oil pressure is established, oil pressure switch S8 (26) closes, lighting DS6 (22), "Oil Pump", and energizing relay K6 (23). Contacts K6 (14, 15) reverse positions, energizing relay K3 (14). In turn, the K3 contacts (16) close, arming the low oil pressure circuit interrupter, CB1 (14). A third K6 contact (34) closes, energizing timer motor S4 (34). Twenty-five seconds later, contacts S4 (33) close, keeping the S4 timer motor energized throughout its timing cycle. After another 25 seconds have elapsed, S4 contacts (28) close, lighting DS7 (28), "System", and energizing compressor motor starter K1 (29). The closing of the K1 contacts (29) holds power on the motor starter. A second set of K1 contacts (33) energizes relay K10 (33).

One set of K10 contacts (32) closes forming a holding circuit for relay K10. A second set (29) opens, removing the start signal from the K1 starter circuit. Consequently, the start pulse lasts only long enough to energize the starter. A third K1 contact (45) maintains power to the oil pump motor as long as the main compressor starter remains energized.

When the compressor motor starter reaches the "run" configuration, the K1 interlock (40) feeds control power to terminal 84 of the capacity control module, U1 (40), through the low refrigerant temperature switch, S2. Once energized, U1 transmits variable duration load/unload pulses to the inlet vane actuator, A3 (39). As discussed, the pulse duration is established by processing the signals from the chilled water temperature sensor, U3 (38) and the demand limiter, which is an integral part of U1. Since U1 is not powered until the compressor comes to speed, the chiller starts unloaded.

Note that relay S2, "Low Refrig. Temp.", has normally closed (40) and normally open (14) contacts. In the event a low refrigerant temperature develops, contacts S2 (40) open, causing U1 (38) to transmit a constant "unload" signal to the compressor vane actuator, A3 (39). If an additional temperature drop equal to the differential of S2 occurs, contacts S2 (14) close, tripping circuit interrupter CB3 (16), "Low Refrig. Temp.".

The arming of the "Starter Fault" circuit interrupter is initiated when relay K9 (26) is energized, opening its contacts (25). The arming is completed 40 seconds after the initial pulse is sent K1, when timer contact S4 (26) switches from 13-81 to 13-79, energizing relay K7 (24). In turn, the K7 contacts (25) close, locking relay K7 into the circuit. With this circuit arrangement, if some fault causes K1 to open, relay K9 (26) de-energizes, closing contacts K9 (25). This energizes relay K8 (25), closing contacts K8 (15), opening the "Starter Fault" circuit interrupter, CB5 (16).

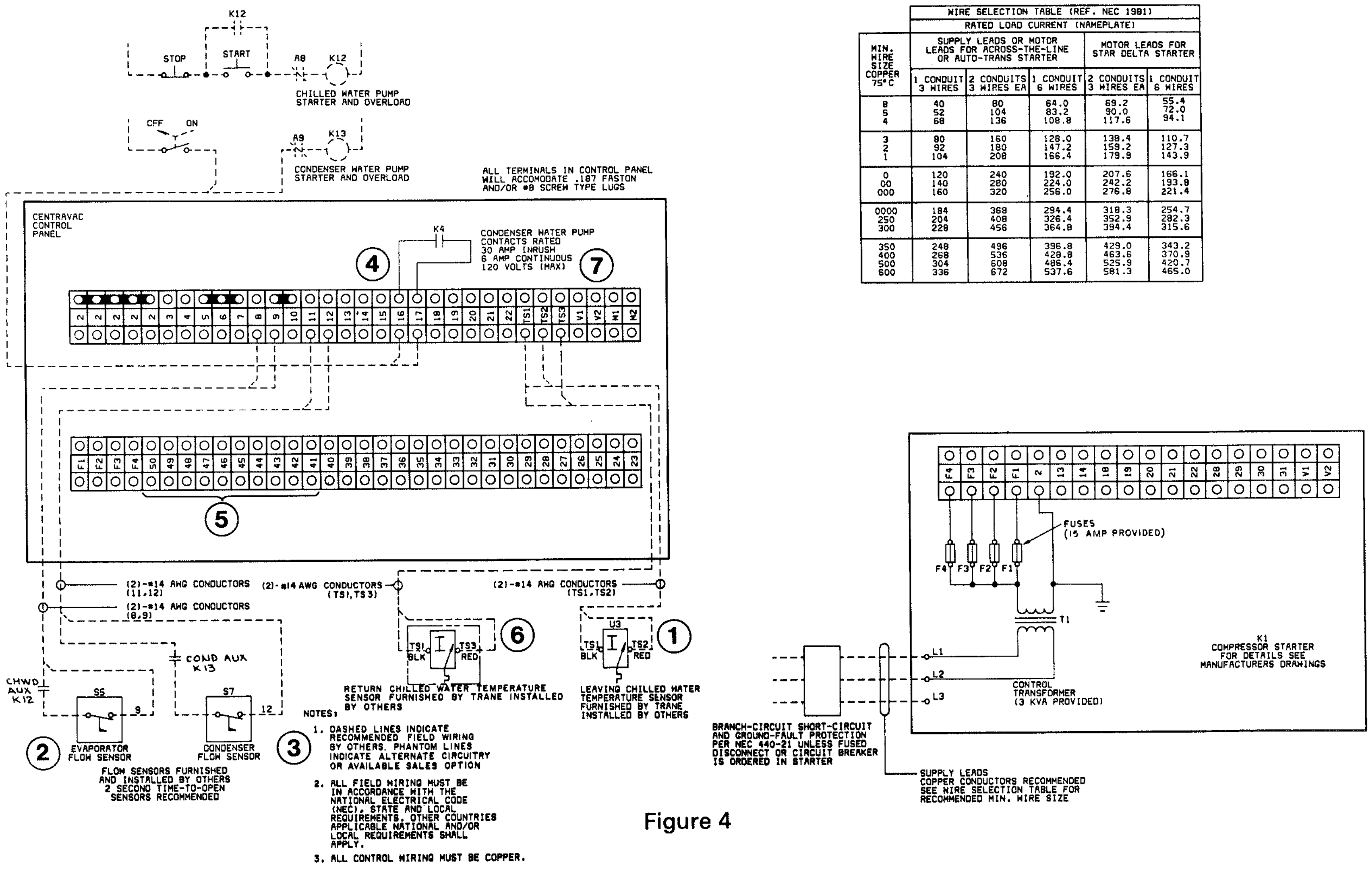
Sequence Of Operation

When the CenTraVac is stopped normally by the cooling demand switch, S3 (26), or abnormally by a safety trip-out, the relays (K1 and K5) within the oil pump control circuit de-energize. To provide bearing oil pressure during compressor coast-down, a contact of timer S9 (44) remains closed for 2 minutes 40 seconds to operate both the oil pump and timer motors.

Loss of oil pressure while the compressor is running causes the oil pressure switch, S8 (26), to open. This interrupts control power at terminal 13, de-energizing the compressor and, in particular, relay K6 (23). With K6 de-energized, power feeds from terminal 12 (26) through contacts K3 (16) and the normally closed K6 contacts (14) to trip circuit interrupter CB1, "Low Oil Pressure", de-energizing the control circuit.

Finally, the purge unit may be operated continuously by placing the "Man.-Off-Auto." switch, S11 (49) in the "Man." position. When placed in the "Auto" position, purge operation is cycled by timer contacts S14 (50) as long as the compressor is operating and relay contacts K9 (51) remain closed. The timer, S14 (51), is adjustable from 0 to 60 minutes. The typical adjustment produces 5 minutes of purging per hour of unit operation.

External Panel Wiring



ALL TERMINALS IN CONTROL PANEL WILL ACCOMODATE .187 FASTON AND/OR #8 SCREW TYPE LUGS

CONDENSER WATER PUMP CONTACTS RATED 30 AMP INRUSH 6 AMP CONTINUOUS 120 VOLTS (MAX)

FLOW SENSORS FURNISHED AND INSTALLED BY OTHERS 2 SECOND TIME-TO-OPEN SENSORS RECOMMENDED

RETURN CHILLED WATER TEMPERATURE SENSOR FURNISHED BY TRANE INSTALLED BY OTHERS

LEAVING CHILLED WATER TEMPERATURE SENSOR FURNISHED BY TRANE INSTALLED BY OTHERS

BRANCH-CIRCUIT SHORT-CIRCUIT AND GROUND-FAULT PROTECTION PER NEC 440-21 UNLESS FUSED DISCONNECT OR CIRCUIT BREAKER IS ORDERED IN STARTER

SUPPLY LEADS COPPER CONDUCTORS RECOMMENDED SEE WIRE SELECTION TABLE FOR RECOMMENDED MIN. WIRE SIZE

NOTES:

1. DASHED LINES INDICATE RECOMMENDED FIELD WIRING BY OTHERS. PHANTOM LINES INDICATE ALTERNATE CIRCUITRY OR AVAILABLE SALES OPTION
2. ALL FIELD WIRING MUST BE IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE (NEC), STATE AND LOCAL REQUIREMENTS. OTHER COUNTRIES APPLICABLE NATIONAL AND/OR LOCAL REQUIREMENTS SHALL APPLY.
3. ALL CONTROL WIRING MUST BE COPPER.

WIRE SELECTION TABLE (REF. NEC 1981)

RATED LOAD CURRENT (NAMEPLATE)

MIN. WIRE SIZE COPPER 75°C	SUPPLY LEADS OR MOTOR LEADS FOR ACROSS-THE-LINE OR AUTO-TRANS STARTER			MOTOR LEADS FOR STAR DELTA STARTER	
	1 CONDUIT 3 WIRES	2 CONDUITS 3 WIRES EA	1 CONDUIT 6 WIRES	2 CONDUITS 3 WIRES EA	1 CONDUIT 6 WIRES
8	40	80	64.0	69.2	55.4
5	52	104	83.2	90.0	72.0
4	68	136	108.8	117.6	94.1
3	80	160	128.0	138.4	110.7
2	92	180	147.2	159.2	127.3
1	104	208	166.4	179.9	143.9
0	120	240	192.0	207.6	166.1
00	140	280	224.0	242.2	193.8
000	160	320	256.0	276.8	221.4
0000	184	368	294.4	318.3	254.7
250	204	408	326.4	352.9	282.3
300	228	456	364.8	394.4	315.6
350	248	496	396.8	429.0	343.2
400	268	536	428.8	463.6	370.9
500	304	608	486.4	525.9	420.7
600	336	672	537.6	581.3	465.0

Figure 4

(Figure 4) The wiring and corresponding terminal points used to interconnect the panel with the various external control functions are:

1. Chilled water temperature sensor...Terminals TS1 and TS2 accept wiring from the chilled water temperature sensor (U3), located in the supply water piping.

2. Evaporator flow sensor (S5)...Terminals 8 and 9.

3. Condenser flow sensor (S7)...Terminals 11 and 12.

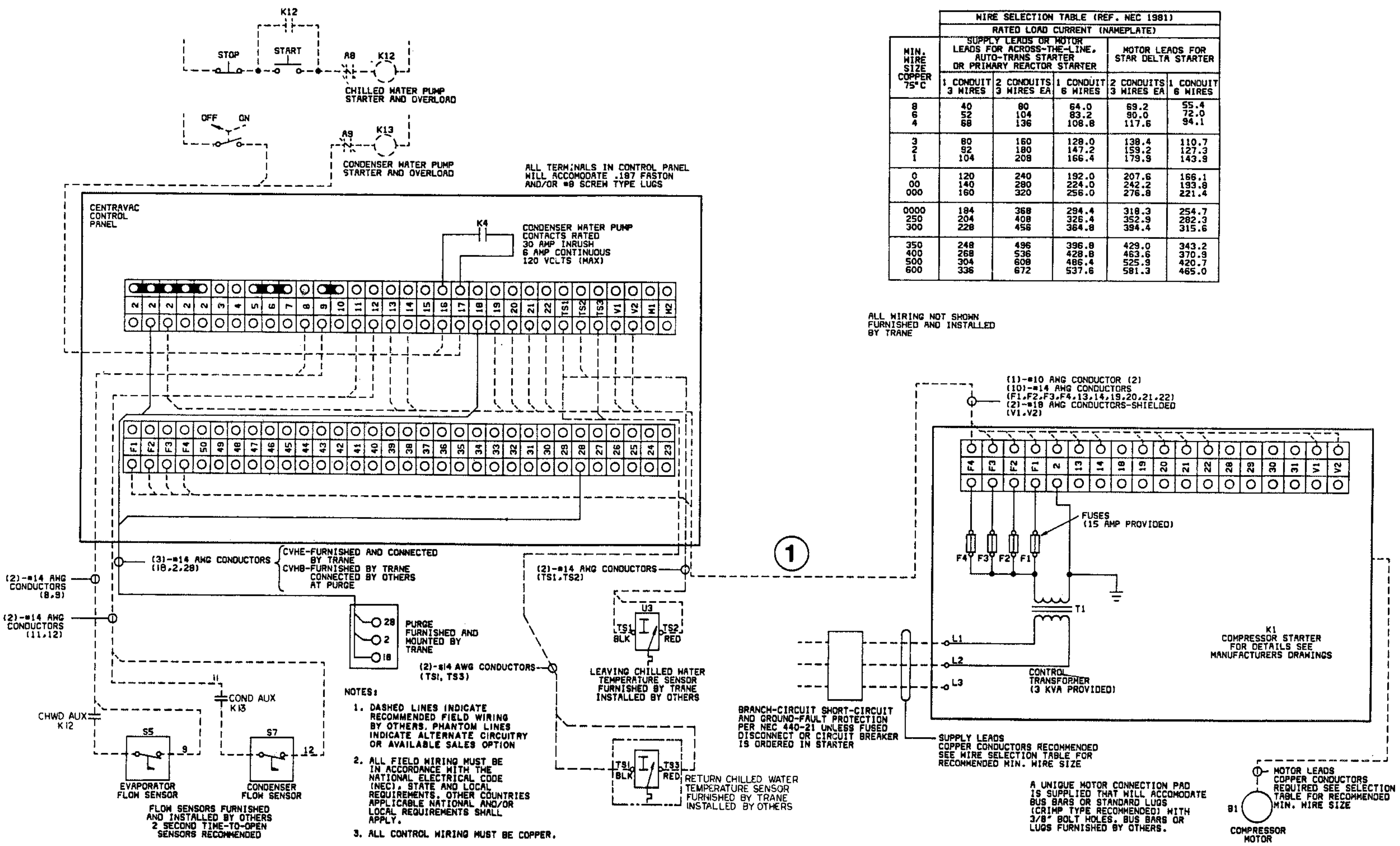
4. Condenser water pump relay (K4)...Wiring from relay K4 exits at terminals 16 and 17. In addition, terminal points are provided for optional connections:

5. External alarm...Terminals 41 through 50 can be used as N.O. or N.C. contacts for connection to external alarms.

6. Return chilled water temperature sensor...-Terminals TS1 and TS3 accept input from this sensor. In turn, the capacity control module (U1) processes the signal to provide chilled water temperature reset.

7. Remote demand limiter control...Terminals V1 and V2 (connected to the electronic overload relay A1) will accept additional input from a 0 to 8.25 VDC source. This additional signal can be used to provide separate demand limiting capability.

External Panel Wiring



WIRE SELECTION TABLE (REF. NEC 1981)

MIN. WIRE SIZE COPPER 75°C	RATED LOAD CURRENT (NAMEPLATE)				
	SUPPLY LEADS OR MOTOR LEADS FOR ACROSS-THE-LINE, AUTO-TRANS STARTER OR PRIMARY REACTOR STARTER			MOTOR LEADS FOR STAR DELTA STARTER	
	1 CONDUIT 3 WIRES	2 CONDUITS 3 WIRES EA	1 CONDUIT 6 WIRES	2 CONDUITS 3 WIRES EA	1 CONDUIT 6 WIRES
8	40	80	64.0	69.2	55.4
6	52	104	83.2	90.0	72.0
4	68	136	108.8	117.6	94.1
3	80	160	128.0	138.4	110.7
2	92	180	147.2	159.2	127.3
1	104	208	166.4	179.9	143.9
0	120	240	192.0	207.6	166.1
00	140	280	224.0	242.2	193.8
000	160	320	256.0	276.8	221.4
0000	184	368	294.4	318.3	254.7
250	204	408	326.4	352.9	282.3
300	228	456	364.8	394.4	315.6
350	248	496	396.8	429.0	343.2
400	268	536	428.8	463.6	370.9
500	304	608	486.4	525.9	420.7
600	336	672	537.6	581.3	465.0

NOTES:

1. DASHED LINES INDICATE RECOMMENDED FIELD WIRING BY OTHERS. PHANTOM LINES INDICATE ALTERNATE CIRCUITRY OR AVAILABLE SALES OPTION
2. ALL FIELD WIRING MUST BE IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE (NEC), STATE AND LOCAL REQUIREMENTS. OTHER COUNTRIES APPLICABLE NATIONAL AND/OR LOCAL REQUIREMENTS SHALL APPLY.
3. ALL CONTROL WIRING MUST BE COPPER.

Figure 5

(Figure 5) In addition to the required and optional wiring discussed and illustrated in Figure 4, the wiring needed to interconnect the panel with a remotely mounted starter is:

1. Starter (K1)...Thirteen wires interconnecting the motor starter and panel.

Fused control power, start-stop relay signals and starter interlocks use eleven wires. The remaining two, connecting V1 and V2, conduct a VDC signal from the overload relay (A1) to the load limiting function of the capacity control module (U1).

Factory-Mounted Starter Panel

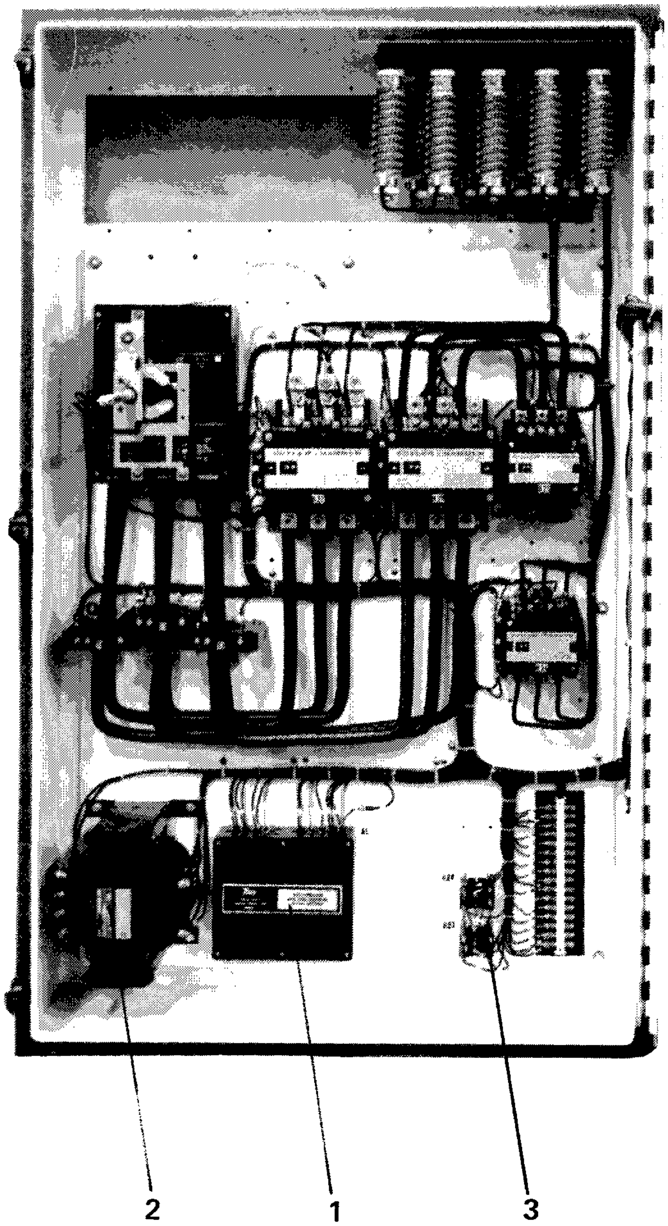


Figure 6

(Figure 6) As a standard option, factory-mounted starter panels are available for all low voltage (200 to 575 volts) Model CVHE CenTraVacs. They contain conventional star-delta, closed transition starters. Factory mounting eliminates field placement of the starter plus all wiring interconnecting the panel and starter and the starter and the CenTraVac.

The starter panels have these advanced features:

1. Solid state electronic overload relay and distribution fault protector.

2. 3 KVA control power transformer.

3. Two (redundant) pilot relays, plus run and start interlocks and a low loss, non-threaded motor connection system.

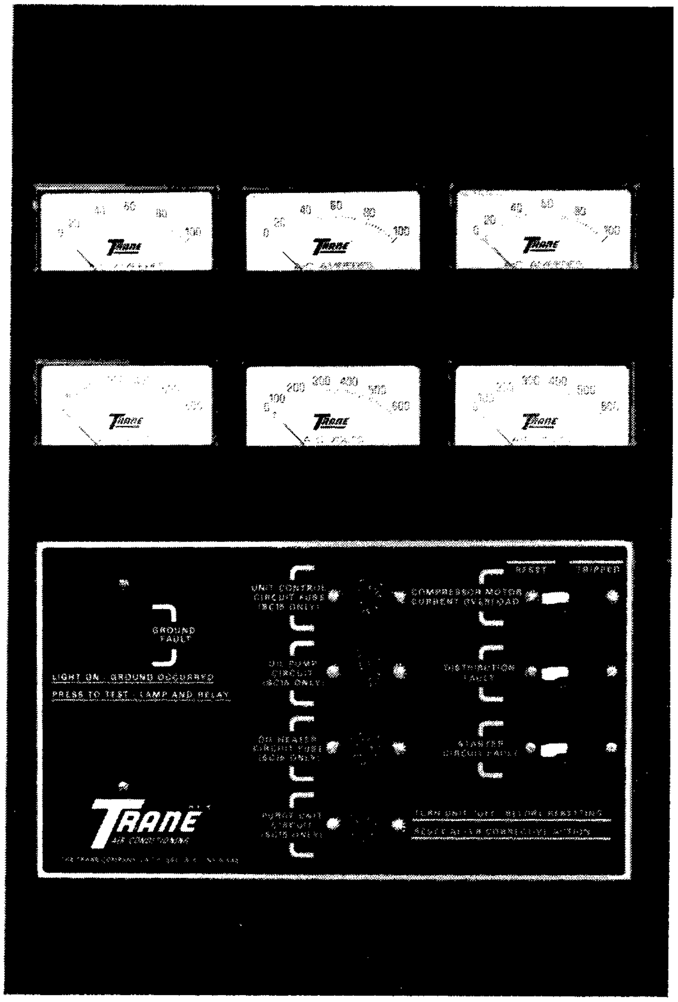


Figure 7

(Figure 7) In addition, the occurrence of a starter fault, overload or distribution fault is displayed by fault trip indicators located in the panel door. Optionally, a ground fault indicator and voltage and amperage meters, for each of the phases, are available.

The CenTraVac motor is started in the star, or wye, configuration and accelerates to the normal operating speed (3575 ± 0.7 percent). Starting current is monitored by the electronic overload module (A1) and, as soon as the current falls to approximately 85 percent of motor RLA, transition to full voltage (delta) is initiated.

When transition is complete, motor current is monitored against a value of 107 percent of RLA. If the current should reach this value, the overload will trip, disconnecting the motor.

Motor Overload Protection

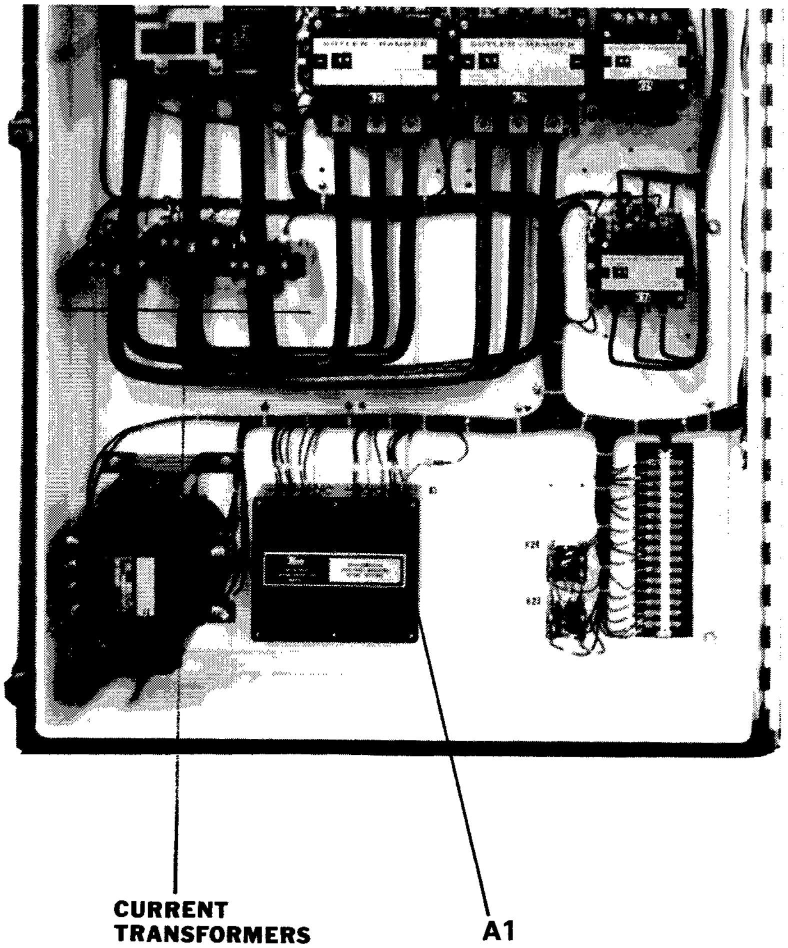


Figure 8

(Figure 8) Three-phase current is monitored by three polarized current transformers located in the primary motor power feeders. The outputs of these current transformers allow the electronic overload A1 to perform its functions. Further, the outputs are used to signal the load limiting function of the capacity control module U1.

The degree of protection afforded by the solid state electronic overload is significantly better than any electro-mechanical device available. The motor is protected throughout its starting and running cycles. Should the current fall outside specific bounds, electronic circuitry will trip the motor starter instantly.

The overload will stop the compressor if any of a variety of system abberations (low voltage, phase failure, phase unbalance or phase reversal) cause high motor current. If specific lockouts are required to cope with these problems, starters may be fitted with such standard options as low voltage protectors and phase failure — phase reversal relays.

Complete description of the CenTraVac motor overload system appears in Installation, Operation and Maintenance MPCA-IOM-1.

Distribution System Fault Protector

Modern electrical distribution systems employ state-of-the-art circuit switching equipment. This allows the utility to supply "uninterrupted" power to its customers during electrical storms and periods of high circuit usage. A definition of "uninterrupted", however, reveals a potential problem. The utility overlooks short duration interruptions. Certain types of loads are adversely affected by short duration power interruptions.

Obviously, electronic loads such as computers and medical monitoring equipment can be severely affected. In addition, high inertia centrifugal equipment can experience trauma when subjected to short duration power interruptions.

The mechanics of this problem are based on the fact that an induction motor, rotating near its synchronous speed, generates a "back e.m.f." that is nearly as large as the driving voltage. When the driving voltage is removed, the back e.m.f. remains, allowing control circuits to remain active for about 60 cycles (1 second).

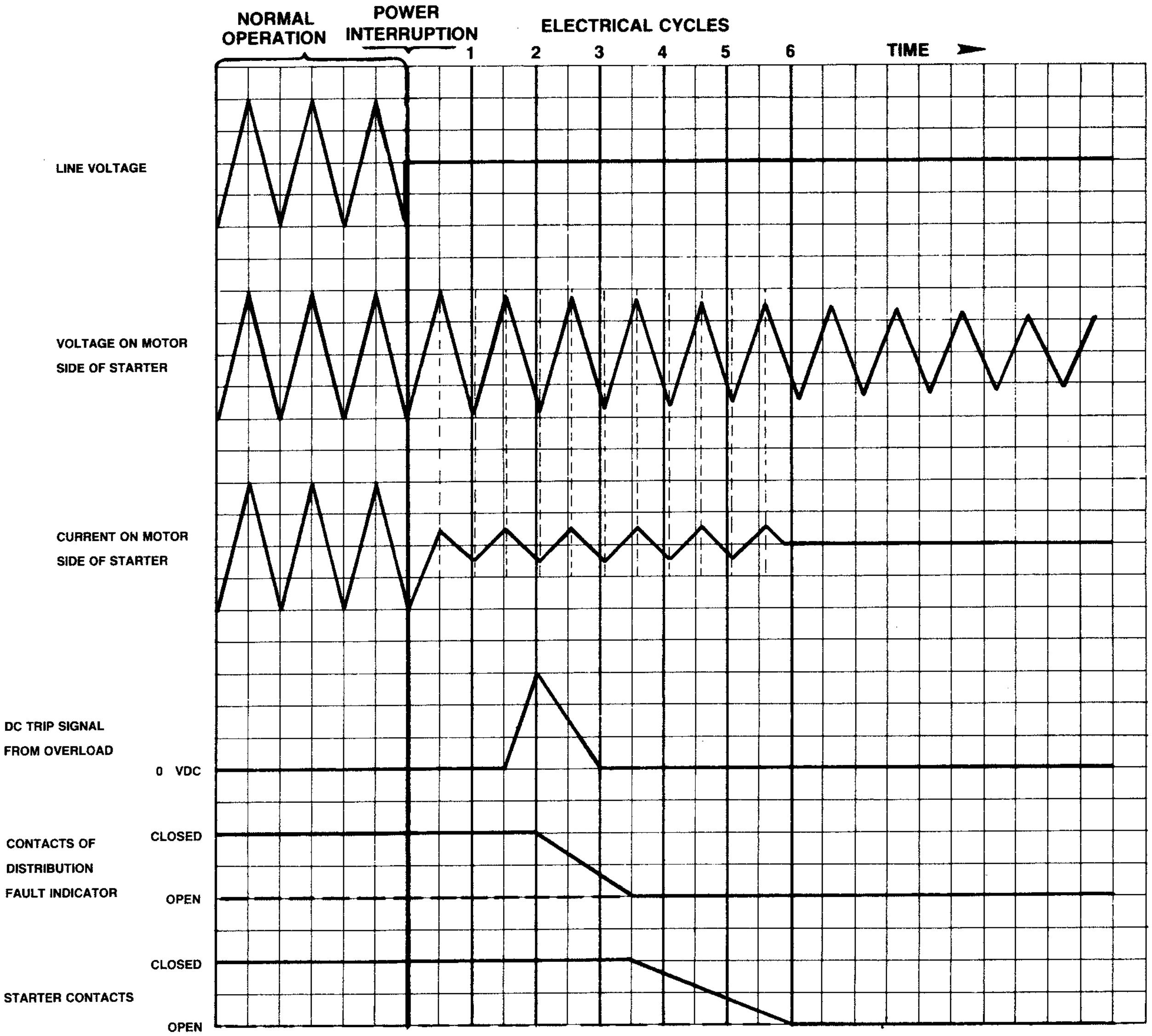


Figure 9

(Figure 9) The frequency of the remaining back e.m.f. follows the decelerating motor, as shown in this brush recording. Therefore, when utility voltage is restored, the motor and power frequencies are "out of synch". The result is extremely high mechanical torques attempting to put the motor and compressor back into synchronization.

Distribution System Fault Protector

(Figure 10) These high torques are potentially damaging to motor windings, shafts, bearings and, as shown, compressor keyways and impellers can also be severely damaged. Therefore, high torque conditions must be avoided at all cost.

The CenTraVac distribution system fault protector can detect short duration interruptions and take the motor off the line within six electrical cycles (1/10 second). It accomplishes this by sensing motor current decline (instead of voltage loss). When motor current decreases to a value less than 20 percent RLA and the starter (K1) contacts remain closed, this module sends a signal to the starter to disengage immediately.

A power interruption of 2 cycles duration (1/30 second) initiates a starter trip with the starter becoming fully disengaged at approximately 6 cycles (1/10 second).

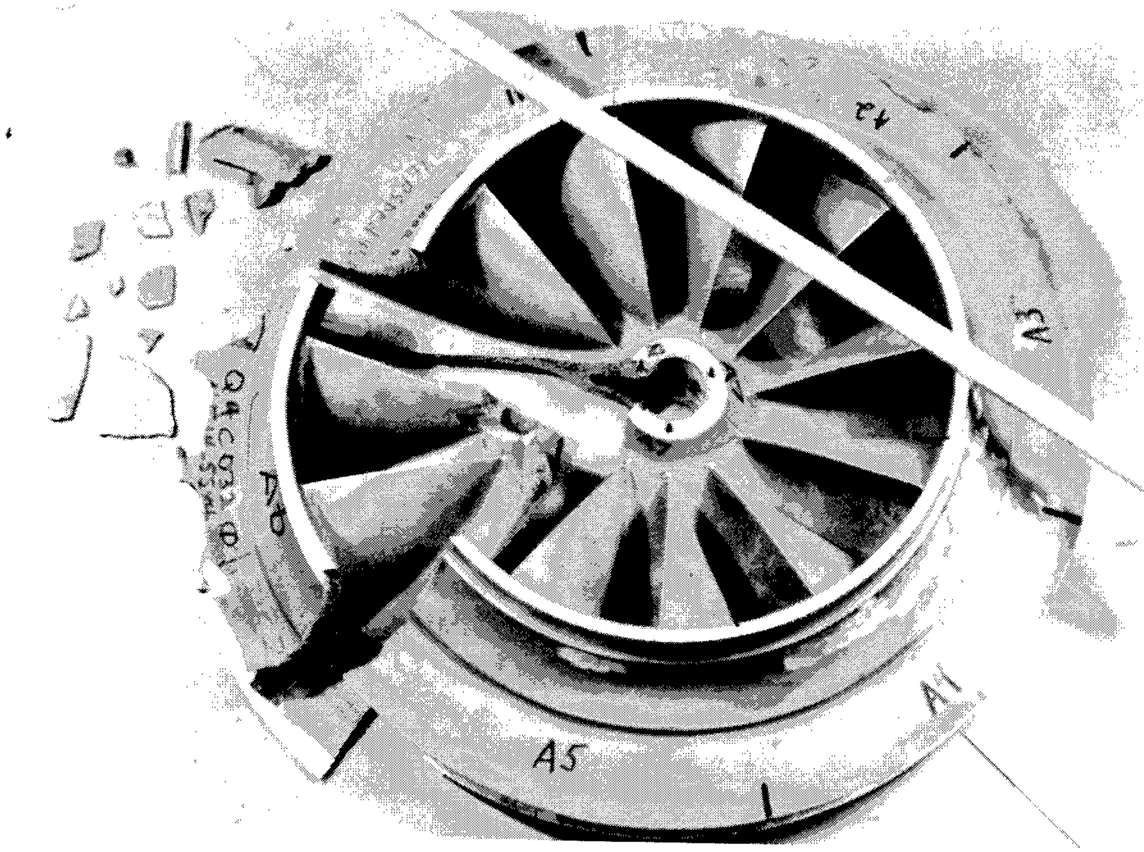


Figure 10

Water Piping And Control

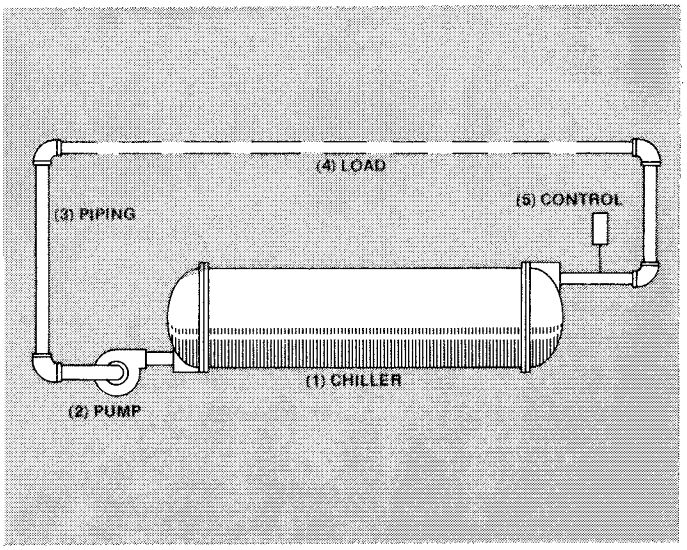


Figure 11

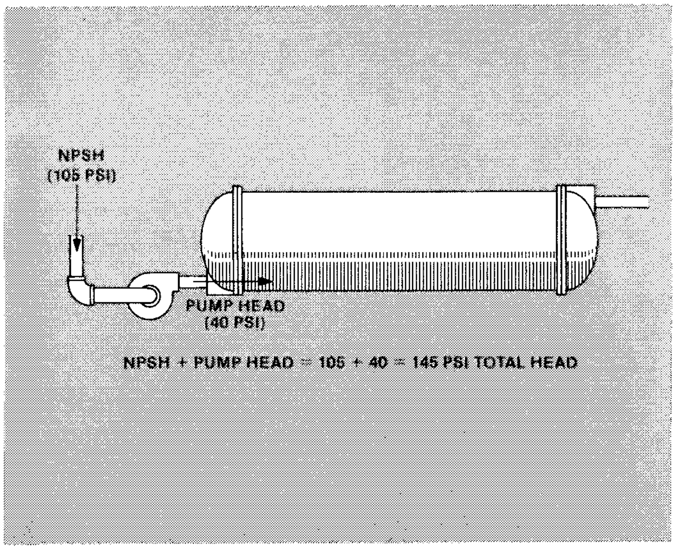


Figure 12

(Figure 11) The basic closed loop chilled water system consists of five elements:

1. Chiller
2. Pump
3. Piping
4. Load
5. Control

Pump location...Should the chilled water pump "pull" or "push" through the chiller? The answer lies in the system's ability to deliver an adequate net positive suction head (NPSH) to the pump. Therefore, in general, pumps are placed upstream of chillers. Exceptions to this generalization occur when the NPSH of a system is very high. This causes the dynamic pressure in the chiller itself to be even higher. And, it may force chiller construction into a higher cost pressure range.

(Figure 12) For example, a system may develop a pump NPSH of 105 psi (243 ft. of water). The pump might be sized to produce 40 psi (92 ft.). The total is 5 psi below the chiller rating of 150 psi. However, the "zero flow" pressure capability of the pump can be well over 45 psi, pushing the pressure at the chiller beyond its rating. In this circumstance, the pump would be better placed downstream from the chiller.

Chilled water flow range...(Figure 13) By changing evaporator pass arrangements, a wide range of chilled water flow rates can be accommodated. Catalog DS-CTV1 shows the various pass arrangements that are available. Two generalizations can be made:

1. Higher flow rates require lower numbers of evaporator passes.

2. CenTraVac capacity increases with higher numbers of evaporator passes.

Therefore, it can be said that high system temperature rise (low flow rate) generally promotes increased chiller efficiency and capacity when the number of passes is optimized.

Flow variations...Once a system flow rate is established, it is usually not changed. While variable flow is sometimes a desirable concept from an energy standpoint, it presents several operating difficulties. First, flow variations can fall

Evaporator Flow Limits and Connection Sizes

UNIT COMPRESSOR DESIGNATION	EVAPORATOR BUNDLE SIZE DESIGNATOR	ONE PASS			TWO PASS			THREE PASS			CONNECTION' ARRANGEMENTS
		MINIMUM GPM	MAXIMUM GPM	CONNECTION SIZE(IN)	MINIMUM GPM	MAXIMUM GPM	CONNECTION SIZE (IN)	MINIMUM GPM	MAXIMUM GPM	CONNECTION SIZE (IN)	
CVHE 013-020	1	582	1,280	6	175	640	5	116	427	4	A, B, C, D, J, K, L, M, N, P, Y, Z, 1, 3
	2	525	1,156	6	158	578	5	105	385	4	
	3	465	1,022	6	139	511	5	93	341	4	
	4	398	877	6	120	439	5	80	292	4	
	5	362	795	6	108	397	5	72	265	4	
CVHE 022-032	1	915	2,013	8	274	1,006	6	183	671	5	A, B, C, D, J, K, L, M, N, P, Y, Z, 1, 3
	2	817	1,796	8	245	898	6	163	599	5	
	3	722	1,589	8	217	795	6	144	530	5	
		[illegible]	1,435	8	196	717	6	130	478	5	
				8	175	640	6	116	427	5	
							8	290	1,063	6	

Figure 13

outside the allowable tube flow ranges (DS-CTV1). Second, flow variations appear to the control system as a change in "system size". Consequently, the control system must be able to cope with "system size" changes without manual attention. Few existing chiller control systems have this capability. Application of chillers to variable flow systems should be done only with great care.

Control...The Model CVHE CenTraVac chilled water temperature control system is based on the concept of providing a constant supply water temperature. However, the system embodies sufficient flexibility to allow a variety of control strategies.

The basic system is described on page 5. It is a proportional control system in the sense that the inlet vane actuator movement rate is changed depending on the amount of temperature offset (error). The system also employs floating point control. Corrective action is taken whenever the actual temperature varies from the setpoint. Consequently, the CenTraVac control system is a hybrid system that employs the best features of proportional and floating point control. Additional features are optionally available.

Remote reset of chilled water temperature...The addition of a separate remote manual resetting control accomplishes remotely the same thing that can be done at the panel by adjusting the chilled water temperature setpoint control.

Automatic reset of chilled water temperature...Some control strategies call for higher supply chilled water temperature at reduced system load. Generally, reduced system load is evidenced by a decreasing return water temperature. A separate sensor is placed in the return water stream and its output is plugged into terminals TS1 and TS3 of the control panel. The "command module" uses this input to automatically reset the setpoint. The reset "authority" can be adjusted between zero and 2.0 degrees per degree.

Remote demand limiting...Energy management systems are used commonly to shed electrical loads during times of high demand. CenTraVac systems should never by cycled in response to energy managers. Duty cycling is not useful in controlling large motors such as those used in large centrifugal chillers. Instead, it is possible to shed electrical load by injecting a DC voltage in series with the signal between the electronic overload and the command module.

Application of alternative controls...The basic CVHE CenTraVac control system and hardware are fixed. Alternative devices to perform similar functions cannot be used to replace individual components in the CenTraVac control system.

Modifications to the temperature control system can only be made outside the physical property boundaries of the CenTraVac.

Condenser water...Several suitable condenser water supplies are potentially available. The most common heat sink is an open circuit cooling tower. Heat is rejected to the atmosphere by evaporating a portion of the circulating condenser water. About 1000 Btu's are rejected for each pound of water that is evaporated. Consequently, contaminants are concentrated as more and more water is evaporated.

Cooling towers require chemical treatment, maintenance and control. Temperature control is usually based on fan control, water bypass, or both. The basic concept of tower water control is to maintain a minimum temperature to the CenTraVac condenser. If the temperature is too high, the CenTraVac may not be able to meet the cooling load. Or, it may cause unnecessarily high power consumption. If the temperature is too low, the CenTraVac may not be able to maintain enough pressure differential between the evaporator and condenser to keep all lubrication and refrigerant flow systems functioning properly.

Other heat sinks may be used. "Once through" systems can use water from lakes, rivers or wells. Sea water can be used when it is separated from condenser water by a heat exchanger. Since the temperature of these "infinite heat sinks" cannot be controlled, the flow is controlled. The simplest way to execute condenser pressure control is to use a proportional pressure controller to regulate a simple V-port (linear action) condenser water valve. A typical arrangement is shown in Figure 14.

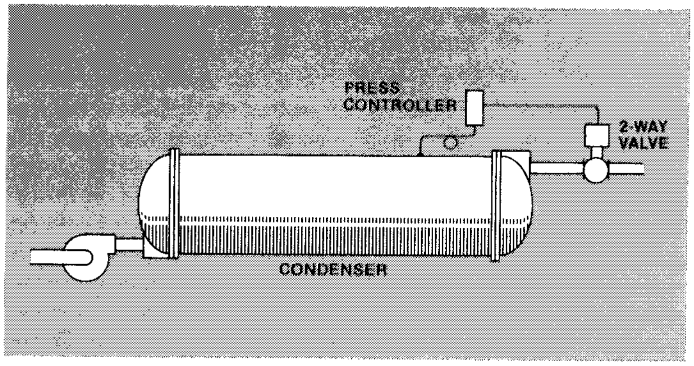


Figure 14

Electrical Interlocking

The Model CVHE CenTraVac requires a modest amount of system interlocking. Using the factory mounted starter option, interlocking is limited to six devices, per figure 4:

1. Chilled water flow switch (S5)
2. Condenser water flow switch (S7)
3. Condenser water pump pilot relay (K4)
4. Leaving chilled water temperature sensor (U3)
5. Chilled water pump interlocking contacts (K12).
6. Condenser water pump interlocking contacts (K13).

Separately mounted starters require additional control and power wiring. Figure 5 shows the specific terminals and wires that are needed to complete this interlocking.

Pneumatic Control

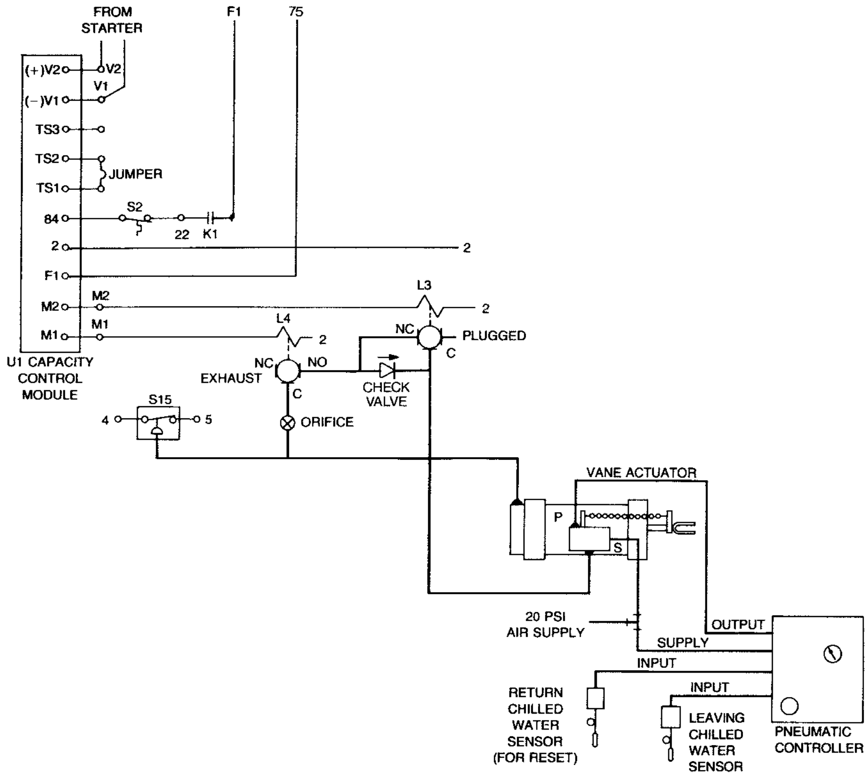


Figure 15

Clearly, the CVHE CenTraVac temperature control system is not pneumatic. However, for those designers that prefer to accomplish their control objectives pneumatically, an interface scheme is provided.

(Figure 15) In this scheme, an analog (proportional) signal from a conventional pneumatic temperature controller is fed into the pilot port (P) of the pilot positioner of a pneumatic inlet vane actuator. In addition, a jumper between terminals TS1 and TS2 of capacity control module U1 is substituted for the electronic leaving chilled water sensor U3, used in the previous scheme.

When the compressor motor starter assumes the "run" configuration, closing interlocking contacts K1, the continuous circuit between TS1 and TS2 causes the module to transmit a repeated, pulsed loading signal to solenoid valve L3. Unlike the previous scheme, the duration of this pulse is solely the function of motor current, in terms of its relationship to the "% Current" setting of the demand limiter. As before, the selected 10 to 310 second time lapse is observed between successive load pulses.

During the load pulse, the normally closed (NC) port of valve L3 is opened, permitting the output air pressure from the pilot positioner to be transmitted through the normally open (NO) and common (C) ports to L4 to the vane actuator. Within the time interval of the load pulse, the pneumatic temperature controller has the authority to open the vanes or to hold the current vane position. However, its unloading authority is continuous. A reduction in chilled water temperature, resulting in a reduced output pressure from the pilot positioner, causes air to bleed back through the check valve. This equalizes the pressure within the vane actuator with that output by the pilot positioner, repositioning the vanes to balance the lesser load.

When the system is shutdown, opening K1, or a low refrigerant temperature condition opens S2, control module U1 transmits a continuous unloading signal. This signal closes the normally open (NO) and opens the normally closed (NC) ports of valve L4, exhausting control air pressure from the actuator, closing the vanes.

Load limiting is handled as it is in the previous scheme. As motor current rises, the duration of the loading pulse decreases. At 100 percent of the "% Current" setting of the demand limiter, the pulse duration drops from .25 second to zero. At 103 percent, a .25 second unloading pulse is initiated, followed by a 10 to 310 second null period, in an attempt to return the current to 100 percent of the demand limiter setting. Finally, at 105 percent, a continuous unloading pulse is established. It is terminated when the motor current is reduced to 95 percent of the setting.

While the loading function is curtailed during load limiting, the unloading function is not. As discussed, any load reduction is handled by the bleed-off of actuator pressure through the check valve. This enables the pneumatic temperature controller to retain uninterrupted unloading authority throughout the load limiting function.

Notice that control air is supplied to and exhausted from the vane actuator through an orifice. This orifice is factory adjusted to produce the same vane movement rate as that produced by the actuator used in the electric control system.

Finally, the pneumatic-electric switch (S15) replaces and performs the same function as the end switch (A3) of the electric inlet vane actuator, Figure 3, line 26.

The remaining circuitry of the pneumatic system is the same as that used by electric control.

Multiple Chiller Systems

Varying control strategies give rise to a great number of multiple chiller piping nd control concepts. Most CenTraVac installations involve more than one chiller. Therefore, it is important to describe a variety of common arrangements.

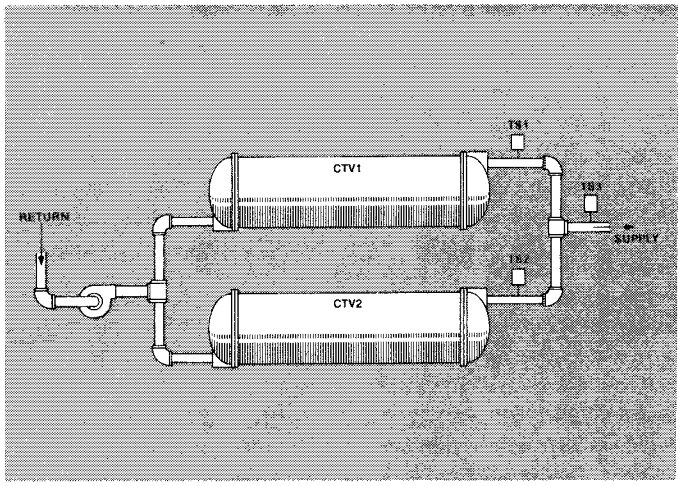


Figure 16

Two chillers, one pump...(Figure 16) A constant flow of chilled water is circulated through both chillers whether they are running or not. Obviously, this scheme allows water streams of possibly different temperatures to mix. The system return water temperature is common to both chillers. If one chiller is off, return water from CTV 1 mixes with supply water from CTV 2 to become the system supply temperature. This causes the common supply temperature to be higher than that of the water leaving the operating machine. It is an unavoidable consequence of this arrangement.

To obtain a controlled system supply temperature, the sensors of each chiller must be located in the common supply. The danger is that either operating chiller could "over chill" in an attempt to reach the correct common temperature. Each CVHE CenTraVac is equipped with a "low refrigerant" limit and cut out control. Used as a limiter, it will monitor refrigerant temperature and prevent it from becoming too low. This allows placement of the active water temperature sensor in the common supply line.

The next function to control is machine sequencing. The concept is to monitor CenTraVac motor current as it is processed into a 0 to 8.25 V. DC signal by A1. As the current exceeds a specific value for a duration of time, a second, or 'lag", chiller is allowed to start and accept load.

Sequencing is changed by simply reversing the position of a single pole double throw switch located in the sequence control panel.

The panel also contains two microprocessor based current monitors. One monitor module is dedicated to the "lead" chiller and the other to the "lag" chiller. In addition, several multi-pole relays are included in the panel.

The sequence of operation begins with a manual setting of the "lead-lag" switch. The lead chiller is now under the control of sensor TS3 located in the common chilled water supply. When the second chiller is directed to start, control of each CenTraVac is transferred to sensors TS1 and TS2 located in their respective supply water lines.

The reverse occurs when current in the "lag" chiller falls below the set current threshold, again, for an established duration of time. The "current and time to load" can each be set independently from the "current and time to unload". This provides a wide variety of loading strategies to be executed. Overlapping can be designed to obtain optimized performance from two machines. Lag chiller startup can be automatically delayed to accommodate a "real" need for two-machine operation.

In application, it is not necessary for the two CenTraVacs to be equally sized. Chillers are always operating on their own temperature controllers. Thus, the temperature control systems can be discretely set to operate as single chillers. The sequence control panel will not interfere with sensitivities or "ramp rates" originally dialed into the individual control panels. Separate flow switches are required for normal interlocking with each chiller.

Two chillers, two pumps...Figures 17 and 18 show two schemes. In the case of Figure 17, two pumps simply take the place of one. Thus, control is identical to the first arrangement.

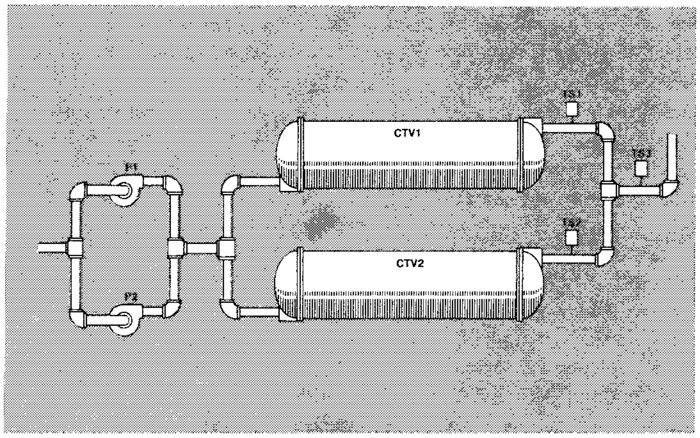


Figure 17

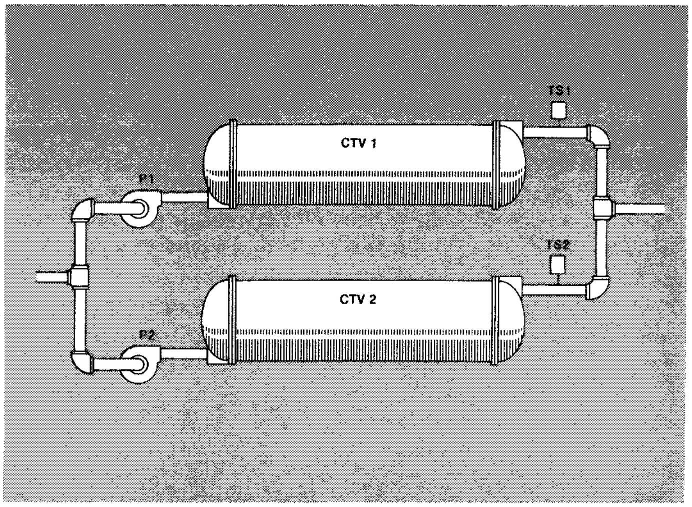


Figure 18

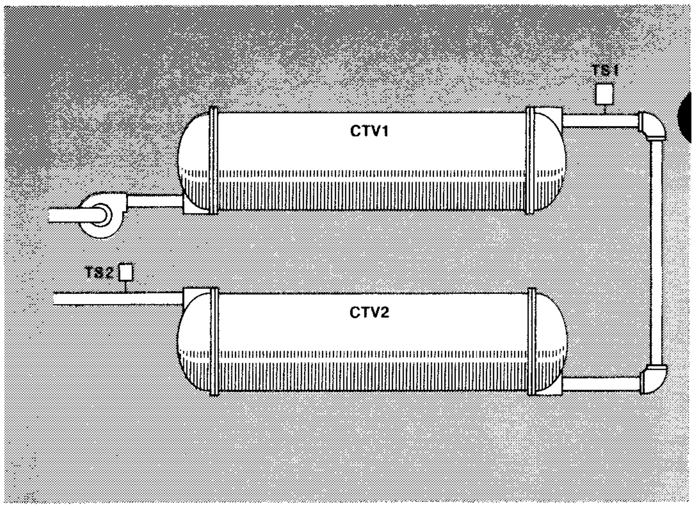


Figure 19

When pumps are to be sequenced in response to system demand, it can be accomplished as shown in Figure 18. In this case, a third temperature sensor is not needed because there is no mixing of dissimilar supply water temperatures.

Clearly, system flow changes as the number of pumps changes. This disruption in system dynamics introduces a measure of complication. Assume a condition of increasing load. As the "lead" chiller reaches its maximum capacity, the second pump is turned on. System water flow will nearly double even though the return water temperature will not fall immediately. The second CenTraVac will accept load as it responds to sensor TS2. Next, the return water temperature will fall rapidly as more system water is bypassed by the 3-way valves at the terminal coils. As long as the "drop out" current and time settings are below the reduced values that occur, the "lag" chiller will stay on the line. The required time setting can be expected to be longer than with the single pump system because of the time needed to restore system stability. However, the basic sequence control panel remains unchanged. The signal to start and stop the "lag" chiller also operates the "lag pump".

The two systems do not respond identically. In this case, the system is subjected to two different flow rates; one about 60 percent of the other. As long as all air conditioning terminals are satisfied with 60 percent flow (until the second chiller starts), loads will be met. But, if any loads cannot be met with low flow, they will simply suffer until the entire system loads the "lead" chiller to its "call" current. At that point, the "lag" pump and chiller are called to start. Again, this is a system characteristic and cannot be altered by control tactics or hardware.

Two chillers in series...(Figure 19) The sequence of control is identical to "two chillers, one pump", except that two sensors (TS1 and TS2) are used. Sensors are located just downstream from each chiller. Both chillers are set to control at the design supply temperature, so that either one can act as the "lead" machine. When both chillers are operating, they do not share the load equally. Instead, the upstream machine will take the greater load until both chillers are at full capacity.

Dual chiller control...The optional Sequence Panel (Figure 20) provides the type of control described previously for each of the dual CenTraVac arrangements (Figures 16 through 19).

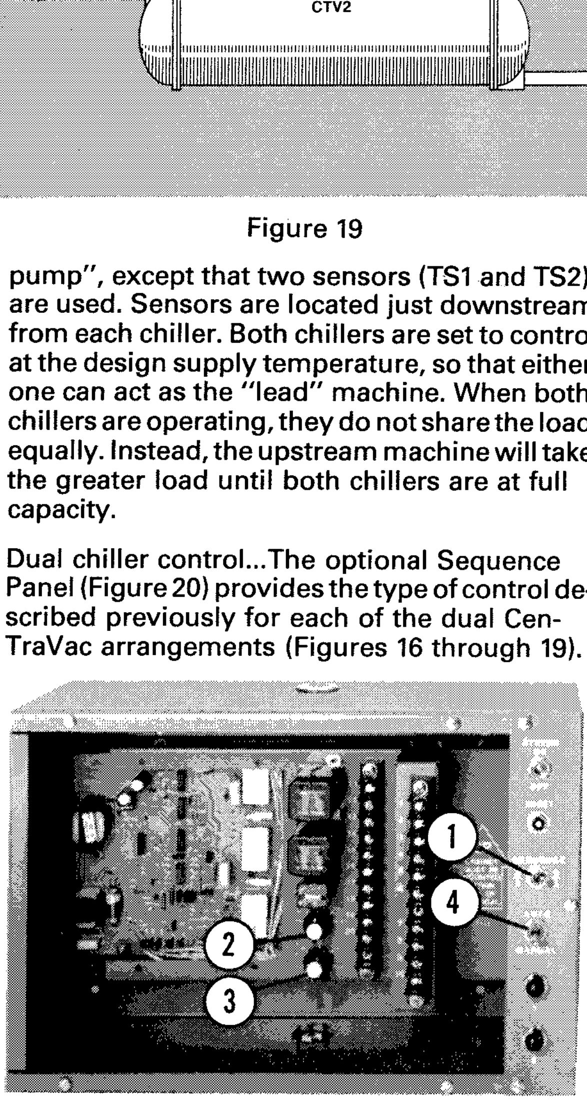


Figure 20

The "Sequence" switch (1) enables the operator to select the lead chiller. Once started, the panel monitors the current draw of the active machine. When the current equals, or exceeds, the adjustable "Load" threshold value (2) for a continuous 15 minutes, the lag chiller is started. The chillers then share the load.

When the current draw of both chillers equals, or falls below, the adjustable "Unload" threshold (3) for a continuous 15 minutes, the panel turns off the lag machine. The lead machine then loads, as necessary, to balance the remaining chilled water load requirement.

Placing the "Auto-Manual" switch (4) in the "Manual" position, bypasses the sequence panel. This arms both chillers, enabling them to respond to their individual control systems.

Multiple (3 or more) chiller control...Problems associated with temperature mixing, cross-connected pumps, flow variations and chiller redundancy create considerable design confusion for multiple chiller applications. The number of permutations and combinations of design schemes is well beyond the scope of this manual. In fact, most designers cannot afford the time to investigate all possible arrangements.

A simplifying technique has been applied successfully to a great number of multiple chiller systems. It involves separating the distribution pumping system from the production pumping system. Thus, the system hydraulics are "decoupled".

Figure 21 shows this basic arrangement. The variable flow distribution system can employ single or multiple pumps. Or, it can be a number of secondary pumping systems. The common element is a length of bypass piping that connects the return and supply headers.

Taken separately, the distribution and production pumping functions form complete hydraulic systems. Thus, events in one system do not affect pressures or flows in the other. The systems are hydraulically "decoupled".

From a control standpoint, the entire system is greatly simplified. Each pump-chiller combination operates as an individual and is independent from the remaining chillers. Capacity control is exactly as if each chiller were alone. Therefore, the conventional single chiller control system is perfectly suited for this arrangement.

Decisions on the number of chillers to operate are also simplified. Instead of using temperature as an indicator of system demand, flow is used. More accurately, relative flow is the indicator. If the distribution system demands greater flow than is being supplied by the number of chiller-pump combinations, return water is forced through the bypass into the supply header (left to right in the illustration). This will eventually cause the supply water temperature to rise and the system flow rate to increase further. This is a clear indication of the need for additional chiller capacity. Therefore, bypass flow in that direction is a signal to start another chiller-pump set. The additional flow will cause a reversal of the bypass line flow. Flow in this direction satisfies the needs of the distribution system.

Over capacity is also detected by bypass flow—but in the opposite direction (right to left in the illustration). When the flow in that direction exceeds the flow capacity of a chiller-pump, that pump (and its chiller) can be turned off without causing a flow reversal. Thus, bypass flow is used to indicate the need for more or fewer chiller-pump combinations.

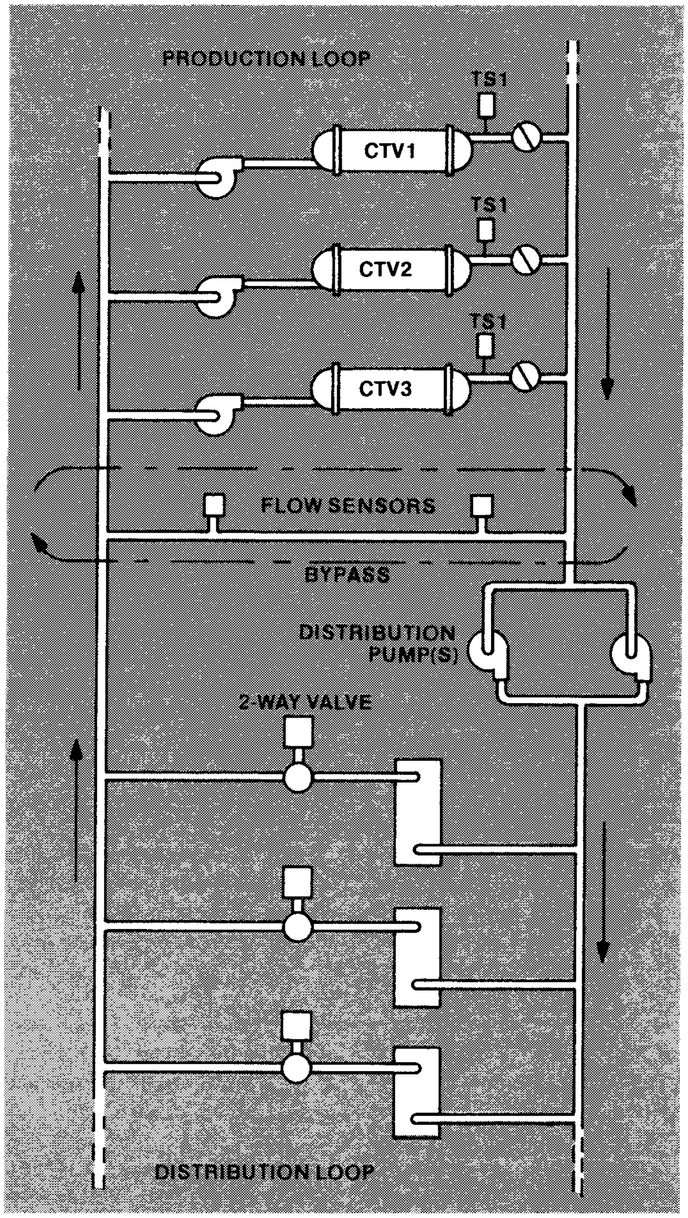


Figure 21

Integrating this concept with the Model CVHE CenTraVac control system is straightforward. The signal that requests additional flow accomplishes two things:

1. Starts an additional chilled water pump

2. Closes a pair of contacts bridging terminals F1 and 3 in the control panel of the associated CenTraVac. (Figure 3, line 16).

This initiating signal can be manual or automatic, depending on the control philosophy of the designer. Both arrangements use a simple impact type flow sensor signal. Figure 22 shows the manual scheme. Signals from electrical switches on the flow sensor (similar to "Annubar type 75") simply energize annunciator lights. The system operator can then start or stop chiller-pump combinations at his discretion.

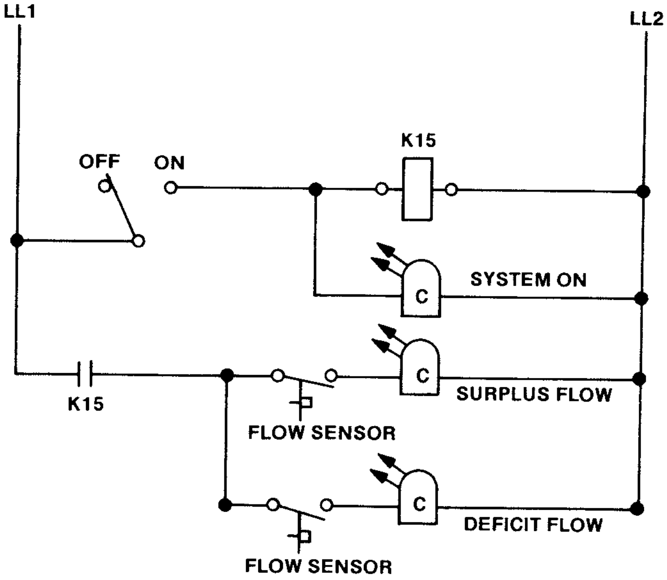


Figure 22

The automatic scheme shown in Figure 23 employs a Honeywell S684 step controller to actuate chiller-pump combinations. Signals from the flow sensors run the step controller in opposite directions to operate more or fewer chillers. Flow switches continue to be used as interlocks in each CenTraVac control panel (terminals 8 and 9).

Once this interlocking is completed, the CenTraVac capacity control system performs in the usual single chiller mode. An important benefit of this scheme is its energy optimization capabilities.

1. Chilled water is not produced unless it is required by the loads.

2. Chilled water is not allowed to circulate in the distribution system without experiencing a temperature rise.

3. Variable chilled water flow rate minimizes distribution system pumping power.

4. Chiller pumping is minimized (low pressure head; minimum chillers in operation).

5. Chillers run at their most efficient operating point.

Additionally, the decoupler system can be easily applied with thermal storage, heat recovery and on expansion projects. Chiller size, type and age are not critical. Thus, this system is extremely versatile and has wide application.

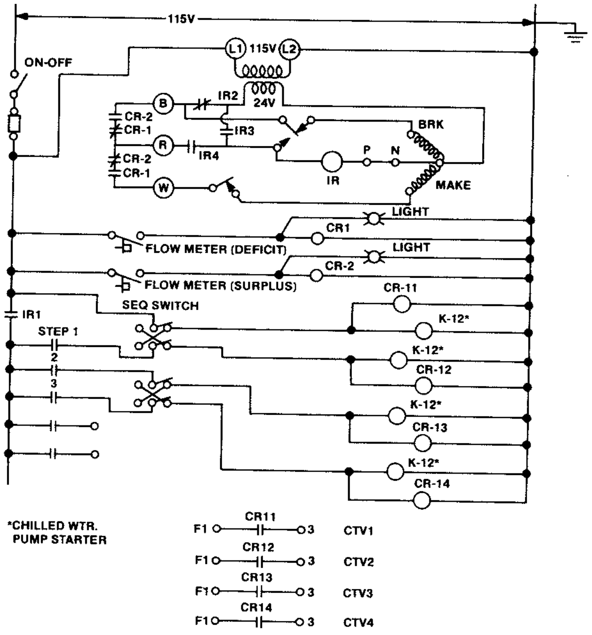


Figure 23