SUBCOURSE
OD1750

EDITION
A

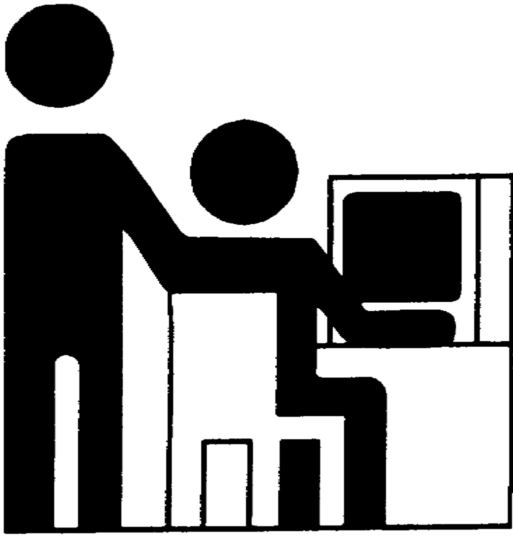
REFRIGERATION AND AIR CONDITIONING IV (EQUIPMENT COOLING)

AIPD

READINESS/PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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REFRIGERATION AND AIR CONDITIONING IV (EQUIPMENT COOLING)

Subcourse OD1750
Edition A

United States Army Combined Arms Support Command
Fort Lee, VA 23801-1809

14 Credit Hours

INTRODUCTION

This subcourse is the last of four subcourses devoted to basic instruction in refrigeration and air conditioning.

The scope of this subcourse takes in unit components of the absorption system, including their functions and maintenance; water treatment methods and their relationship to centrifugal systems; centrifugal water pumps and electronic control systems, including the relationship of amplifier, bridge and discriminator circuits to electronic controls.

The subcourse consists of three lessons.

Lesson 1. Direct Expansion and Absorption System.

2. Centrifugal Systems and Water Treatment.

3. Centrifugal Water Pumps and Electronic Control Systems.

Unless otherwise stated, whenever the masculine gender is used, both men and women are included.

CONTENTS

Page

Preface.......... ii

Acknowledgment.......... iii

Lesson 1
Chapter

1 Direct Expansion Systems 1

2 Absorption Systems 26

Lesson 2
Chapter

3 Centrifugal Systems 46

4 Water Treatment 77

Lesson 3
Chapter

5 Centrifugal Water Pumps).......... 96

6 Fundamentals of Electronic Controls.......... 103

7 Electronic Control Systems 132

Answers to Review Exercises.......... 139

The passing score for ACCP material is 70%.

Preface

YOU HAVE studied the fundamentals and commercial refrigeration and air-conditioning systems. This final volume deals with another phase of your career ladder-equipment cooling. Since the principles of equipment cooling are common to all refrigeration systems, your mastery of the subject should be easy. All of the systems covered in this volume can be applied to commercial refrigeration and air conditioning.

To qualify you in equipment cooling, we will present the following systems in this volume:

(1) Direct expansion
(2) Absorption
(3) Centrifugal
(4) Water treatment
(5) Centrifugal water pumps
(6) Fundamentals of electronic controls
(7) Electronic control

Keep this memorandum for your own use.

ACKNOWLEDGMENT

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Direct Expansion Systems

JUST WHAT DO we mean when we say "direct expansion"? In the dictionary we find that the word "direct" means an unbroken connection or a straight bearing of one upon or toward another; "expansion" relates to the act or process of expanding or growing (in size or volume). Now we can see that a direct expansion system for equipment cooling is one in which the controlled variable comes in direct contact with the single refrigerant source, thereby causing the liquid refrigerant to boil and expand. The centrifugal and absorption systems differ in that that they us a secondary refrigerant-water or brine-to cool the variable.

2. We will cover various components peculiar to large direct expansion systems, normally of 20 tons or more in capacity. Remember, the window- and floor-mounted air-conditioning units are also considered direct expansion systems. Before we discuss the installation of a semihermetic condensing unit-the most commonly used unit for direct expansion systems-we will cover the various coils that are used in a direct expansion system. The application of the water-cooled semihermetic condensing unit will concern us in the second section, and we will conclude the chapter with system servicing and troubleshooting.

1. Coil Operation

1. There are three coils used in the typical system. From the outside in, the coil sequence is: (1) preheat, (2) direct expansion (D/X), and (3) reheat. We will discuss the application of these coils, their use and control, and the valves and dampers which control the flow of water and air.

2. **Preheat Coil**. You must consider three things before installing a preheat coil in an equipment cooling system. These are:

(1) Is preheat necessary?
(2) Will the coil be subjected to subfreezing temperature?
(3) What size preheat coils are needed?

3. After you have determined a need, provided for freezing temperatures, and correctly sized the coil, you are ready to install the coil. The next problem is where to install it. The preheat coil is installed in the outside air duct, before the mixing of outside and return air. Now we are ready to discuss a few applications of a preheat coil.

4. *Thermostatically controlled water or steam valve.* Figure 1 shows a system that uses a narrow range temperature controller. The temperature of the incoming air is sensed by the thermostat feeler bulb. The thermostat is calibrated to modulate the valve open when the temperature is 35° F.

5. The damper on the face of the preheat coil closes when the fan is turned off and opens when it is turned on. This damper is normally closed when the fan is off or if the fan fails to operate. This prevents preheat coil freezeup.

6. *Thermostatically controlled face and bypass dampers.* The mixed air temperature remains relatively constant until the outside air temperature exceeds the desired mixed air temperature. The use of the face and bypass damper, illustrated in figure 2, makes it possible to control mixed air temperature without endangering the preheat coil. The damper is controlled by a temperature controller in the mixed air duct while the preheat coil is controlled by a valve which is modulated by a narrow range temperature controller in the outside air duct. The face and bypass damper will close and the return air opens when the supply fan is turned off.

7. **D/X Coil**. In equipment cooling systems, the D/X coil is located after the preheat coil. It serves two primary functions-cooling and dehumidification.

8. *Simple on-off control.* The compressor is controlled by a space thermostat in an on-off manner. Figure 3 shows a system using this type of control. This system is best suited for use on small compressors and where large variations in temperature and humidity are not objectionable.

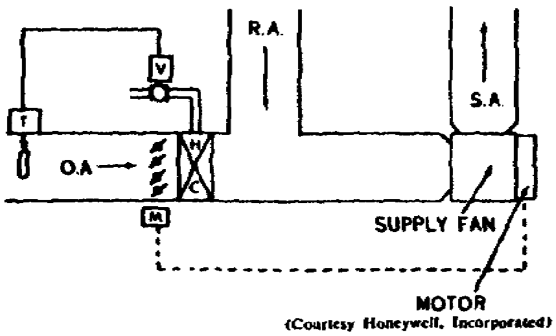


Figure 1. Control of preheat with outdoor air thermostat.

9. The differential adjustment on the thermostat should be set relatively wide to prevent short cycling under light load conditions. The control circuit is connected to the load side of the fan starter so that turning on the fan energizes the control systems.

10. *Two-speed compressor.* Figure 4 shows a typical two-speed compressor installation. A two-stage thermostat (space) cycles the compressor between low speed and off during light load conditions and cycles the unit between high and low speed during heavier loads. The thermostat also shuts off the compressor if the space temperature falls below the set point.

11. The humidistat cycles the compressor from low to high speed when space humidity rises above the high limit set point. It can do this when the compressor is on low speed. This system is best suited for use on reasonably small compressors where large swings in temperature and relative humidity can be tolerated.

12. *Solenoid valve installation.* Figure 5 shows a system which uses a space thermostat to operate a solenoid valve and a nonrestarting relay. The

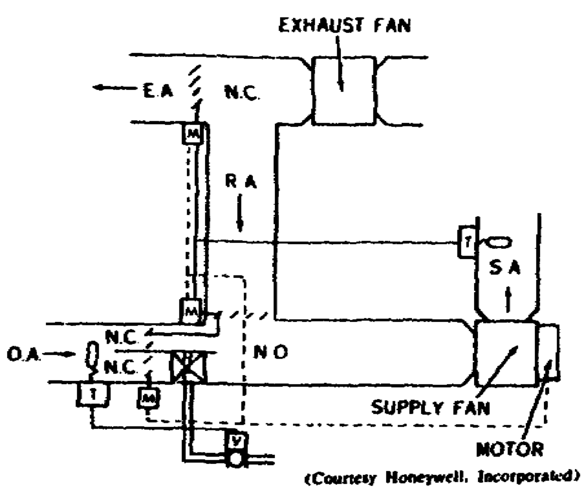


Figure 2. Preheat control with bypass and return air dampers.

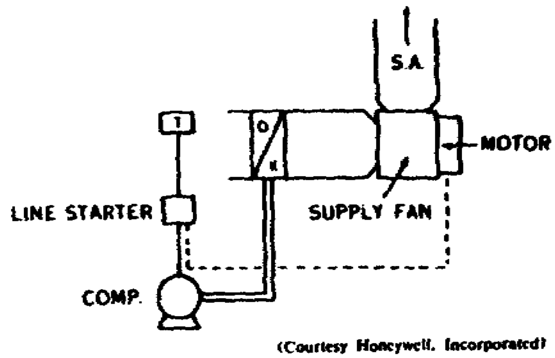


Figure 3. On-off compressor control.

two-position thermostat opens the refrigerant solenoid valve when the space temperature rises and closes it when the temperature drops below the set point. This control action will cause large swings in temperature and relative humidity. The nonrestarting relay prevents short cycling of the compressor during the off cycle. It allows the compressor to pump down before it cycles "off."

13. *Multiple D/X coil solenoid valves.* The system shown in figure 6 is similar to that previously discussed (fig. 5) except that it now has two D/X coils and two solenoid valves. The two-stage space thermostat operates D/X coil 1 in an on-off manner when the cooling load is light. It also holds the valve to coil 1 open and operates the valve to coil 2 in an on-off manner during heavy load conditions. The nonrestarting relay functions the same as the one in figure 5.

14. The supply fan starter circuit must be energized, in both applications, before the control circuit to the solenoid valves can be completed.

15. *Two-position control and modulating control of a face and bypass damper.* This system uses a face and bypass damper (shown in fig. 7) to bypass air around the D/X coil during light load conditions. The space thermostat opens the refrigerant solenoid valve when the face damper opens to a position representing a minimum cooling

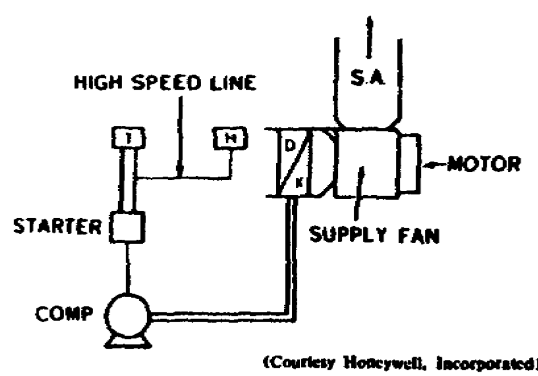


Figure 4. Two-speed compressor control.

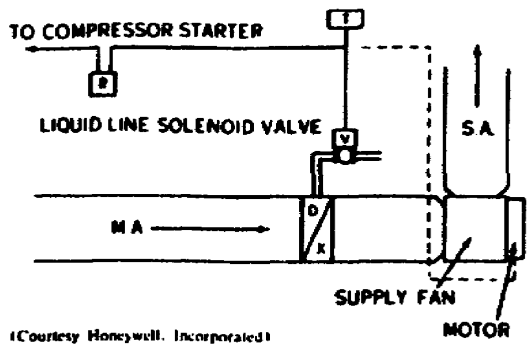


Figure 5. On-off control with a solenoid valve.

load. It also modulates the face and bypass dampers to mix the cooled air with the bypassed air as necessary to maintain the correct space temperature. A capacity controlled compressor must be used if short cycling, under light load conditions, is to be avoided.

16. It is necessary to adjust the face damper so that it does not close completely. This will help prevent coil frosting under light load conditions. The control circuit to the solenoid valve is wired in series with the supply fan motor. When the fan is shut off, the solenoid valve will close.

17. *Two-position control and modulating control of a return air bypass damper.* This system, shown in figure 8, is similar to the system we have just discussed. The only difference is that we bypass return air instead of mixed air under light load conditions.

18. **Reheat Coil**. The reheat coil is used to heat the air after it has passed through the D/X coil. It expands the air, thus lowering the relative humidity. A D/X coil and reheat coil are used to control humidity.

19. *Simple two-position control.* Figure 9 shows a system which uses a space thermostat to control a reheat coil and a D/X coil. It opens the solenoid valve to the heating coil when the space temperature falls below the set point temperature, and opens the D/X coil solenoid valve when the temperature is above the set point. A two-position humidistat is provided to open the cooling coil solenoid valve when the space relative humidity exceeds the set point of the controller. When a humid condition exists, the humidistat will override the thermostat. The thermostat senses the reduced air temperature and opens the reheat coil solenoid valve which will lower the relative humidity. The D/X coil solenoid valve will close when the supply fan is shut off.

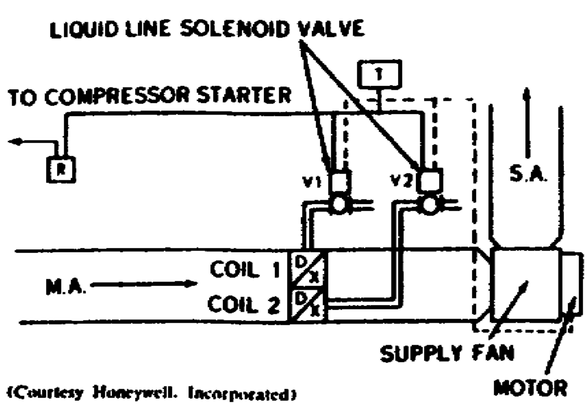


Figure 6. On-off control of multiple D/X coil solenoid valves.

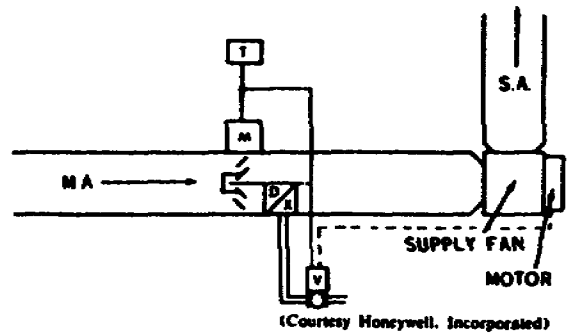


Figure 7. Two-position control of a D/X coil solenoid valve and modulating control of a face and bypass damper.

20. *Control of dehumidification with a face and bypass damper.* We discussed the use of face and bypass dampers when we discussed D/X coils. Now we will apply this damper system to humidity control, as shown in figure 10. A space humidity controller is used to open the D/X coil valve when a predetermined minimum dehumidification load is reached. It also modulates the face and bypass damper to provide the mixture of dehumidified and bypass air necessary to maintain space relative humidity.

21. The space thermostat modulates the reheat coil valve as needed to maintain space temperature. If the space humidity drops below the set

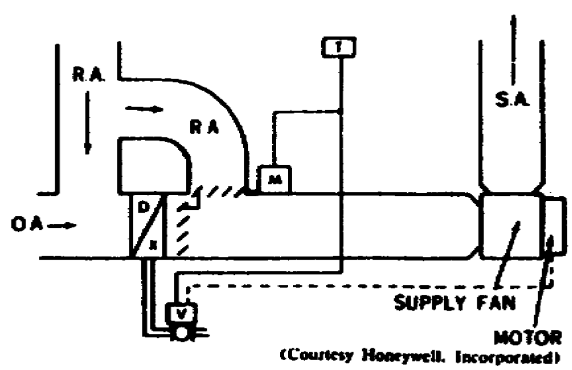


Figure 8. Two-position control of a D/X coil solenoid valve and modulating control of a return air bypass damper.

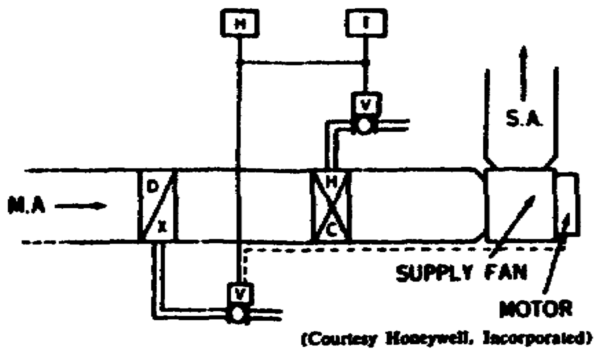


Figure 9. Dehumidification control in a two-position D/X system.

point of the humidity controller, and the space temperature rises because the discharge air is too warm to cool the space, the thermostat will open the D/X coil valve and modulate the face and bypass damper to lower the space temperature. The reheat coil must be controlled by a modulated valve so that the thermostat can position the valve within its range. This will prevent large swings in temperature and relative humidity. This system also provides a method of closing the D/X coil valve when the supply fan is shut off.

22. *Control of dehumidification with a return air bypass system.* Figure 11 shows a system which uses a return air bypass damper to control airflow across the D/X coil for dehumidification. The space humidistat opens the D/X coil valve when a predetermined minimum cooling load is reached and positions the bypass damper to maintain space relative humidity.

23. The space thermostat acts in a way that is similar to that of the thermostat in figure 10. The control circuit to the D/X coil valve is connected to the supply fan so that the valve will close when the fan is shut off. This arrangement helps prevent coil frosting and reheat coil freezeup.

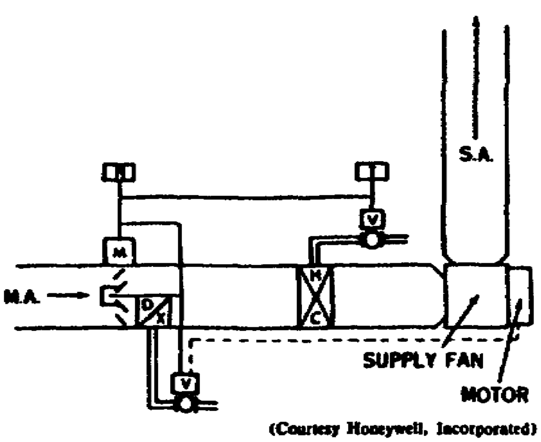


Figure 10. Dehumidification control in a D/X face and bypass system.

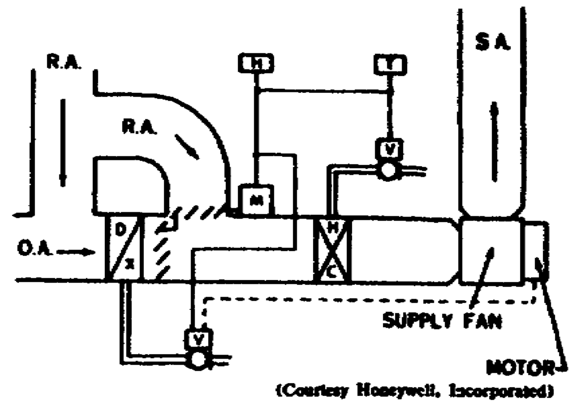


Figure 11. Dehumidification control in a D/X return air bypass system.

24. We have discussed the three coils that you will find in a typical equipment cooling system. Now we will discuss a complete system which maintains temperature, relative humidity, and air changes.

25. **Typical D/X Equipment Cooling System**. Figure 12 shows a system which may be used to condition air for electronic equipment operation. Thermostat T_1 senses outdoor (incoming) air and modulates the preheat coil valve to the full open position when the temperature falls below the controller set point. A further drop in temperature will cause the thermostat T_1 to modulate the outside and exhaust air dampers shut and the return air damper open.

26. The space thermostat (T_2) operates the reheat coil valve as necessary to maintain a predetermined space temperature. The space thermostat (T_2) will modulate the cooling coil valve when the space humidity is within the tolerance of the humidistat. The space humidistat opens the cooling coil valve when a minimum cooling load is sensed. It has prime control of this valve. The outside and exhaust air dampers are fitted with a stop so that they will not completely close. This procedure allows for the correct amount of air changes per hour.

27. There are many other direct expansion systems. The blueprints for your installation will help you to better understand the operation of your system. Most of the system components are similar to those previously discussed.

2. Application of Water-Cooled Condensing Units

1. Water-cooled semihermetic condensing units are rated in accordance with ARI Standards with water entering the condenser at 75°F.

2. Condensing units are available for different temperature ranges. We are interested in the "high temperature" unit, as it is used for air conditioning

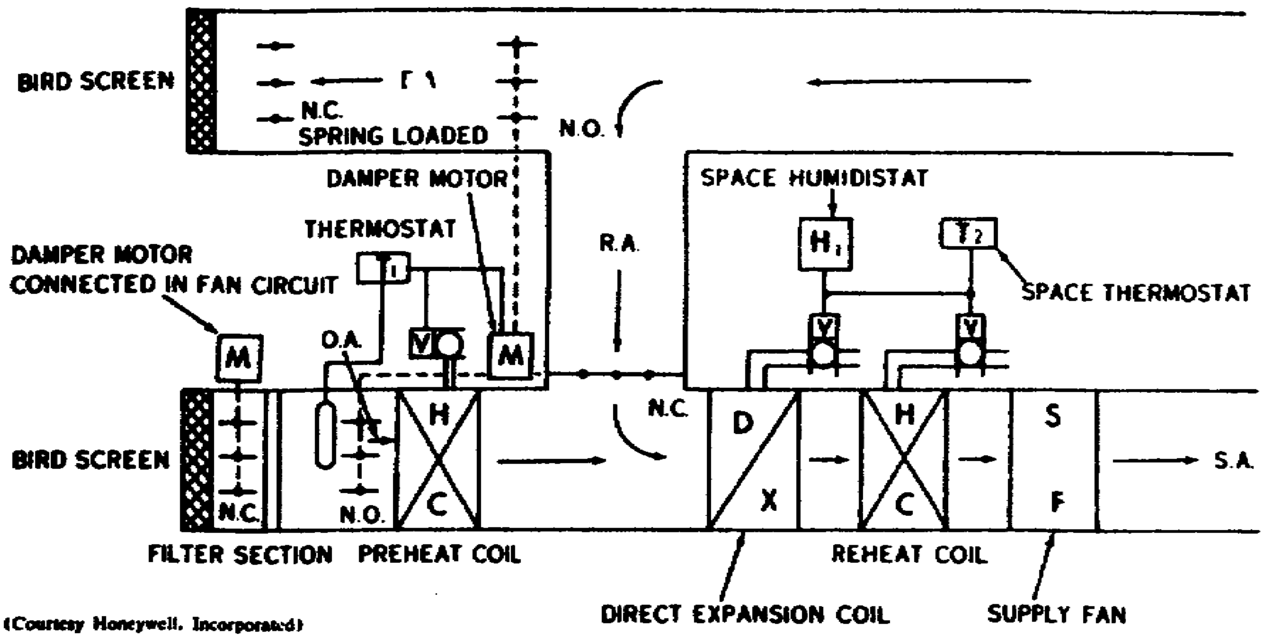


Figure 12. Typical D/X equipment cooling system.

or other applications requiring a +25°F. to +50°F suction temperature.

3. A medium temperature unit (-10° F. to +25° F.) should not be selected or equipment cooling applications where the compressor would be subjected to high suction pressure over extended shutdown periods. This would result in motor overload and stopping when the cooling load is peak. To prevent this possibility, the proper unit must be selected considering the highest suction pressure the unit will be subjected to for more than a brief period of time.

4. **Compressor Protection**. During shutdown, refrigerant may condense in the compressor crank-case and be absorbed by the lubricating oil. The best protection against excessive accumulation of liquid refrigerant is the automatic pump-down control. The compressor must start from a low-pressure switch (suction pressure) at all times. Figure 19 (in Section 3) shows a recommended control wiring diagram that incorporates an automatic pump-down control. When the pressure in the crankcase rises, the compressor will cycle on. It will run until the pressure drops to the low-pressure switch cutoff setting.

5. In systems where the refrigerant-oil ratio is 2:1 or less, automatic pump-down control may be omitted. It may also be omitted on systems where the evaporator is always 40° or more below the compressor ambient temperature. However, the use of an automatic pump-down control is definitely preferable whenever possible.

6. **Water Supply**. Water-cooled condensing units should have adequate water supply and disposal facilities. Selection of water-cooled units must be based on the maximum water temperature and the quantity of water which is available to the unit. Now that you have selected the proper equipment, let's discuss the installation of equipment.

3. Installation

1. Before you start installing the unit you must consider space requirements, equipment ventilation, vibration, and the electrical requirements.

2. The dimensions for the condensing unit are given in the manufacturer's tables. You must allow additional room for component removal, such as the compressor or dehydrator. The suction and discharge compressor service valves, along with the compressor oil sight glass, must be readily accessible to facilitate maintenance and troubleshooting. The space must be warmer than the refrigerated space to prevent refrigerant from condensing in the compressor crankcase during extended shutdown periods. Water-cooled units must be adequately protected from freezeup. Some method of drainage must be provided if the unit is to be shut down during the winter months.

3. Install the unit where the floor is strong enough to support it. It is not necessary to install it on a special foundation, because most of the vibration is absorbed by the compressor mounting springs. On critical installations (e.g., hospitals and communication centers) it may be desirable to inclose the unit in an equipment room to prevent direct transmission of sound to occupied spaces. Place the unit where it will not be damaged by traffic or flooding. It may be necessary to cage or elevate the unit.

4. The next step in installing a unit is to

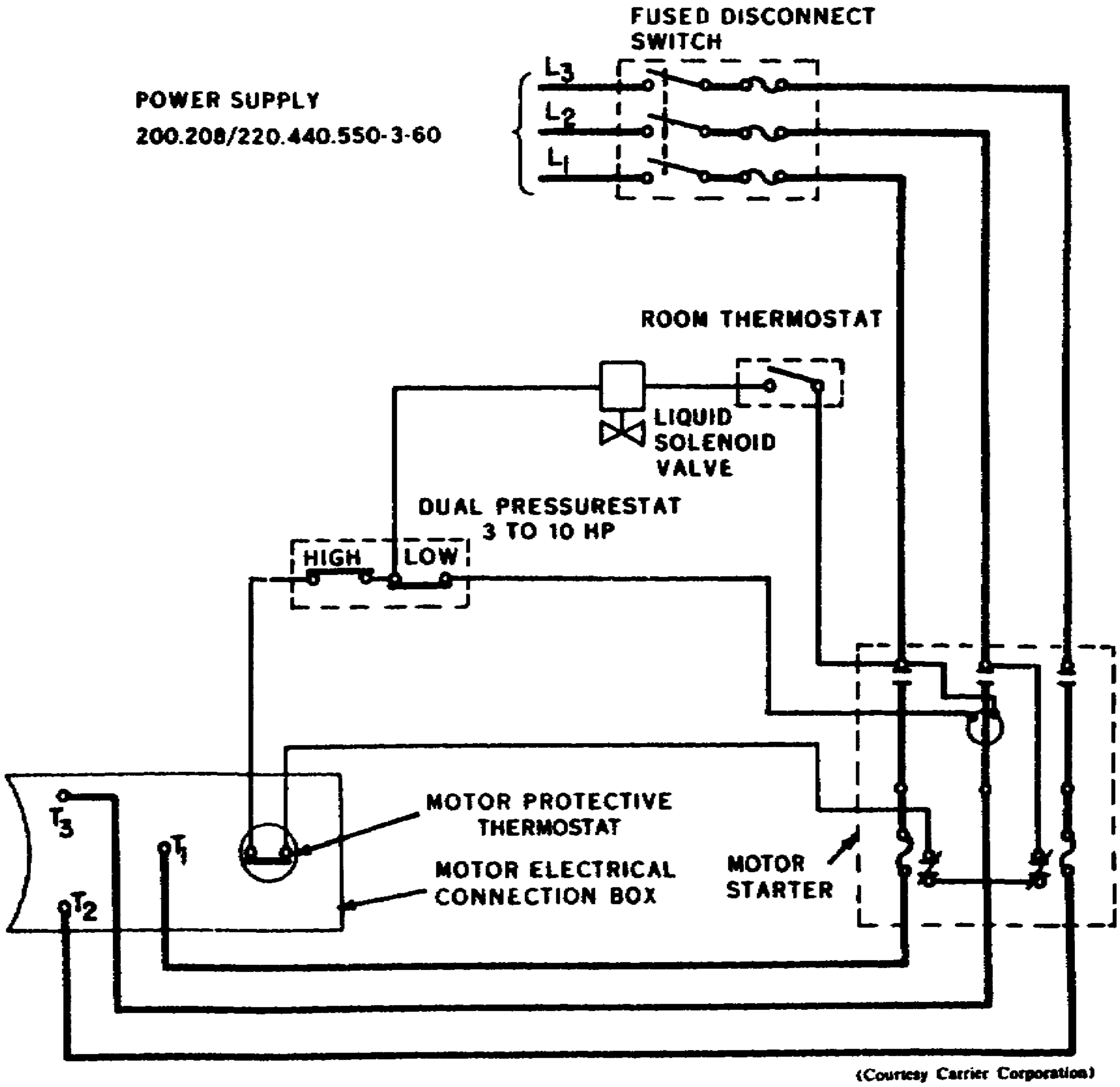


Figure 13. Three phase wiring diagram for a semihermetic condensing unit.

inspect the shipment for loss or damage. You must report any loss or damage to your supervisor immediately. Refer to ASA-B9.1-1953, American Standards Association's "Mechanical Refrigeration Safety Code" when you install the unit.

5. Before installing the unit, check the electric service to insure that it is adequate. The voltage at the motor terminals must not vary more than plus or minus 10 percent of the rated nameplate voltage requirement. Phase unbalance for three-phase units must not exceed 2 percent. Where an unbalance exists, you must connect the two lines with the higher amperages through the switch heater elements. Figure 13 shows a typical wiring diagram for a semihermetic condensing unit.

6. A table of wire size requirements is provided with the manufacturer's installation handbook. For instance a 220-volt three-phase condensing unit requiring 8 amperes at full load must be wired with number 8 wire if the length the run is 300 feet. However, number 14 wire can be used if the run is limited to 10 feet.

7. **Piping and Accessories**. The liquid and suction lines are usually constructed of soft copper tubing. To help absorb vibrations, loop or sweep the two lines near the condensing unit. Use a vibration isolation type hanger, show in figure 14, to fasten the tubing on walls or supports.

8. *Shutoff valves*. The suction and discharge shutoff valves (service valves) are of the back-seating type and have gauge ports. Frontseating the valve closes the refrigerant line and opens the gauge port to the pressure in the compressor.

9. Backseating the valve shuts off pressure to the gauge port. To attach a gauge or charging line to the gauge port, backseat the valve to prevent escape of refrigerant.

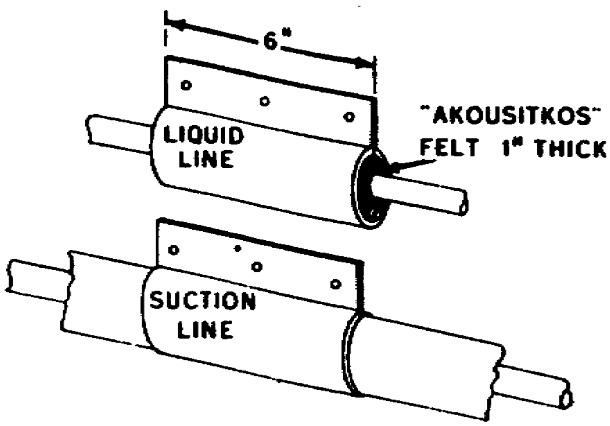


Figure 14. Vibration isolation type hanger.

10. Use a square ratchet or box-end wrench (1/4-inch) to open and close the valve. Do not use pliers or an adjustable wrench since they are likely to round the valve stem. Do not use excessive force to turn the stem. If it turns hard, loosen the packing gland nut. If the valve sticks on its seat, a sharp rap on the wrench will usually break it free.

11. *Liquid line solenoid valve.* Many manufacturers use this type of valve on their units to prevent damage to the compressor which would result from flooding of the crankcase with refrigerant during shutdown. This type of valve also provides a compressor pump-down feature on many units. The valve is installed in the liquid refrigerant line directly ahead of the expansion valve. It must be installed in a vertical position and wired as shown in the wiring diagram (fig. 13).

12. *Liquid line sight glass.* The liquid line sight glass is installed between the dehydrator and expansion valve. You should locate the sight glass so that it is convenient to place a light behind the glass when you are observing the liquid for a proper charge.

13. *Water regulating valves.* Install the water regulating valve with the capillary down and the arrow on the valve body in the direction of water-flow. Backseat the liquid line shutoff valve and connect the capillary of the water regulating valve of the 1/4-inch flare connection on the liquid line shutoff valve. Open the shutoff valve one turn from the backseated position. This allows refrigerant pressure to reach the water regulating valve and still leaves the liquid line open.

14. *Water-cooled condenser connections.* When city water is used as the condensing media, the condenser circuits are normally connected in series. When cooling tower water is used for condensing, the condenser circuits are connected in parallel. See figure 15 for correct condenser water connections.

15. **Leak Testing the System**. After all the components have been installed, you are ready to leak test the system. Charge the system with dry nitrogen or carbon dioxide (40 p.s.i.g.) and check all the joints with a soap solution. Release the pressure and repair any leaks that may have been found. After the leaks have been repaired, charge the system with the recommended refrigerant to 10 p.s.i.g. Add enough dry nitrogen or carbon dioxide to build the pressure to 150 p.s.i.g. and leak test with a halide leak detector. Purge the system and repair all leaky joints that you may have found. Do not allow the compressor to build up pressure since overheating and damage may result. Do not use oxygen to build up pressure!

16. **Dehydrating the System**. Moisture in the system causes oil sludge and corrosion. It is likely to freeze up the expansion valve during operation. The best means of dehydration is evacuation with a pump especially built for this purpose. The condensing unit is dehydrated at the factory and is given a partial or holding charge. Leave all the service valves on the condensing unit closed until the piping and accessories have been dehydrated. Do not install a strainer-dehydrator until the piping is complete and the system is ready for evacuation.

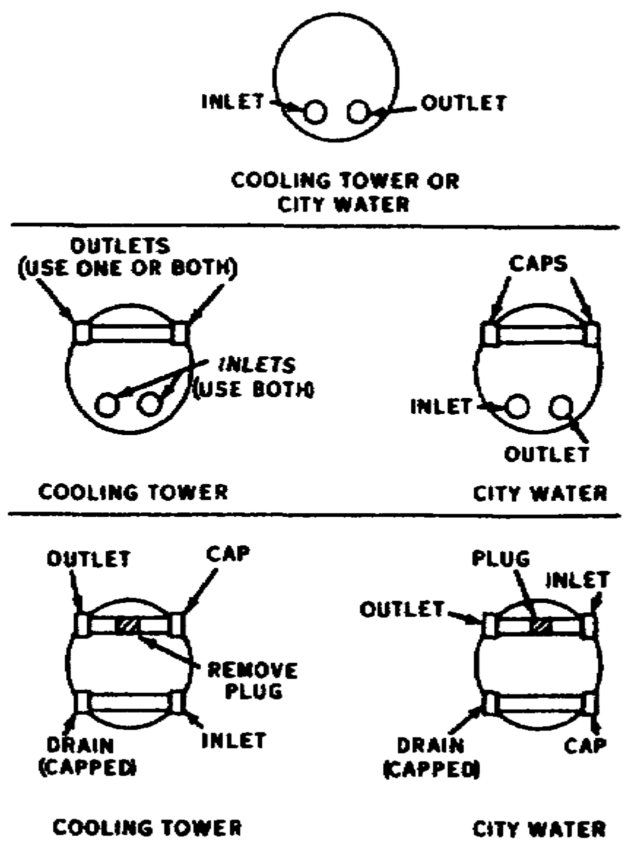


Figure 15. Condenser connections.

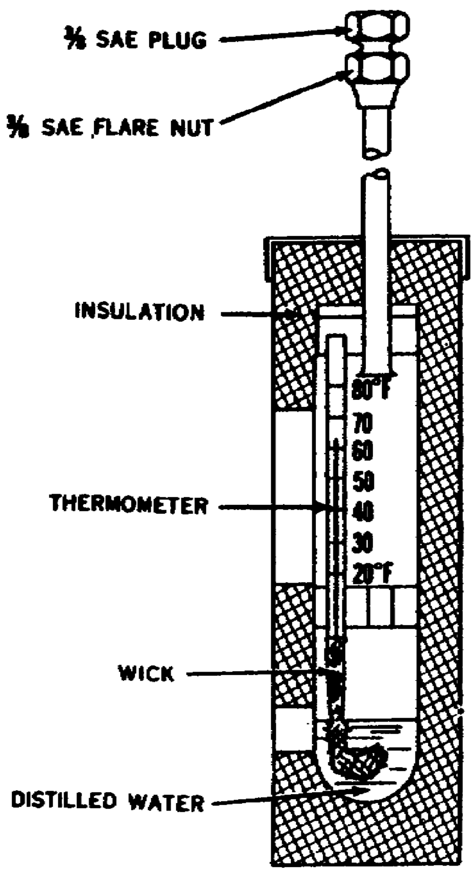


Figure 16. Vacuum indicator.

17. Make the following preparations before dehydrating the system:

(1) Obtain a vacuum pump that will produce a vacuum of 2 inches Hg absolute. Do not use the compressor as a vacuum pump since this may cause serious damage to the compressor.

(2) Obtain a vacuum indicator similar to that shown in figure 16. These indicators are available through manufacturers' service departments.

(3) Keep the ambient temperature above 60° F. to speed the evaporation of moisture.

18. *Description and use of the vacuum indicator.* The vacuum indicator consists of a wet bulb thermometer in an insulated glass tube containing distilled water. Part of the tube is exposed so that the thermometer can be read and the water level checked. When the indicator is connected to the vacuum pump suction line, the thermometer reads the temperature of the water in the tube. The temperature is related to the absolute pressure in the tube. Figure 17 gives the absolute pressures corresponding to various temperatures. To determine the vacuum in inches of mercury, subtract the absolute pressure from the barometer reading.

19. Handle the vacuum indicator with care. It must be vacuum-tight to give a true reading. The top seal of the indicator is not designed to support a long run of connecting tubes. Fasten the tubes to supports to prevent damage to the indicator. Use only distilled water in the indicator and be sure the wick is clean. Oil or dirt on the wick causes erroneous readings.

20. To prevent loss of oil from the vacuum pump and contamination of the indicator, you must install shutoff valves in the suction line at the vacuum pump and the vacuum indicator. When shutting off the pump, close the indicator valve and pump valve, and then turn off the pump. Now we are ready to dehydrate the system.

21. *Procedure for dehydrating the system.* Connect the pump and vacuum indicator to the system. Put a jumper line between the high and low side so that the pump will draw a vacuum on all portions of the system. Open the compressor shutoff valves and start the vacuum pump. Open the indicator shutoff valve occasionally and take a reading. Keep the valve open for at least 3 minutes for each reading. You must keep the indicator valve closed at all other times to decrease the amount of water the pump must handle and to hasten dehydration. When the pressure drops to a value corresponding to the vapor pressure of the water in the indicator, the temperature will start to drop.

22. In the example illustrated in figure 18, the ambient temperature and the temperature of the water in the indicator is 60° F. Starting at 60° F., and 0 time, the temperature of the indicator water remains at 60° F. until the pressure in the system is pulled down to the pressure corresponding to the saturation temperature of the water (60° F.). Point A in figure 18 shows the temperature saturation point. At this point the moisture in the system begins to boil. The temperature drops slowly until the free moisture is removed. Point A to Point B illustrates the time required for free moisture evaporization. After the free moisture is removed, the

Temperature °F Observed On Vacuum Indicator	Absolute Pressure Inches of Mercury
70	0.739
60	0.522
55	0.436
50	0.363
45	0.300
40	0.248
35	0.204
32	0.180

Figure 17. Temperature-pressure relationship.

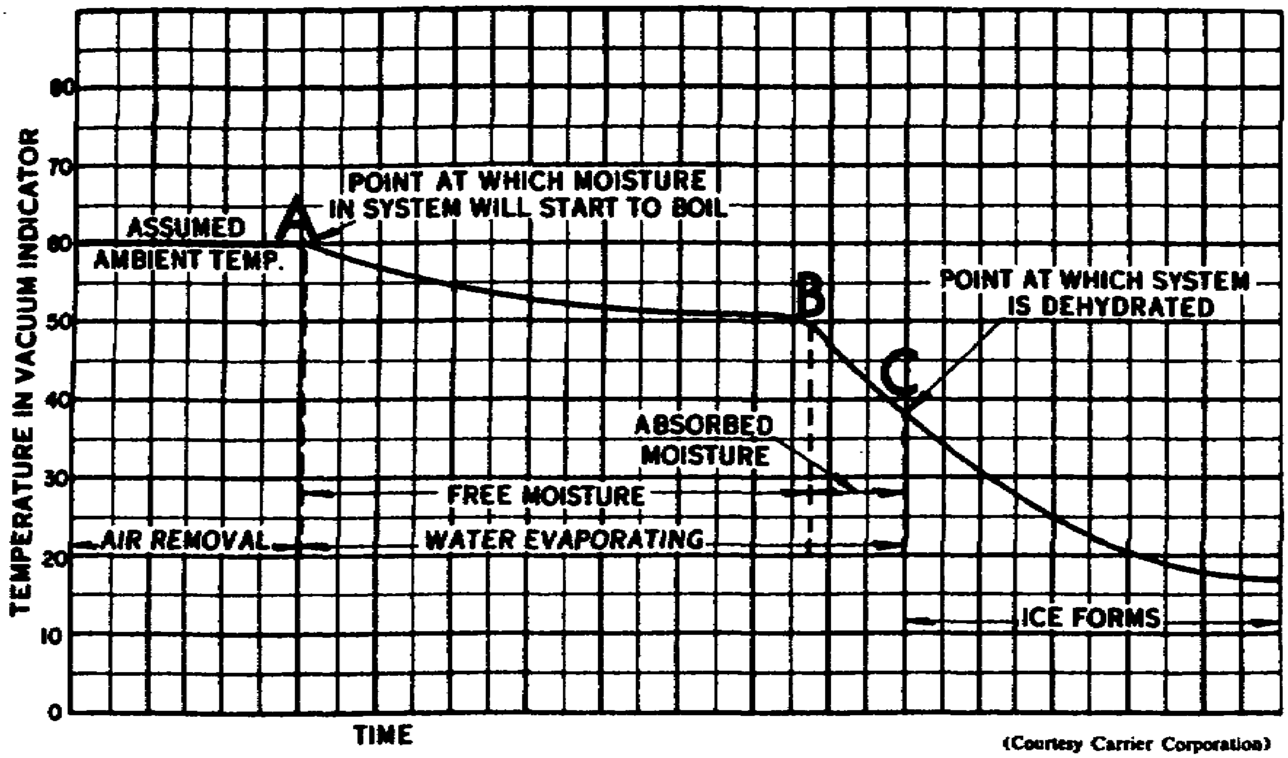


Figure 18. Dehydration pulldown curve.

absorbed moisture is removed, point B to point C. Dehydration is completed at point C, provided the ambient temperature stays at 60° F. or higher. If the ambient temperature falls below 60° F., the moisture will form ice before moisture removal is complete.

23. You should continue the dehydrating procedure until the vacuum indicator shows a reading of 35° F. Looking back at figure 17, you will find that a 35° F. reading corresponds to a pressure of 0.204 inch Hg absolute. This procedure may take several hours, and many times it is advantageous to run the vacuum pump all night. After evacuation, turn off the indicator valve (if open) and the pump suction shutoff valve, and break the vacuum with the recommended refrigerant. Disconnect the pump and vacuum indicator.

24. **Charging the System**. The refrigerant may be charged into the low side of the system as a gas or into the high side as a liquid. We will discuss both methods of charging in this section.

25. To charge into the low side as a gas, backseat the compressor suction and discharge valves and connect your gauge and manifold to the appropriate compressor gauge connections The next step is to connect a refrigerant drum to the middle manifold hose. Open the drum valve and purge the hoses, gauges, and manifold. Then tighten all the hose connection. Turn the suction shutoff valves a couple of turns from the backseat position and open the drum valve as far as possible. Remember, keep the refrigerant drum in an upright position to prevent liquid refrigerant from entering the compressor. You can now turn the compressor discharge shutoff valve about one-fourth to one-half turn from the backseat position so that compressor discharge pressure can be read at the manifold discharge pressure gauge.

26. Before you start the compressor you must check the following items:

(1) Proper oil level in the compressor sight glass (one-third to two-thirds full).

(2) Main water supply valve (water-cooled condenser).

(3) Liquid line valve. Valve stem should be positioned two turns from its backseat to allow pressure to be applied to the water regulating valve.

(4) Main power disconnect switch (ON position).

27. After you have started the compressor you must check the following items:

(1) Correct oil pressure.

(2) Water regulating valve adjustment.

(3) Control settings.

(4) Oil level in the compressor crankcase.

28. Check the refrigerant charge frequently while charging by observing the liquid line sight glass. The refrigerant charge is sufficient when flashing (bubbles) disappears. If the pressure within the drum, during charging, drops to the level of the suction pressure, all the remaining refrigerant in the drum may be removed by frontseating the compressor suction shutoff valve.

This procedure will cause a vacuum to be pulled on the refrigerant drum.

29. When the system is sufficiently charged, close the refrigerant drum valve and backseat the compressor suction and discharge shutoff valves. Disconnect the charging lines from the compressor gauge ports and connect the lines from the dual pressurestat to the charging lines and "crack" the valves off their backseat.

30. Liquid charging into the high side can be done by either of two methods. One method is to charge into the liquid line with the compressor running. The other method is to charge directly into the systems liquid receiver. Since charging liquid into the receiver is much faster, systems containing more than 100 pounds of refrigerant are usually charged this way. Let us discuss both methods in detail.

31. Systems to be charged into the liquid line first must have a charging port installed in the liquid line. Then use the following procedure:

(1) Close king valve.

(2) Connect inverted drum to charging port.

(3) Open drum service valve.

(4) Purge air from charging lines.

(5) Operate unit until fully charged.

(6) Reopen king valve; this system is now in operation.

32. Charging liquid into the receiver is performed according to the following general procedure:

(1) Turn off electrical power to unit.

(2) Connect the inverted and elevated refrigerant drum to the receiver charging valve.

(3) Open drum service valve.

(4) Purge air from charging line.

(5) Open the charging valve.

(6) Several minutes are required to transfer a drum of refrigerant in this manner; the transfer time can be shortened by heating the drum (do not use flame).

(7) When sufficient charge has been transferred into the system, power can be turned on.

(8) By checking the pressure gauges and the sight glass, you can determine when the system is fully charged. To maintain the efficiency of the machinery you have installed, you must service and troubleshoot it.

33. **Checking Operation**. When you are starting a newly installed compressor, be on the alert for any sign of trouble.

34. The high-pressure setting of the dual pressurestat, shown in figure 19, should not require a change; however, the low-pressure setting will probably require adjustment, depending upon the evaporator temperature. Check the high-pressure cutout by throttling the condenser water. This will allow the head pressure to rise gradually. The cut-out and cut-in pressures should be within 10 to 15 pounds of the values outlined in the manufacturer's handbooks. If they are not, the pressurestat would be readjusted. You can check the low-pressure settings by frontseating the compressor shutoff valve or the liquid line shutoff valve. The cut-in and cut-out point may be adjusted if it is necessary.

35. The units are shipped with "full" oil charges. Do not assume that the charge is sufficient. Stop the unit, without pump-down, after 15 or 20 minutes of operating time and immediately recheck the oil level in the compressor sight glass. The oil level must be one-third to two-thirds of the way up on the sight glass. You can check oil pump pressure by looking at the oil pressure relief valve through the sight glass during compressor operation. Pressure is adequate if oil is being discharged from the relief valve.

36. Adjust the water regulating valve to the most economical head pressure for the locality. Normally, this is 120 to 140 p.s.i.g. for R-12 and 200 to 230 for R-22.

4. Servicing and Troubleshooting

1. We have covered several service techniques in the previous section that relate to installation, including leak testing, dehydrating, and charging into the low side as a gas and into the high side with liquid. We shall now go further into servicing as it relates to disassembly, inspection, and reassembly of individual components. By means of tables at the end of this chapter, you will then focus on troubleshooting techniques.

2. **Servicing**. Servicing direct expansion systems embodies a wide range of related topics, from removing the refrigerant charge and testing for leaking valves to terminal assembly and testing capacitors and relays.

3. Removing Refrigerant. The refrigerant charge can be removed by connecting a refrigerant drum to the gauge port of the liquid line shutoff valve. Turn the stem two turns off its backseat and run the unit. Most of the refrigerant can be removed in this manner. The remainder may be removed by placing the drum in a bucket of ice or by slowly releasing it to the atmosphere.

4. Pump-down procedure. If possible, you should allow the compressor to run until it is warm before pumping it down. Then pump the system down as follows:

(1) Close (frontseat) the liquid line shutoff valve on the condenser.

(2) Hold the pressurestat switch closed so that the unit will not trip off on low pressure.

(3) Run the compressor until the compound

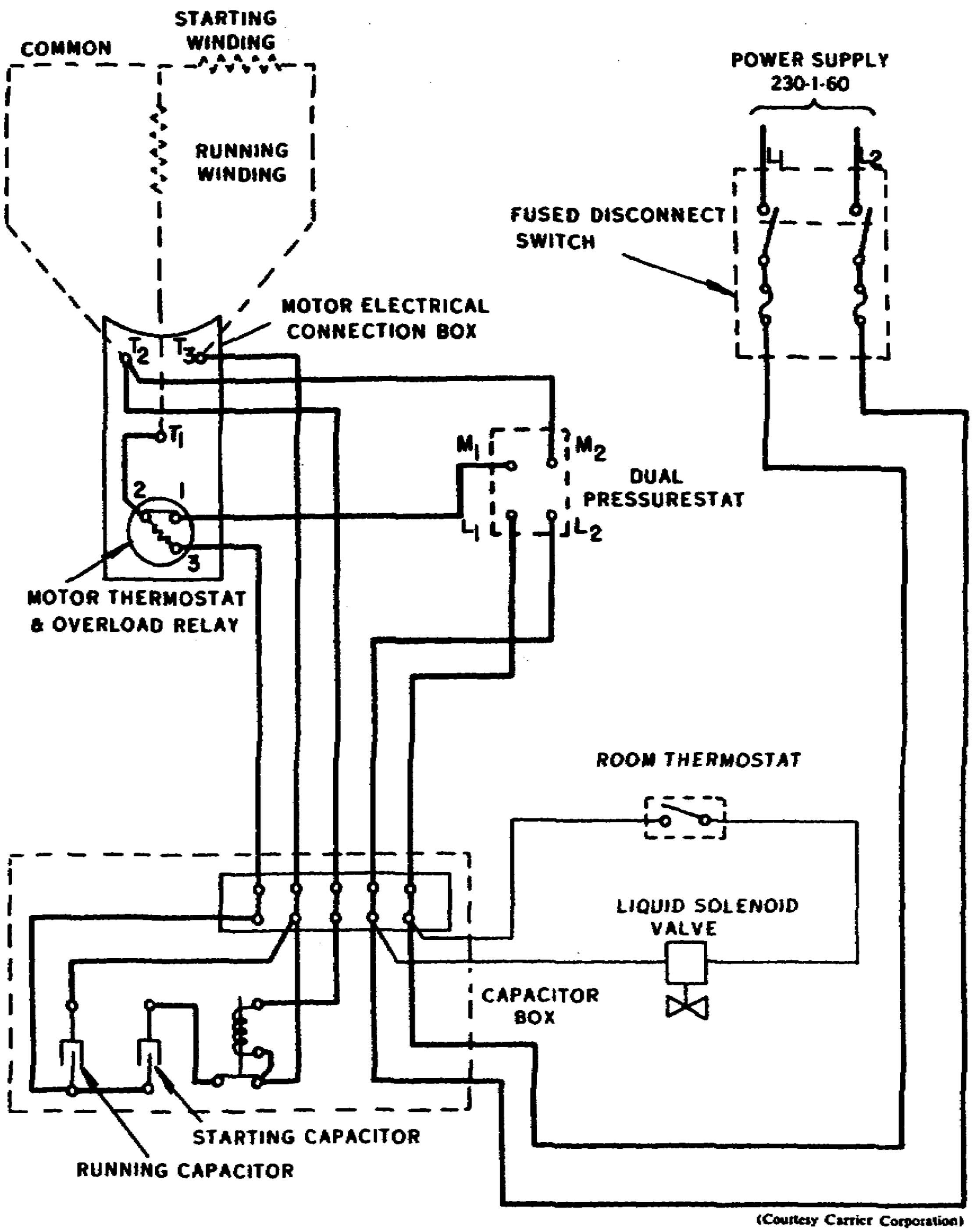


Figure 19. Single-phase wiring diagram for a semihermetic condensing unit.

gauge (registering low side pressure) registers 2 p.s.i.g.

(4) Stop the compressor and watch the gauge. If the pressure rises, pump down again. Repeat the operation until the pressure remains at 2 p.s.i.g.

(5) Frontseat the compressor discharge and suction shutoff valves.

(6) If the compressor is to be left pumped down for any period, tag the disconnect switch to prevent accidental starting of the unit.

5. If the compressor is the only component to be removed, pumping down the crankcase will be sufficient. This may be done by front-seating the suction shutoff valve and completing steps (1)-(5) listed under *pump-down procedure.*

You must stop the compressor several times during pump-down to prevent excessive foaming of the oil as the refrigerant boils out since the foaming oil may be pumped from the crankcase.

6. *Breaking refrigerant connections*. When it becomes necessary to open a charged system, the component or line to be removed or opened should be pumped down or evacuated to 2 p.s.i.g. You must allow enough time for all adjacent parts to warm to room temperature before you break the connection. This prevents moisture from condensing on the inside of the system.

7. After the component has warmed to room temperature, you are ready to break the connection and make the necessary repairs.

8. *Cleaning the expansion valve strainer.* To clean the expansion valve strainer, you must close the liquid line shutoff valve and pump down the system to 2 p.s.i.g. Disconnect the valve and plug the tube ends. Remove the screen and clean it with a recommended cleaning solvent. After the screen is clean and dry, reinstall it in the valve and connect the valve in the system. Purge the lines and valves; then open (two turns off the backseat) the liquid line shutoff valve.

9. *Cleaning suction strainers*. Most suction strainers are located in the suction manifold on the compressor. Pump down the compressor to 2 p.s.i.g. and frontseat the discharge shutoff valve. At this point, you must check the manufacturer's handbook to locate the strainer. Remove and clean it with solvent. After the strainer drys, replace it, purge the compressor, and start the unit. Figure 20 shows two different types of strainers, basket and disc, and their location in the compressor motor.

10. *Purging noncondensable gases*. Noncondensable gases (air) collect in the condenser (water-cooled) above the refrigerant. The presence of these gases cause excessive power consumption, a rise in leaving water temperature, and high compressor discharge pressure.

11. To purge these gases from the system, stop the compressor for 15 to 20 minutes. Then open the purge cock (if available) or loosen a connection at the highest point of the condenser for a few seconds. After purging is completed, close the purge cock (or tighten the connection) and run the compressor. If the discharge pressure is still high, repeat the procedure until the discharge pressure returns to normal.

12. *Adding oil.* Add only the recommended oil listed in the manufacturer's handbook. The oil should be taken directly from a sealed container. Do not use oil that has been exposed to the atmosphere because it may contain some absorbed moisture.

13. To add oil, pump down the compressor to 2 p.s.i.g. Remove the oil filter plug (if available) or disconnect the pressurestat connection on the suction manifold. Insert a funnel and pour in the oil. Hold the oil container close to the funnel to minimize contact with the air. The correct amount of oil needed can be estimated by observing the oil sight glass (one-third to two-thirds full). After sufficient oil is added, connect the pressurestat or replace the oil filler plug, purge the compressor, and start the unit.

14. *Removing oil.* To remove excess oil from the crankcase, pump down the compressor to 2 p.s.i.g. Loosen the oil plug (if available), allowing the pressure to escape slowly. Then use a hand suction pump to remove the desired amount of oil. If a filler plug is not available, loosen the bottom plate or drain plug. Retighten the plate or plug when the oil assumes a safe level in the crankcase one-third to two-thirds full. Purge and start the compressor.

15. *Testing for leaking valves*. Leaky compressor valves will cause a serious reduction in the capacity of the system. Install a manifold and gauge set. Start the compressor and allow it to run until it is warm; then frontseat the suction shutoff valve. Pump down the compressor to 2 p.s.i.g. Stop the compressor and quickly frontseat the discharge shutoff valve. Observe the suction and discharge gauges. If a discharge valve is leaking, the pressures will equalize rapidly. The maximum allowable discharge pressure drop is 3 p.s.i.g. per minute.

16. There is no simple method of testing suction valves. If there is an indicated loss of capacity and the discharge valves check properly, you must remove the head and valve plate and check the valves physically.

17. *Disassembly, inspection, and reassembly of valve plates*. Pump down the compressor to 2 p.s.i.g. and remove the compressor head capscrews. Tap the head with a wooden or plastic mallet to free it if it is stuck and remove the cylinder head.

18. Remove the discharge valves and valve stops as shown in figure 21. Free the valve plate from the dowel pins and cylinder deck. Many valve plates have tapped holes. The capscrews are screwed into them and function as jacking screws. Now you can remove the suction valves from the dowel pin. Figure 22 shows the suction valve and suction valve positioning spring. Inspect the valve seats and valves. If the valve seats look worn or damaged, replace the valve plate assembly (fig. 21).

19. It is preferable to install new valves with a new valve plate. If new valves are not available, turn the old valves over and install them

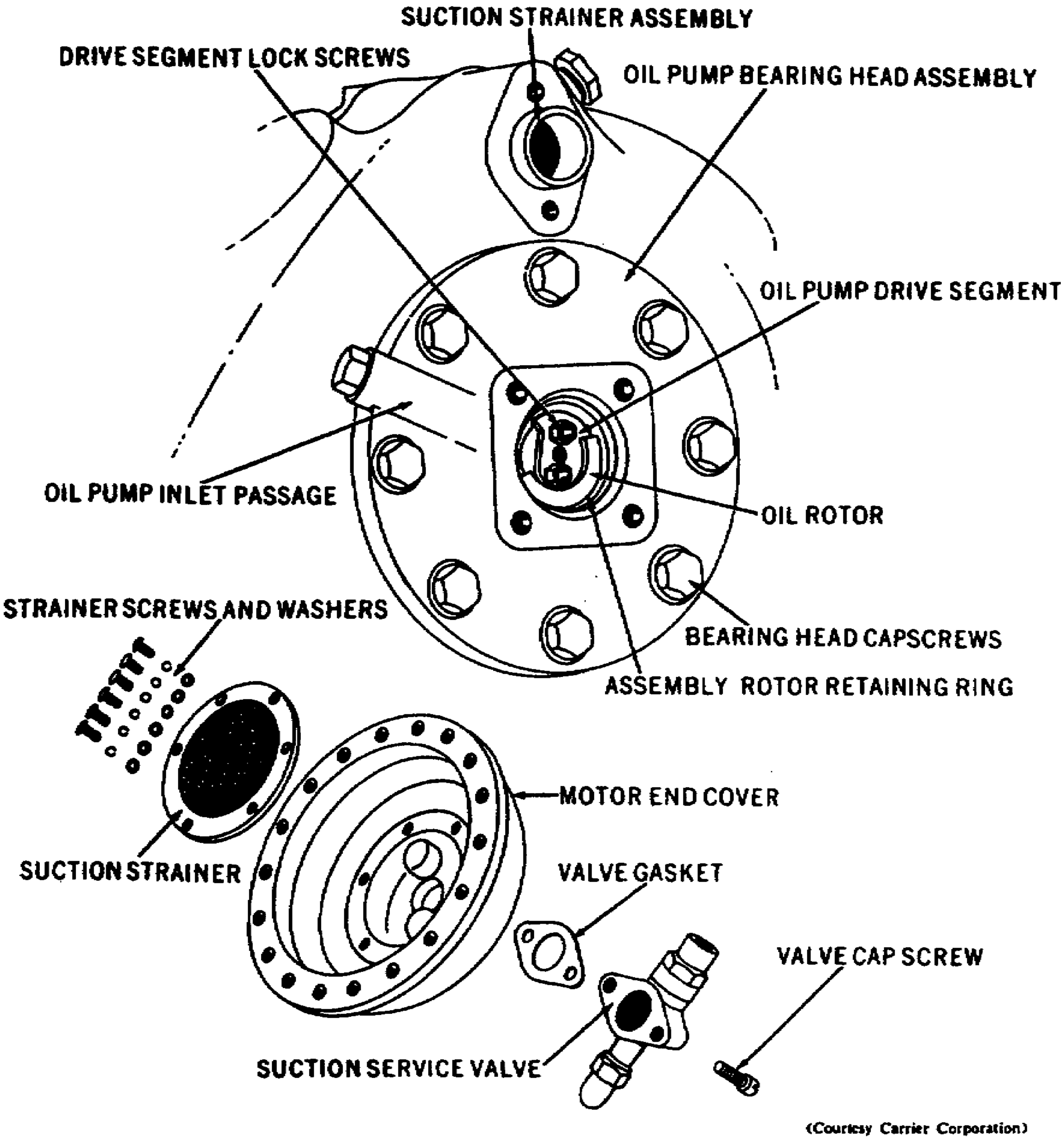


Figure 20. Suction strainers

with the unworn seat toward the valve seat. If the valve seats and valves are not noticeably worn, it is still good practice to turn the discharge valves; otherwise they may not seat properly.

20. The suction valves are doweled and may be reinstalled as they were originally. You must never interchange valves. Be careful when replacing the suction valves. The positioning springs must be placed on the dowels first. Place them with their ends toward the cylinder deck and the middle bowed upward.

21. Worn valves may be reconditioned by lapping them, using a fine scouring powder and a piece of glass. Mix refrigerant oil with the powder to form a liquid paste. Then move the valve in a figure 8 motion over the paste and glass. After the valve is reconditioned, clean and reinstall it.

22. Use new valve plate and cylinder head gasket when you install the valve plate and cylinder head.

23. *Disassembly, inspection and assembly of the oil pump and bearing head.* Remove the oil pump cover, shown in figure 23. This will free the oil feed guide retainer spring and the oil feed guide. Then remove the oil pump drive segment.

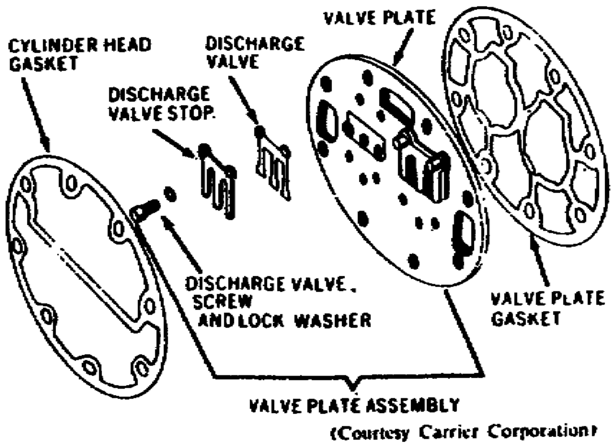


Figure 21. Valve plate assembly.

24. After you remove the bearing head you can remove the plunger snaprings which hold the plunger, plunger spring, and guide spring in the pump plunger cylinder. Snapring or jeweler's needle-nose pliers are recommended for removing the shapings.

25. Push the pump rotor out of the bearing head by pressing against the bearing side of the rotor. The rotor retaining ring will come out with the rotor. Installing a new pump and bearing head is the only positive way of eliminating oil pump trouble. However, if the cause of the trouble is determined, replacement parts are available for almost all compressors.

26. The first step in installing the oil pump and bearing head is to install the rotor retaining ring in the ring groove of the rotor, with the chamfered edge toward the compressor. Compress the retaining spring and insert the pump rotor into the bearing head.

27. The plungers (flat ends in), plunger springs, spring guides, and snaprings are installed in the plunger cylinders. Compress the snaprings and force them into their grooves. Place a new bearing head gasket and the bearing head into position and bolt them to the crankcase. Install the drive segment. Be careful not to forget the lockwashers (shown in fig. 23). Insert the oil feed guide with the large diameter inward. Place the guide spring so that it fits over the

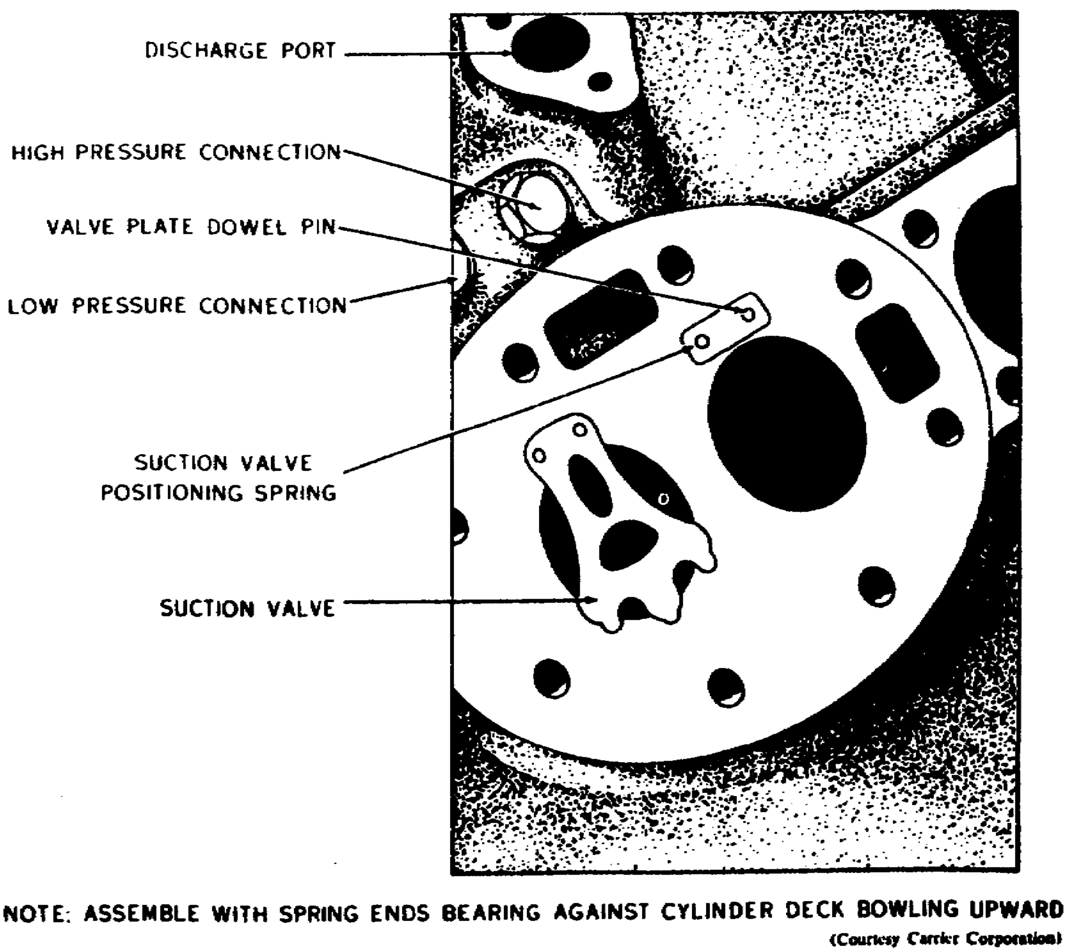
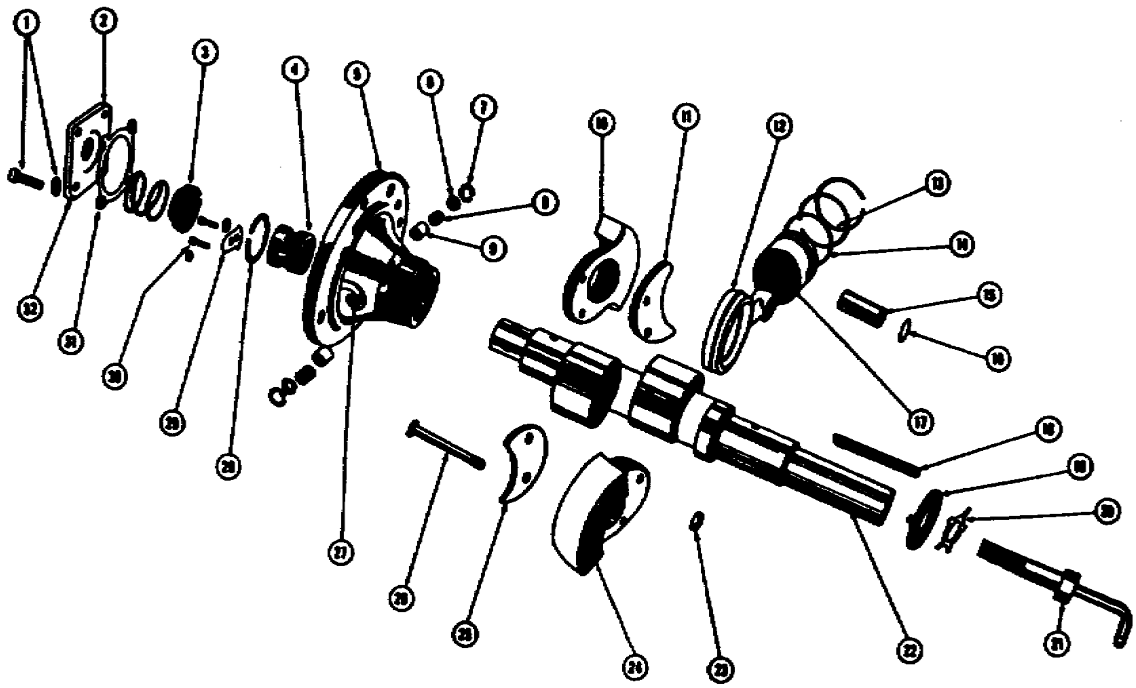


Figure 22. Suction valve positioning spring.



1. PUMP COVER CAPSCREWS AND WASHER
2. OIL FEED GUIDE RETAINER SPRING
3. OIL FEED GUIDE
4. PUMP ROTOR
5. BEARING HEAD
6. SPRING GUIDE
7. PLUNGER SNAP RING
8. PLUNGER SPRING
9. PLUNGER
10. PUMP END COUNTERWEIGHT
11. ECCENTRIC STRAP SIDE SHIELD
12. ECCENTRIC STRAP
13. COMPRESSION RINGS
14. OIL RING
15. PISTON PIN
16. PISTON
17. PISTON PIN LOCK RING
18. ROTOR DRIVE KEY
19. ROTOR LOCK WASHER
20. LOCK WASHER
21. EQUALIZING TUBE AND LOCK SCREW ASSEMBLY
22. ECCENTRIC SHAFT
23. LOCK NUT
24. MOTOR END COUNTERWEIGHT
25. ECCENTRIC STRAP SIDE SHIELD
26. COUNTERWEIGHT BOLT
27. PUMP PLUNGER CYLINDER
28. ROTOR RETAINING RING
29. OIL PUMP DRIVE SEGMENT
30. DRIVE SEGMENT CAP SCREWS AND LOCK WASHERS
31. COVER GASKET
32. OIL PUMP COVER

(Courtesy Carrier Corporation)

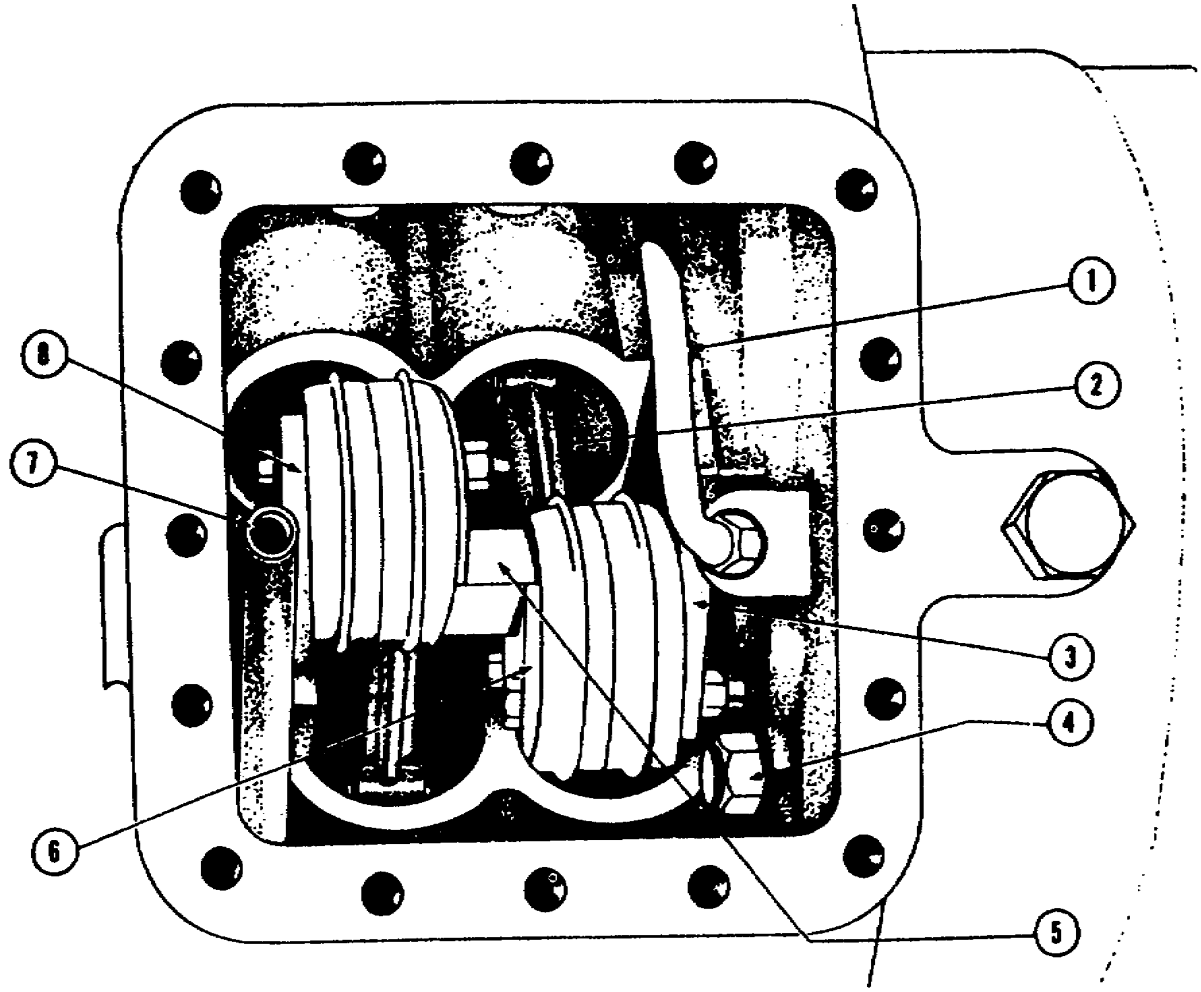
Figure 23. Compressor breakdown.

small diameter of the oil feed guide; then install a new pump cover gasket and pump cover.

28. *Disassembly, inspection, and assembly of the eccentric shaft and pistons.* Remove the oil pump and bearing head previously described. Remove the motor end cover, being careful not to damage the motor windings. Do not allow the cover to drop off. You must support it and lift it off horizontally until it clears the motor windings. Remove the bottom plate and block the eccentric so that it will not turn. Remove the equalizer tube and lock screw assembly from the motor end of the shaft. Look at figure 23 for the location of these components.

29. Pull the rotor out, using a hook through the holes on the rotor. Do not hammer on the motor end of the shaft or rotor since this may cause the eccentric straps or connecting rods to bend.

30. Remove the bolts holding the counterweights and eccentric strap shields onto the eccentric shaft. (Refer to fig. 24 during these procedures.) Remove the eccentric strap side shields and the pump end counterweight through the



1. OIL RELIEF VALVE ASSEMBLY
2. PISTON AND ECCENTRIC STRAP ASSEMBLY
3. MOTOR END COUNTER-WEIGHT
4. OIL RETURN CHECK VALVE ASSEMBLY
5. ECCENTRIC SHAFT
6. ECCENTRIC STRAP SIDE SHIELDS
7. OIL SUCTION TUBE
8. PUMP END COUNTER-WEIGHT

(Courtesy Carrier Corporation)

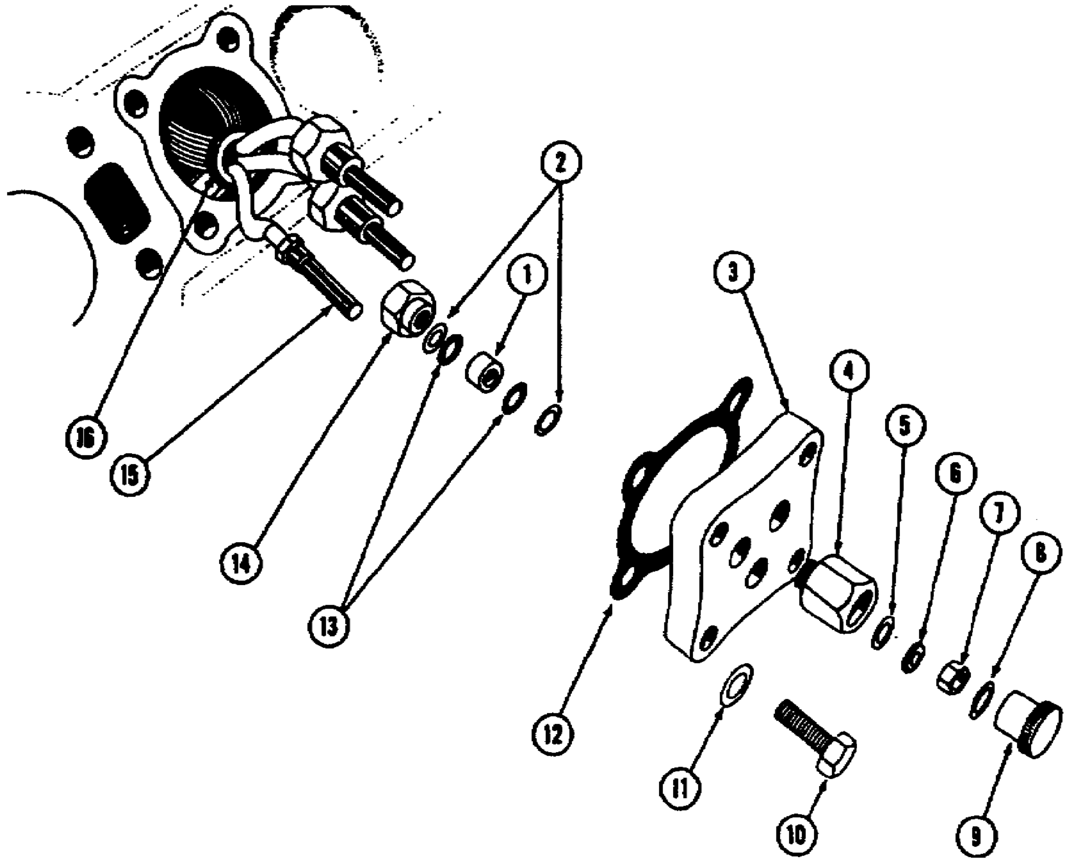
Figure 24. Removing counterweights and eccentric strap shields.

bearing head opening. The motor end counterweight will hang on the eccentric shaft until the shaft is removed. Pull the eccentric shaft through the bearing head opening. Rotate the shaft, tapping it lightly to prevent the eccentric straps from jamming. Guide the straps off the shaft by hand. The eccentric straps and pistons are removed through the bottom plate opening.

31. The piston pin is locked in place with a lockring. The pin can be removed by tapping lightly on the chamfered end of the pin (the end not having a lockring).

32. Examine the parts to see that they are not worn beyond the limits given in the manufacturer's handbook. To reassemble, follow the disassembly instructions in reverse order.

33. *Terminal assembly.* Refer to figure 25 for the relative positions of the parts. The washers



1. TERMINAL BUSHING
2. TERMINAL BLOCK WASHER (GREY)
3. TERMINAL MOUNTING PLATE
4. TERMINAL BLOCK OUTER
5. TERMINAL WASHER
6. SPRING LOCK WASHER
7. TERMINAL BLOCK NUT
8. LOCK WASHER
9. TERMINAL NUT
10. CAPSCREW
11. CAPSCREW GASKET
12. COVER GASKET
13. TERMINAL BLOCK WASHER (RED)
14. TERMINAL BLOCK INNER
15. TERMINAL SCREW
16. GROMMET

(Courtesy Carrier Corporation)

Figure 25. Terminal block breakdown.

are usually color coded and slightly different in size. Assemble them as shown.

34. The terminal mounting plate assembly is originally installed with a small space left between the outer terminal block and the surface of the mounting plate. This provides further tightening of the terminal bushing in case of a leak. To stop a leak, tighten the terminal block capscrews only enough to stop the leakage of gas. Do not tighten the capscrews so that the terminal block is flush with the mounting plate. If further tightening will cause this situation, the terminal assembly must be replaced.

35. To replace the assembly, pump down the compressor to 2 p.s.i.g. and remove the assembly. Install the new assembly, using the recommended

torque on the capscrews (1.5 ft. lbs.); purge and start the compressor. Avoid excess torque since terminal block and components are generally constructed of plastic or bakelite.

36. *Testing capacitors and relay.* The starting capacitor used in single-phase units is wired as shown in figure 19. Capacitors are connected in series with one power lead to the motor starting winding. These capacitors may fail because of a short or open circuit. If they are short circuited, the starting current draw will be excessive. The compressor may not start and will cause fuses to blow because of the increased load. If it is connected in a circuit feeding lights, the lights will dim. A humming sound from the compressor motor indicates improper phasing between the starting and running windings caused by an open-circuited capacitor. To check starting capacitors, replace them with good capacitors and observe the operation of the unit.

37. The running capacitors are connected across the running and starting terminals of the compressor. If short circuited, they will allow an excessive current to pass to the start winding continuously. The compressor may not start. If it does, it will be cut off by the motor over-load switch. If they are open, the compressor will operate, but will draw more power than normal when running and will stall on heavy loads. To test for open-circuited capacitors, an ammeter should be connected in series with one power lead. With good running capacitors, the current requirement will be less than it is when the capacitor is disconnected. An open capacitor will cause no change in current draw when it is disconnected.

38. The relay is the potential or voltage type. The contacts are normally closed when there is no power to the unit and open approximately one-fifth of a second after power is applied. The operation of the relay magnetic coil is governed by the voltage through its windings. Upon starting, the counter EMF of the motor builds up, causing a rise in voltage through the relay coil. As the voltage across the coil rises, the magnetic attraction of the relay arm overcomes the spring tension. This causes the arm to move and force the relay contacts open. The starting capacitors, which are in series with the starting winding when the relay contacts are closed, are disconnected from the circuit.

39. If the relay fails with the contacts open, the starting capacitors will not be energized. The compressor motor will hum but will not start. After the power has been on for 5 to 20 seconds, the overload relay will cut off the power to the compressor motor.

40. To check the relay for contacts that fail to close, put a jumper across the relay contacts and turn on the power. If the unit starts with the jumper, but will not start without it, you must replace the relay.

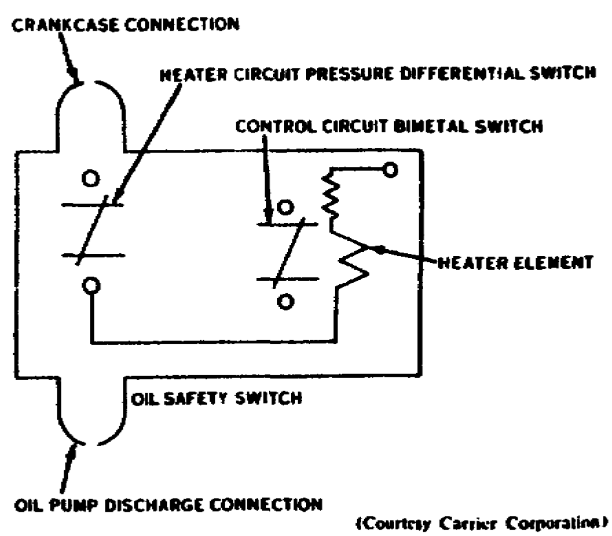
41. When the relay fails with the contacts closed, the starting capacitors will continue to be energized after the compressor has come up to speed. The compressor will start but will run with a loud grinding hum. The overload relay will shut the compressor off after the compressor has run for a short time due to the extra load of the start winding. This type of relay failure can cause damage to the motor windings and the running capacitor.

42. A visual inspection will determine if relay contacts fail to open. Remove the relay cover and observe its operation. If it does not open after the power has been applied for a few moments, you must replace the relay.

43. *Oil safety switch.* Many units have oil safety switches which protect the compressor from low or no oil pressure. This control has two circuits-heater and control.

44. This switch measures the difference between oil pump discharge pressure and crankcase pressure. If the net oil pressure drops below the permissible limits, the differential pressure switch energizes the heater circuit which will cause the bimetal switch in the control circuit to open in approximately 1 minute. Low oil pressure may result from the loss of oil, oil pump failure, worn bearings, or excessive refrigerant in the oil. Figure 26 shows a typical oil pressure safety switch.

45. The differential pressure switch is factory calibrated to open when the oil pump discharge pressure is 18 p.s.i.g. greater than the crankcase pressure. It will close when the difference is 11 p.s.i.g. Its adjustment should not be attempted



(Courtesy Carrier Corporation)

Figure 26. Oil pressure safety switch.

in the field. If the differential pressure switch functions properly and the compressor continues to run after 1 minute, the time-delay heater circuit is defective and the oil pressure safety switch should be replaced. The switch should be checked monthly for correct operation.

46. **Troubleshooting**. One of your most important responsibilities is the troubleshooting and correction of malfunctions of these systems. Throughout this chapter we have given basic principles of D/X systems. Using this knowledge and the information that we have provided in tables 1 through 10, you should have little trouble in achieving the desired skill levels.

TABLE 1
COMPRESSOR FAILS TO START

Fault	*Cause*	*Remedy*
No current on line side of motor starter.	Power failure.	Check for blown fuse of tripped circuit breaker.
Electric current tester glows but not at full brilliance.	Low voltage.	Check with voltmeter. If low, correct cause before starting the compressor.
Full voltage at motor terminals but motor will not run.	Burned-out motor.	Replace motor.
Inoperative motor starter.	Burned-out holding coil or broken contacts.	Replace motor starter.
Compressor will not turn.	Frozen compressor due to damaged parts.	Replace compressor.
Suction pressure below cut-in setting of low-pressure cutout switch.	Open contacts on low-pressure switch. Suction pressure may be below cut-in setting.	Check for loss of refrigerant. Repair leak and recharge.
Discharge pressure above cut-in setting of low-pressure cutout switch.	Open contacts on high-pressure switch. Discharge pressure may be above cut-in setting.	Clean condenser tubes and cooling tower.
Starter will not pull in.	Starter overload or contacts open.	Reset contacts and determine cause of failure.

TABLE 2
COMPRESSOR SHORT CYCLES

Fault	*Cause*	*Remedy*
Normal operation except too frequent stopping and starting.	Intermittent contact in electrical control circuit.	Repair or replace faulty electric or pneumatic-electric control.
	Low-pressure differential set too close.	Reset control.
Normal operation except too frequent stopping and starting on low-pressure control switch.	Lack of refrigerant.	Repair leakage and recharge.
Suction pressure too low and frosting at strainer.	Restricted liquid line strainer.	Replace strainer.
Compressor fully loaded cuts out on freeze protection control.	Lack of air pressure in pneumatic control system.	Restore air pressure.
Compressor will not load or unload.	Inoperative compressor unloading system.	Repair or replace faulty control.

TABLE 3
COMPRESSOR RUNS CONTINUOUSLY

Fault	*Cause*	*Remedy*
High temperature in conditioned area.	Excessive load.	Check for excessive heat infiltration.
Low temperature in conditioned area.	Controlling at too low a water temperature.	Adjust temperature controller.
Bubbles in sight glass.	Lack of refrigerant.	Repair leak and charge.
Compressor noisy.	Leaky valves in compressor.	Recondition valves.
Compressor fully or partially unloaded but will not stop.	Solenoid stop valve leaks.	Repair valve.

TABLE 4

COMPRESSOR LOSES OIL

Fault	*Cause*	*Remedy*
Oil level too low.	Insufficient oil in compressor before starting.	Add sufficient oil.
Oil level gradually drops.	Clogged strainers.	Clean strainers.
Oil around compressor base.	Crankcase fittings leak oil.	Repair leak and add sufficient oil.

TABLE 5

COMPRESSOR NOISY

Fault	*Cause*	*Remedy*
Compressor cuts out on oil pressure control.	Lack of oil.	Add sufficient oil.
Compressor knocks.	Internal parts of compressor broken.	Overhaul compressor.
Abnormally cold suction line.	Refrigerant liquid flood back.	Check for loose remote bulb on suction line.
High head pressure. Water valve chatters or hammers.	Condenser pressure control too high.	Readjust control.
Abnormally cold suction line.	Expansion valve stuck in open position.	Repair or replace expansion valve.
Compressor jumps on base.	Compressor loose on base.	Tighten compressor holddown bolts.

TABLE 6

SYSTEM NOT WORKING AT CAPACITY

Fault	*Cause*	*Remedy*
Expansion valve hisses.	Flash gas in liquid line.	Add refrigerant.
Temperature change in refrigerant line through strainer or solenoid stop valve.	Clogged strainer or solenoid stop valve.	Clean or replace strainer or valve.
Reduced waterflow.	Obstructed condenser water line.	Remove obstruction.
Short cycling or continuous running of compressor.	Expansion valve stuck in open position.	Repair or replace expansion valve.
Superheat too high.	Excess pressure drop in evaporator.	Adjust expansion valve.
Short cycling or continuous running of compressor.	Improper superheat adjustment.	Adjust expansion valve.

TABLE 7

DISCHARGE PRESSURE TOO HIGH

Fault	*Cause*	*Remedy*
Excessively warm water leaving condenser.	Too little condenser water.	Readjust condenser pressure control.
Excessively cool water leaving condenser.	Fouled tubes in shell and tube condenser.	Clean tubes.
Exceptionally hot condenser.	Air or noncondensable gas in system.	Purge system.
	Overcharge of refrigerant.	Remove excess refrigerant.
Cooling tower (if used) appears to be operating satisfactorily, yet excessively high discharge pressure exists.	Cooling tower too small.	Check cooling tower rating table for correct size selection.

TABLE 8

DISCHARGE PRESSURE TOO LOW

Fault	*Cause*	*Remedy*
Excessively cold water leaving condenser.	Too much condenser water.	Adjust condenser pressure control.
Cooling tower (if used) appears to be operating satisfactorily, yet excessively low discharge pressure exists.	Cooling tower too large.	Recheck cooling tower rating table for correct size selection.

TABLE 9

SUCTION PRESSURE TOO HIGH

Fault	*Cause*	*Remedy*
Compressor runs continuously.	Excessive load on evaporator.	Check for excessive infiltration of outside air into conditioned space.
Abnormally cold suction line.	Overfeeding of expansion valve.	Repair or replace valve.
Floodback	Expansion valve stuck in open position.	Repair or replace valve.
Noisy compressor.	Faulty suction valves in compressor.	Recondition faulty compressor valves.

TABLE 10

SUCTION PRESSURE TOO LOW

Fault	*Cause*	*Remedy*
Bubbles in sight glass.	Lack of refrigerant.	Repair leak and charge.
Temperature change in refrigerant line through strainer or solenoid stop valve.	Clogged liquid line strainer.	Clean strainer.
No flow of refrigerant through valve.	Expansion valve power assembly has lost charge.	Replace expansion valve power assembly.
Loss of capacity.	Obstructed expansion valve.	Clean valve or replace if necessary.
Contained space too cold.	Contacts on control thermostat stuck in closed position.	Repair thermostat or replace if necessary.
Compressor short cycles.	Compressor capacity control range set too low.	Reset compressor capacity control range.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. There are three things which must be considered before installing a preheat coil. Name them. (Sec. 1, Par. 2)

2. After you have inspected a thermostatically controlled steam preheat coil, you find that the valve is closed and the outside temperature is 33° F. What is the most probable malfunction, if any? (Sec. 1, Par. 4)

3. What two functions does a D/X coil serve? (Sec. 1, Par. 7)

4. What has occurred when a compressor using simple on-off control short cycles? (Sec. 1, Par. 9)

5. What function does the humidistat serve on a two-speed compressor installation? (Sec. 1, Par. 11)

6. Why is a nonrestarting relay installed in a solenoid (D/X coil) valve installation? (Sec. 1, Par. 12)

7. A service call is received from Building 1020 with a complaint of no air conditioning. The system uses two D/X coils and two solenoid valves. Which component should you check before troubleshooting the solenoid valve control circuit? (Sec. 1, Par. 14)

8. What type compressor must be used when two-position control of a D/X coil and modulating control of a face and bypass damper are employed to control air temperature? (Sec. 1, Par. 15)

9. The most probable cause of low supply air temperature and high humidity in an equipment cooling system _____________. (Sec. 1, Par. 18)

10. How are large swings in relative humidity prevented when face and bypass dampers are used to control dehumidification? (Sec. 1, Par. 20)

11. Which control has prime control of the D/X coil if a space thermostat and humidistat are installed in the system? (Sec. 1, Par. 26)

12. Answering a service call, what conclusion would you make from these symptoms?
    (1) The suction pressure is high.

    (2) The cooling load is at its peak.

    (3) The motor is short cycling on its over load protector. (Sec. 2, Par. 3)

13. What would occur if you installed a medium temperature unit for a 40° F suction temperature application? (Sec. 2, Par. 3)

14. What could cause the compressor on an air conditioner to start when the thermostat controlling the liquid solenoid valve is satisfied? Why? (Sec. 2, Par. 4, and fig. 19)

15. When may the automatic pump-down feature be omitted? (Sec. 2, Par. 5)

16. Name the four factors you should consider before you install a D/X system. (Sec. 3, Par. 1)

17. How can you correct the following situation? Refrigerant is condensing in the compressor crankcase. (Sec. 3, Par. 2)

18. Is it necessary to install a condensing unit on a special foundation? Why? (Sec. 3, Par. 3)

19. What is the minimum and maximum voltages that can be supplied to a 220-volt unit? (Sec. 3, Par. 5)

20. How much phase unbalance is tolerable between phases of a three-phase installation? (Sec. 3, Par. 5)

21. During gauge installation, in which position is the shutoff valve set and why? (Sec. 3, Par. 9)

22. Where would you install a liquid line sight glass in the system? (Sec. 3, Par. 12)

23. When city water is used as the condensing medium, the condenser circuits are connected in _______________. (Sec. 3, Par. 14)

24. When cooling tower water is used, the condenser circuits are connected in ___________________. (Sec. 3, Par. 14)

25. Which types of gases may be used to pressurize the system for leak testing? (Sec. 3, Par. 15)

26. After you have disassembled a compressor, you find an excessive amount of sludge in the crankcase. What caused this sludge? (Sec 3, Par. 16)

27. Why is it important to keep the ambient temperature above 60° F. when you are dehydrating a system with a vacuum pump? (Sec. 3, Par. 17)

28. What pressure corresponds to a vacuum indicator reading of 45° F.? (Sec. 3, Par. 18, and fig. 17)

29. Why are shutoff valves installed in the vacuum pump suction line? (Sec. 3, Par. 20)

30. The type of moisture that is first removed from a refrigeration system is ______________ moisture. (Sec. 3, Par. 22)

31. Why do you have to backseat the suction and discharge shutoff valves before you connect the gauge manifold? (Sec. 3, Par. 25)

32. What four items must be checked before you start a newly installed compressor? (Sec. 3, Par. 26)

33. How does frontseating the suction shutoff valve affect the low-pressure control? (Sec. 3, Par. 34)

34. Why do you place the refrigerant cylinder in ice when you want to evacuate all the refrigerant from a system? (Sec. 4, Par. 3)

35. Why is a partial pressure, 2 p.s.i.g., allowed to remain in the system after pumpdown? (Sec. 4, Par. 4)

36. Why should you allow sufficient time for a component to warm to room temperature before removing it from the system? (Sec. 4, Par. 6)

37. The two types of suction strainers are _______________ and ________________ (Sec. 4, Par. 9)

38. Where do noncondensable gases collect in a water-cooled refrigerating system? (Sec. 4, Par. 10)

39. What condition most probably exists when the following symptoms are indicated?
    (1) Excessive amperage draw.

    (2) The condenser water temperature is normal.

    (3) The discharge temperature, felt by hand at the compressor discharge line, is above normal. (Sec. 4, Par. 10)

40. What would a discharge pressure drop of 10 p.s.i.g. per minute with the discharge shutoff valve frontseated indicate? (Sec. 4, Par. 15)

41. How are valve plates removed from cylinder decks? (Sec. 4, Par. 18)

42. What is the emergency procedure that you can use to recondition worn compressor valves? (Sec. 4, Par. 21)

43. How is the oil feed guide installed? (Sec. 4, Par. 27)

44. Why should you use a hook device rather than a hammer to remove the rotor? (Sec. 4, Par. 29)

45. (Agree)(Disagree) The terminal block is tightened flush with the mounting plate. (Sec. 4, Par. 34)

46. The amount of torque required when tightening the capscrews on a terminal block is _______________. (Sec. 4, Par. 35)

47. The following complaint concerning an inoperative air conditioner is submitted to the shop: the air conditioner keeps blowing fuses when it tries to start. After troubleshooting the unit you find that the starting current draw is above normal. Which component should you check and what should you check it for (Sec. 4, Par. 36)

48. What will cause a humming sound from the compressor motor? (Sec. 4, Par. 36)

49. The contacts of the starting relay are normally _________________. (Sec. 4, Par. 38)

50. What causes the contacts of the starting relay to open? (Sec. 4, Par. 38)

51. Which type of relay failure can cause damage to the motor windings? (Sec. 4, Par. 41)

52. The two circuits that make up the oil safety switch are _______________ and ______________. (Sec. 4, Par. 43)

53. The pressure which cause the oil safety switch to operate are ________________ and ________________ (Sec. 4, Par. 44)

54. (Agree)(Disagree) The differential pressure switch in the oil safety switch will open when the pressure differential drops. (Sec. 4, Par. 45)

55. What can cause an inoperative motor starter? (Sec. 4, table 1)

56. What should you suspect when the dehydrator is frosted and the suction pressure is below normal? (Sec. 4, table 2)

57. A loose feeler bulb for a thermostatic expansion valve will cause an abnormally cold suction line. Why is the line cold? (Sec. 4, table 5)

58. A hissing expansion valve indicates _____________________. (Sec. 4, table 6)

59. Too much superheat will cause ____________________. (Sec. 4, table 6)

60. During a routine inspection, you find the water-cooled condenser exceptionally hot. What are the most probable faults and how should you correct them? (Sec. 4, table 7)

61. A low suction pressure and loss of system capacity indicates ___________________. (Sec. 4, table 10)

62. How would you correct this fault: A capacity controlled compressor short cycling? (Sec. 4, table 10)

CHAPTER 2

Absorption Systems

HOW ABSURD IT is to use water as a refrigerant; yet absorption systems do. You know that this can be done only under specific conditions. Within a deep vacuum, water will boil (vaporize) at a very low temperature. For example, when a vacuum of 29.99 inches is obtained, the water will boil at approximately 40° Fahrenheit. Hence, vacuum is the key to absorption air conditioning.

2. The absorption system is one of the simplest of all types of automatic air-conditioning systems. Though this machine has few moving parts, it has an immense cooling capacity. We shall discuss in this chapter terminology, identification, and function of unit components; starting and operating procedures; and maintenance of the absorption system.

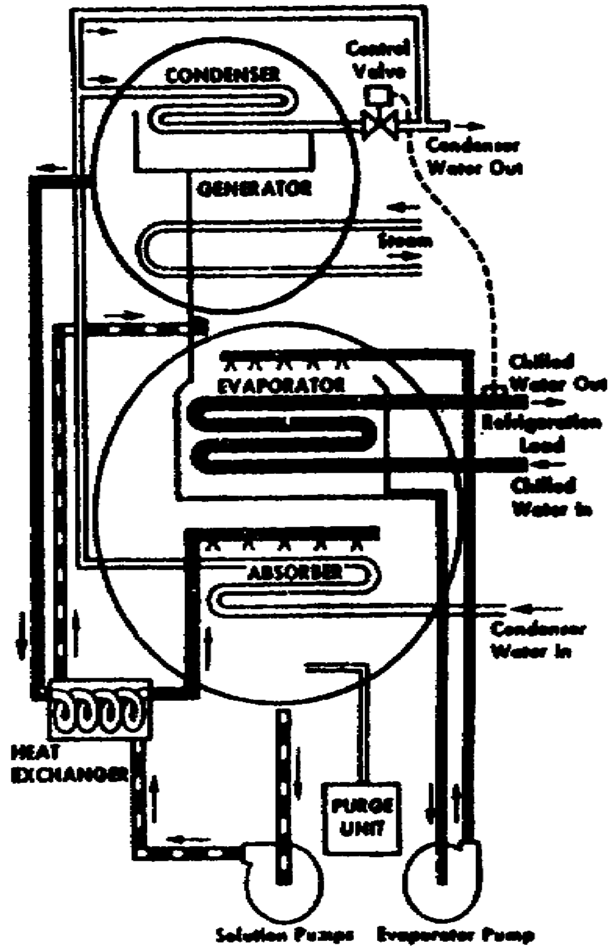
5. Terminology, Identification, and Function of Units

1. The complete absorption refrigeration unit contains a generator, a condenser, an absorber, and an evaporator. The condenser and generator are combined in the upper shell of the machine, while the evaporator and absorber are combined in the lower shell, as shown in figure 27.

2. The heat exchanger, purge unit, solution pump, and evaporating pump are mounted between the support legs of the unit. The purge unit is used to remove noncondensables from the machine. The capacity control valve controls the water leaving the condenser. This valve is controlled thermostatically by a remote bulb placed in the chilled water line.

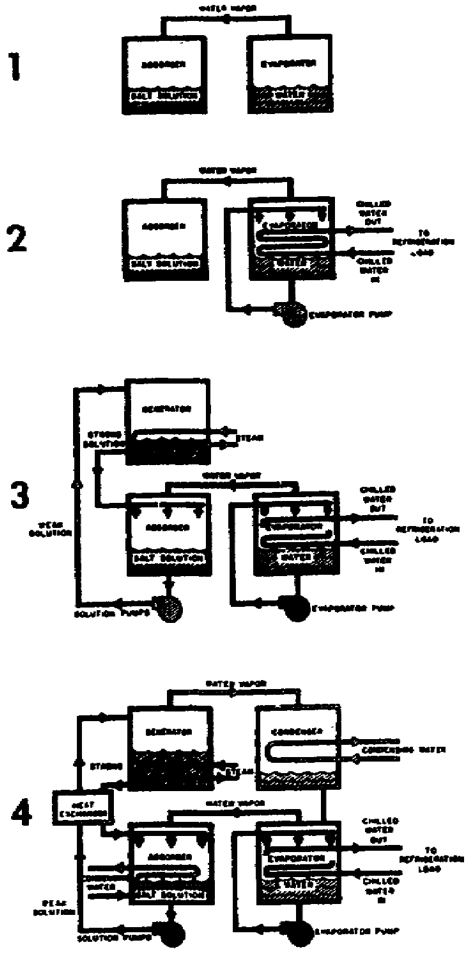
3. Figure 28 is a simple block diagram of the absorption refrigeration cycle. The refrigerant used is common tap water and the absorbent is a special salt, lithium bromide.

4. To understand the operation of the refrigeration cycle, consider two self-contained vessels: one containing the salt solution (absorber) and the other (evaporator) containing water, joined together as shown in item 1 of figure 28. Ordinary table salt absorbs water vapor when it is exposed to damp weather. The salt solution in the absorber has a much greater ability to absorb the water vapor from the evaporator. The water in the evaporator boiling at a low temperature does the same job as refrigerants R-12, R-13, and R-22. As the water vaporizes, the water vapor travels from the evaporator to the absorber, where it is absorbed into the salt solution. The evaporator pump, shown in item 2 of figure 28, circulates water from the evaporator tank to a spray header to wet the surface of the coil. The cooling effect of the spray boiling at approximately 40° F. on the coil surface chills the water inside the coil, and this chilled water is



(Courtesy Carrier Corporation)

Figure 27. Absorption unit components.



(Courtesy Carrier Corporation)

Figure 28. Absorption refrigeration cycle.

circulated in a closed cycle to the cooling coils. This refrigeration effect is known as flash cooling.

5. In reference to item 3 of figure 28, note the addition of the generator and accessory equipment. These components are necessary for continuous and efficient operation. The salt solution would become diluted and the action stopped if it were not for the regeneration of the salt solution. To keep the salt solution in the absorber at its proper strength so that it will have the ability to absorb water, the salt solution is pumped to a generator where heat is used to raise its temperature and boil off the excess water. The salt concentrate is then returned to the absorber to continue its cycle. The water that is boiled off from the salt solution in the generator is condensed in the condenser and returned to the evaporator as shown in item 4 of figure 28. The heat exchanger uses a hot solution from the generator to preheat the diluted solution. This raises the overall efficiency because less heat will be required to bring the diluted solution to a boil. Condensing water, which is circulated through the coils of the absorber and the condenser, removes waste heat from the unit. By comparing figure 29 with figure 27, you will get a better understanding of the relation between basic operating principles and an actual installation.

6. **Controls**. Figure 30 illustrates a typical control panel for an absorption refrigeration unit. The purpose of each control listed in this figure is described in the following paragraphs. Turning the off-run-start switch (1) the START position energizes the electric pneumatic switch (2), which activates the control system of the absorption machine. Supply air pressure of 15 p.s.i.g. (3) passes to the chilled water thermostat (4), then to the concentration limit thermostat (5), and finally to the capacity control valve (7).

7. The chilled water thermostat (4) is a direct acting control with a 7° F. differential. For every degree change in the chilled water temperature, there is approximately a 2-pound change in its branch line air pressure. Its thermal element is located in the leaving chilled water line. As the leaving chilled water temperature drops below the control setting of the thermostat, the supply air pressure (3) is throttled, causing the capacity control valve (7) to throttle the condenser water quantity. With a constant load on the machine, the capacity control valve throttles just enough condensing water to balance the load.

8. The concentration limit thermostat (5) is a direct acting bleed type control, with the thermal element located in the vapor condensate well. Its purpose is to prevent the solution from concentrating beyond the point where solidification results. At startup, the capacity control valve (7) is closed and remains closed until the vapor condensate well temperature rises above the control point of the concentration limit thermostat. As it does, the thermostat begins to throttle the air bleeding to the atmosphere, thus raising the branch line pressure (6) and opening the capacity control valve. This control valve on some absorption models may be controlled electrically instead of pneumatically.

9. *Safety controls*. Two safety controls are usually used in the control systems. They are the chilled water safety thermostat and the solution pressurestat. In moist instances, any malfunction occurring during operation is immediately reflected by a rise in the chilled water temperature. The thermal element of the chilled water safety

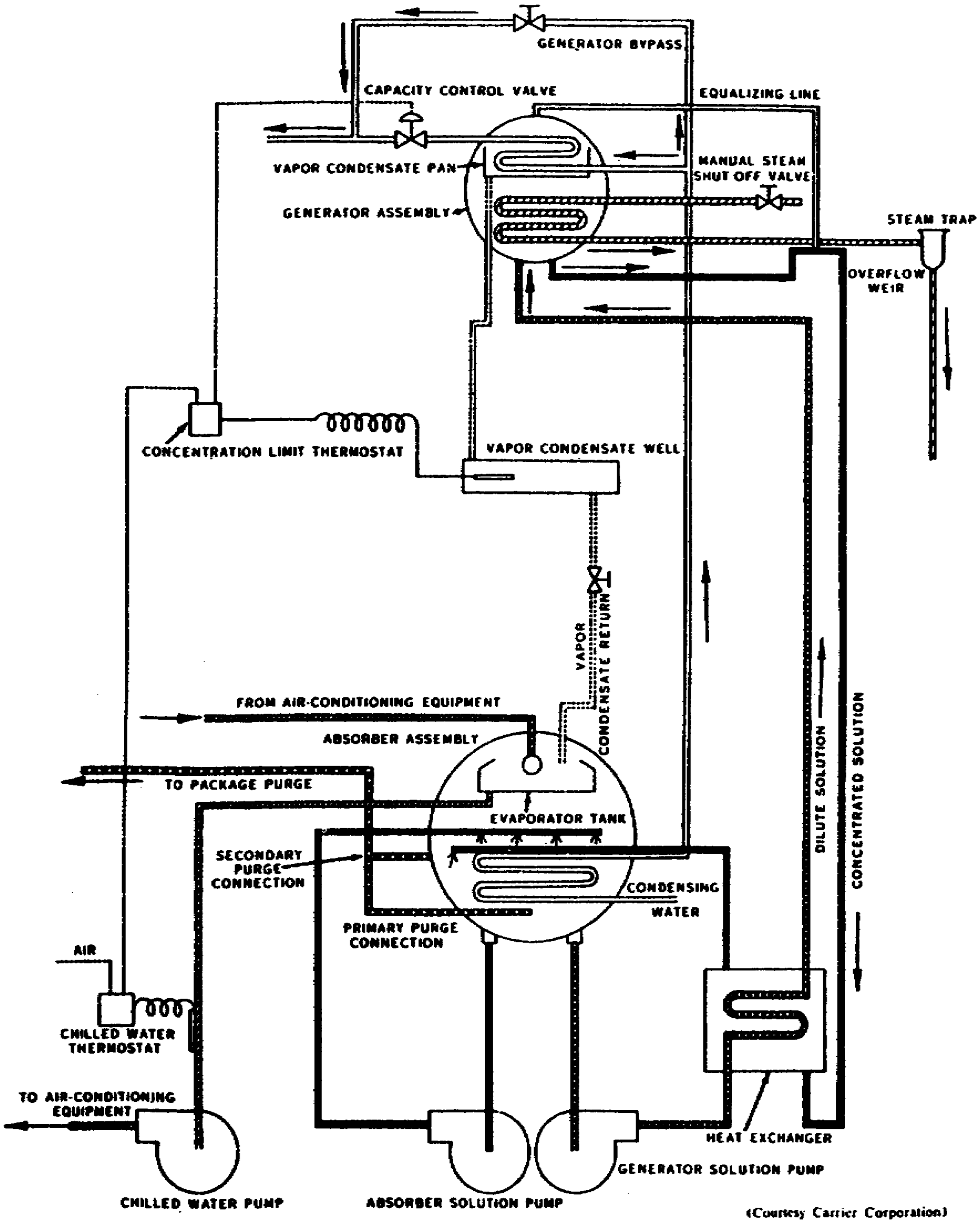


Figure 29. Absorption refrigeration cycle.

thermostat is located in the chilled water line leaving the machine. The control point is set approximately 10° F. above the design leaving chilled water temperature. A temperature rise above the control point shuts off the air supply. All control lines are then bled and the system is shut down. When the off-run-start switch is in the START position, this control is bypassed. The switch should not be placed in the RUN position until after you obtain a chilled water temperature below the control setting.

10. The solution pressurestat located in the

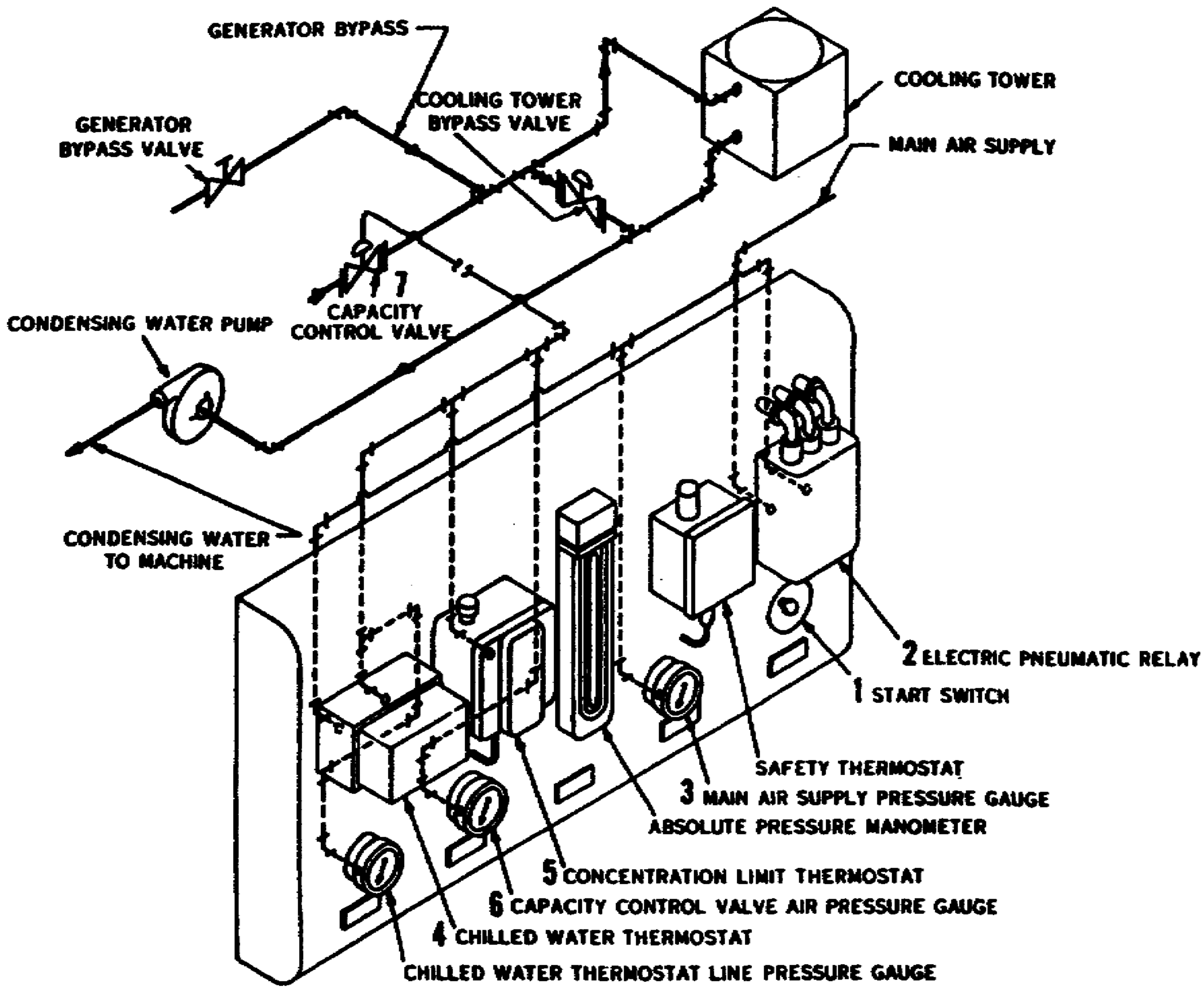


Figure 30. Control panel.

discharge line of the solution pump is set to cut in on a rising pressure at 40 p.s.i.g. and cut out on a falling pressure at 30 p.s.i.g. If for any reason the discharge pressure falls below the control point, the system will be shut down in the same manner as described above.

11. *Special control*. Special chilled water controllers may be installed in the field for special applications. These controls are used to maintain the chilled water temperatures within a plus or minus 2° F. Explosion-proof controls and motor are installed for special applications. Refer to the manufacturer's manual on the operation and maintenance of these controls and motors.

12. **Thermometers**. Thermometers are installed in several locations in the system. Below is a general listing of thermometer locations and their purposes:

(1) Chilled water piping to indicate the entering chilled water temperature.

(2) Chilled water pump suction piping to indicate leaving chilled water temperature.

(3) Condensing water piping entering the absorber section.

(4) Condensing water piping leaving the absorber section. For proper temperature measurements, the thermometer is located in the generator bypass line.

(5) Condensing water piping leaving the condenser section.

(6) Condensing water piping to indicate the total condensing water temperature to the cooling tower or drain.

13. **Pressure Gauges**. Pressure gauges are installed in several locations in the system. The following is a general listing of gauge locations:

(1) Purge water line after the strainer and before the purge water jet.

(2) Purge water line after the jet.

(3) Steam line before the generator section.

(4) Discharge line from the chilled water pump.

(5) Discharge line from the condenser water pump.

14. **Water Seals**. Older models of absorption machines require mechanical seals on the solution and evaporator pumps. However, the newer machines have hermetically sealed pumps that eliminate the need for mechanical seals. The older models require external water seals; therefore, it is necessary to supply a water seal tank to maintain water on the seals for lubrication purposes and so that water rather than air leaks into the machine in case the seals break or leak.

15. The water seal tank has a float control to limit the quantity of water to the seals when the machine is in operation. The operator must open the manual valve supplying the seal water tank before startup and must close the manual valve on shutdown. This is the standard method of control. The alternate method is one where a check valve is installed in the supply line to the tank, as well as an antisyphon vacuum breaker. When the machine is shut down a visual check can be made to determine the condition of the seal and to prevent a large quantity of water from leaking into the machine if the seal is worn or cracked. If mechanical seals have to be replaced, the manufacturer's instructions must be carefully followed in order to do the job correctly and prevent the new seals from leaking. During operation, the evaporator pump makes up for the water lost by a seal; but during shutdown, it is possible to lose a large amount of water from the tank if a large leak exists. Therefore, leaky seals must be replaced immediately. Having learned the importance of water seals in the absorption system, we can now discuss the starting procedures.

6. Starting Procedures

1. Some absorption systems are completely automatic and can be started by simply pushing a start button, while in other systems the machine is automatic but the auxiliary equipment is manually operated. The type of startup determines the starting procedure. Therefore, each starting procedure is outlined separately, and the machine operator can perform the starting operations applicable to the type of startup required. Even though some systems are automatic, it would be advisable to check the system as described below before starting the unit.

2. **Daily Startup**. Use the following steps in performing a normal startup.

(1) Check vacuum in machine (see Maintenance, Section 8).

(2) Check mechanical seals for leakage (see Maintenance, Section 8).

(3) Check water level in evaporator sight glass.

(4) Check absorber section for presence of water.

(5) Start condensing water pump.

(6) Check temperature of condensing water going to machine. Do not start cooling tower fan until the condenser water it has warmed up to the recommended setting.

(7) Start the purge unit.

- Push start button on the purge control panel.
- Open purge steam supply valve.
- Check the standpipe for water seal circulation before starting the pumps.

(8) Start the chilled water pump and open the valves to insure circulation through the evaporator tubes and air-conditioning equipment.

(9) Start the refrigerant pump and open the valve in the refrigerant pump discharge line.

(10) Start the purging machine. Open the absorber purge valve located in the purge line to the absorber. The generator purge valve located in the purge line between the absorber and generator must be open.

(11) Wait until the machine is completely purged. There will be a substantial drop in the leaving chilled water temperature when the machine is completely purged. If the leaving chilled water temperature does not drop and there are no leaks in the machine, then the steam jets should be cleaned.

(12) Open the main steam valve to the machine.

(13) Check steam pressure supply to see that it is within the proper range.

(14) Place the control panel switch in the START position.

(15) Check the main air supply pressure gauge to insure that 15 p.s.i.g. is supplied to the control panel.

(16) Start solution pump. Be sure the strong solution return valve is open at all times.

(17) When the leaving chilled water temperature has dropped below the safety thermostat setting, move the control panel switch from START to RUN.

3. **Startup After Standby Shutdown**. This procedure is basically the same as for daily startup. There are, however, additional preparation steps that must first be performed in order to put the machine in operational condition for startup. In order to prepare the machine for startup, the nitrogen with which the machine has been charged must be removed and a vacuum pulled on the machine. This is done by operating the purge unit until the machine has been purged of nitrogen and a satisfactory vacuum reading attained.

4. **Startup After Extended Shutdown**: This procedure is basically the same as for daily startup except for the additional preparation steps that must first be performed to put the machine in operational condition for startup. The preparations necessary after extended shutdown are similar to an initial startup of a new machine. The complete system must be prepared for operation in these steps:

(1) Check all drains that should be closed in the chilled water and condensing water circuits.

(2) Fill the condensing water circuit.

(3) Start the purge unit to remove all air and nitrogen from the machine.

(4) Fill the primary and secondary chilled water circuits.

(5) Purge the chilled water circuit of air.

- Start the chilled water pump.
- Open the diaphragm valve in the chilled water pump discharge line.
- Open the diaphragm valve in the chilled water return line to the machine and continue purging until the recommended vacuum is obtained.

(6) Purge the refrigerant circuit. Do not start the refrigerant pump until chilled water is circulating through the evaporator tubes.

- Start the refrigerant pump.
- Open the valve in the refrigerant pump discharge line and allow the refrigerant to circulate until the recommended vacuum is obtained on the machine.

(7) Shut down the purge unit.

(8) Shut down the primary chilled water circuit.

- Close the diaphragm valve in the primary chilled water pump discharge line.
- Shut off the primary chilled water pump. The machine is now in operational order and ready for instant startup. The procedures for daily startup should now be followed to place the machine in operation.

7. Operating Procedures

1. You must make periodic checks on the machine while it is in operation and keep a daily operating log. Compare observations with the following recommended operating conditions and make any necessary adjustments.

2. **Evaporator, Absorber, and Generator Levels**. As an operator you will have to visually check the sight glasses on the evaporator, absorber, and generator.

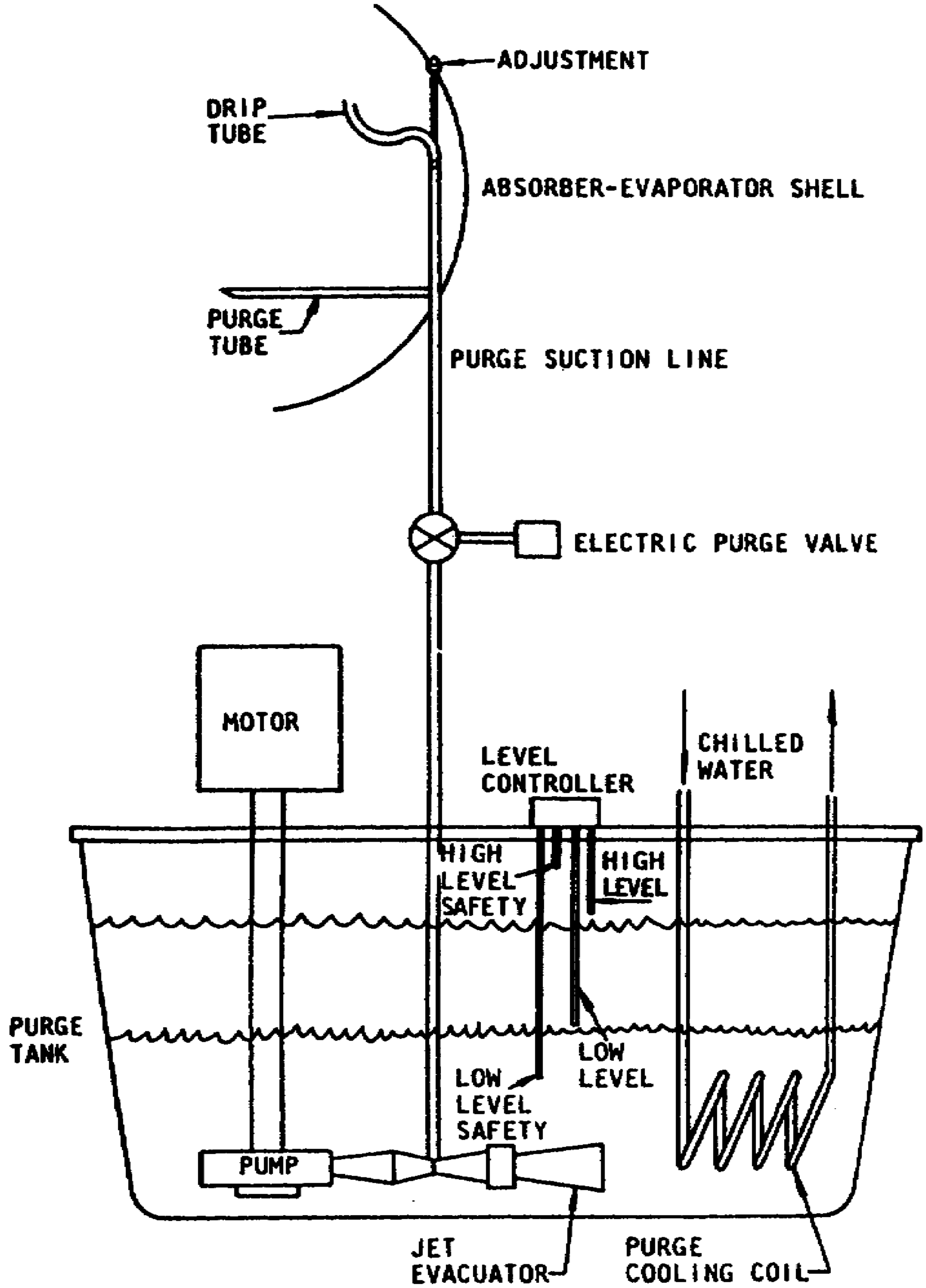
3. *Evaporator sight glass water level*. The normal operating evaporator tank water level is approximately 1 inch above the horizontal centerline. At a high level, the chilled water may spill over the evaporator tank into the solution in the absorber, causing a loss of operating efficiency. A low level will cause the chilled water pump to cavitate (surge).

4. *Solution level in absorber*. Normal operating level is approximately one-third of the absorber sight glass at full load operation. At partial load operation, the solution level will vary between one-third and two-thirds of the sight glass. The solution level may require adjustment when the leaving chilled water temperature is changed, which is done by manually adjusting the chilled water thermostat. If the setting is lowered, the solution level will drop and solution must be added. If the setting is raised, the solution level will rise and solution must be removed from the machine. Operating instructions for the specific machine should be followed in adjusting the solution level.

5. *Solution boiling level in generator*. The solution boiling level is set at initial startup of the machine and should not vary during operation. The boiling level can be checked by looking into the mirror near the generator bull's-eye. A light should be visible at all times. If the light is obscured, the boiling level is too high and should be adjusted. A temporary measure is to adjust the solution flow by throttling the generator flow valve in the line to the generator. For more detailed procedures, consult the service bulletin for your machine on how to check high boiling.

6. **Purging**. Proper purging is necessary to obtain and maintain a vacuum on an absorption system.

7. *Purge operation*. Water pressure, steam pressure, and water temperature must be within recommended limits to insure satisfactory operation. The steam supplied to the jets must be dry. Operate the jets with the bleed petcock open at all times. When jets are operating properly, the first stage will run hot, the second stage warm or cool. When air is being handled, the second stage will tend to get hot. Wet steam will cause the first stage diffuser to run cold. If too wet, the purge system will not operate. Check the circulation of seal water through the seal chambers. If water is circulating through the seal chambers, there will be an overflow of water from the standpipe. If the purge unit stops because of salinity indicator operation, you must immediately close the machine purge valve. Shut off the steam supply to the steam jets and open the reset switch to shut off the alarm. If lithium bromide should pass into the purge water tank, the water should be drained and the tank flushed; also flush the steam jets and condenser. Clean water can be introduced in the pressure tap between the purge valve and the first stage of the purge unit. Resume normal operation by filling



(Courtesy Carrier Corporation)

Figure 31. Jet purge unit.

the tank, bleeding the pump, and closing the reset switch.

8. *Jet purge.* On some systems, the jet purge, shown in figure 31, has been adapted to the unit. It is entirely automatic and provides a source of very low pressure which is capable of removing noncondensables from the machine when required. Since noncondensables travel from high-pressure regions to low-pressure regions-generator, condenser, evaporator, absorber--the purge suction tube is located in the lower section of the absorber. The jet purge system is made up of the following components:

(1) Purge tank (12-gallon capacity).

(2) Purge pump (submersible).

(3) Jet evacuator (operates on the venturi principle).

(4) Purge valve (usually operated by a hydromotor).

(5) Adjustable drip tube (keeps solution in purge tank at 53 percent).

(6) Purge cooling coil (keeps purge solution at a low temperature).

(7) Four-probe level controller (shortest probe and longest probe are safety controls).

(8) Generator purge line (allows purging of the generator during operation).

(9) Purge control switches (auto-manual, auto-off located in the control panel or center).

(10) Purge alarm light (in control panel or center to indicate high or low level). Proper purging of the system is useless unless you maintain the recommended maximum steam pressure.

9. **Machine Supply Steam Pressure**. The maximum steam pressure at the generator should never exceed the manufacturer's specifications. Excessive steam pressures may cause the solution to solidify and make it necessary to shut down the machine.

10. **Solution Solidification**. Excessive steam pressure is not the only possible cause of solution solidification. Entering condensing water at too low a temperature, an excessive air leak, improperly adjusted controls, or power failure shutting the machine off so that it cannot go through a dilution cycle may also cause this difficulty. Solidification will cause the machine to stop, but there will be no permanent damage to the machine. After the solution is desolidified, the machine may be placed back in operation, but the cause of the difficulty should be corrected.

11. A steam desolidification line is encased in the solution heat exchanger of the machine. The procedure for desolidification outlined below should be followed step by step:

(1) Close the absorber purge valve and the purge steam supply valve. This will isolate the machine from the purge unit and prevent air from entering the machine.

(2) Shut off the condensing water pump but leave the main steam supply valve open. This allows the solution to heat without vapor being condensed in the condenser.

(3) Open the manual dilution valve which will allow chilled water to enter the solution circuit and dilute the solution.

(4) Open the steam supply valve and steam condensate return valve in the desolidification line.

(5) Start the solution pump and pump the solution up to the generator; close the generator flow valve. Allow the solution to heat up in the generator; then open the generator flow valve and allow the solution to drain back to the absorber. As it begins to liquefy, the solution will start to flow. This process may have to be repeated several times before the solution has liquefied enough to permit the circulation.

(6) Put the machine back into operation by starting the condensing water pump and purge unit.

(7) The reason for solidification should be determined and corrected.

You have completed desolidification and have the absorption system operating properly. Let us now discuss shutdown procedures.

12. **Shutdowns**. Each shutdown--daily, standby, and extended-requires proper “off” sequencing of the system components to avoid damage to the machine and to keep the lithium bromide from solidifying.

13. *Daily shutdowns*. To stop a completely automatic system you must push the stop button. This will automatically close the capacity control valve and purge valve. All other components will operate for approximately 7 minutes after this short period, the machine will shut down automatically. The following procedure is recommended for daily shutdown on automatic machines with manual auxiliaries:

(1) Move the start switch to the OFF position.

(2) Shut down the purge unit.

- Close the absorber purge valve.
- Close the purge steam supply valve.
- Push the stop button on the purge control panel to stop the purge pump.

(3) Dilute the solution sufficiently to prevent solidification during shutdown.

- Open the manual dilution valve for the proper length of time. The time will range from approximately 2 to 5 minutes and must be determined by experience for each machine.
- Close the manual dilution valve after the proper interval. This valve must not be left unattended during the dilution period since too long an interval will weaken the solution and lengthen the recovery period when the machine is placed back in operation.

(4) Shut down the refrigerant and chilled water circuit

- Shut down the refrigerant water pump.
- Close the valve in the refrigerant pump discharge line.
- Shut down the secondary chilled water pump.

(5) Shut down the condensing water circuit.

- Shut down the condensing water pump.
- Shut down other auxiliaries in this system such as cooling tower, cooling tower fan, and auxiliary valves.

(6) Close the main steam supply valve to shut off the steam to the machine.

(7) Shut down the solution pump. After the solution has drained from the generator back to

the absorber, the solution circuit will be ready for startup. It is not necessary to close either of the solution valves.

14. *Standby shutdown*. This type of shutdown is used at an installation where it is not necessary to use the machine for cooling at irregular intervals during the winter or off-cooling seasons. This procedure does not apply if freeing temperatures are expected in the machine room. The procedure is the same for daily shutdown except for the following two steps:

(1) Dilution should be sufficient to insure that solidification of the solution will not take place at the lowest temperatures expected in the machine room.

(2) The final step in the procedure is to charge the machine with nitrogen.

- Connect the nitrogen tank to the nitrogen charging valve. On some systems, the alcohol charging valve is used as the connection for charging nitrogen into the system.
- Set the pressure-reducing valve on the nitrogen tank to 18 p.s.i.g. This is the maximum allowable pressure that may be used on the machine. Higher pressures will cause leakage at the pump seals.
- Open the nitrogen valve on the nitrogen tank and allow the nitrogen to enter the machine. Observe the pressure on the solution pump discharge gauge. When this gauge reads 3 to 5 p.s.i.g., close the nitrogen valve and remove the nitrogen charging line.

15. *Extended shutdown*. When the machine is to be placed out of service for an extended length of time, as during the winter, there are many special services which may be required to protect the equipment from freezing temperatures. The procedures are the same as for daily shutdown except for the following additional services:

(1) The solution must be diluted enough to insure against solidification at the lowest expected temperatures in the machine room. To do this, put the machine through three dilution cycles before it is shut down.

(2) Store the solution in the generator by closing the strong valve and running the solution pump until the solution is pumped from the absorber into the generator. Then close the diluted solution valve before shutting off the solution pump.

(3) The machine is charged with nitrogen to prevent air from getting into the machine as outlined in the procedure for standby shutdown.

(4) Drain all the chilled water from the machine and other equipment. Leave all the drains open: except the one from the machine proper.

(5) Drain all the condensing water from the machine and other equipment and leave the drains open.

(6) Drain the water from the purge condenser shell by opening the drain connection on the bottom of the purge condenser.

(7) Drain all the water from the purge condenser coil by removing the tubing between the water jet piping and purge condenser coil.

(8) Drain all the water out of the seal tank by opening the drain connection in the bottom of the water seal tank.

(9) Drain all the water out of the water sea lines and the pump seal chambers by opening the petcock located in the line in the bottom of the pump seal chambers.

(10) Drain all the steam traps and steam drop legs.

16. Most maintenance is performed while the system is shut down. Let us now discuss maintenance of absorption air-conditioning systems.

8. Maintenance

1. The maintenance procedures listed in this section are carried out at time intervals listed in the manufacturers' service manuals. We will not set any time interval because it varies with equipment models, and your particular SOP will outline this information. We will discuss annual maintenance because most manufacturers' handbooks list the same tasks to be performed at that time.

2. **Checking Vacuum**. Before starting the machine, you should check it to see if air has leaked into the unit while it was shut down. Open the valve in the line from the absorber to the manometer and determine the pressure in the machine. Figure 32 illustrates a manometer reading. Take the temperature of the machine room and locate the corresponding pressure on the chart in figure 33. If the pressure reading in the machine is more than 0.1 inch of mercury higher than the pressure located on the curve, then there is air in the machine. This should be noted on the daily log sheet. If the condition recurs on the next two or three startups, the machine should be shut down as soon as possible and tested for leaks. Air leakage will cause corrosion inside the machine, and over a period of time will result in serious trouble and shorten the life of the equipment.

3. **Checking Mechanical Pump Seals**. The mechanical pump seals, as shown in figure 34, should be checked for leakage before starting the machine. Close the petcocks in the water lines to the pump seal chambers. Observe the readings of the compound pressure gauges in the water lines between the petcock and the pump seal chambers. If the gauge shows a vacuum, this is

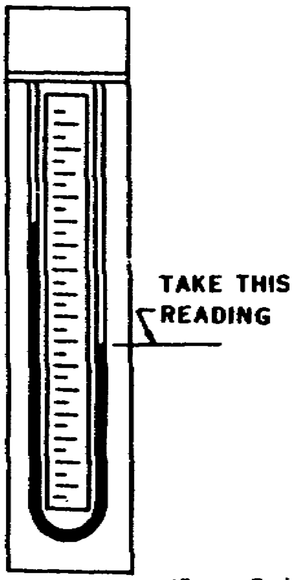


Figure 32. Absorber manometer.

an indication of a leaking seal. If only a small amount of seal water has been lost, the leak is small and the machine may be placed in operation; but the seal should be replaced at the first opportunity. If a large amount of seal water has been lost, then the seal should be replaced before the unit is put into operation.

4. **Flushing Seal Chamber**. Flushing the seal chamber is recommended for lengthening the life of the seals. Approximately 15 minutes after the machine is stated and the solution has concentrated, drain approximately 1 quart of water out of each seal chamber by use of drain petcocks located on each chamber. This is necessary to prevent the buildup of solution concentration in the chamber by the solution that may leak past the seal faces. Make sure that the drain water is replaced, since continually draining water would result in a loss of evaporator water.

5. **Checking Water in Evaporator Sight Glass**. Before starting the machine, the water level in the evaporator sight glass should be checked. If the water level is the same as when the machine was shut down, the condition indicates that there is no leakage. If the level is higher, then chilled water has leaked back into the machine. The machine should not be started under these conditions, since it is possible to lose the solution charge. Consult the instructions for the machine to cover this situation.

6. **Checking Absorber for Presence of Water**. Turn on the light at the absorber bull's-eye. Look into the absorber section through the inspection hole opposite the light. No water should be visible. If water is visible it has leaked into the section from the chilled water or seal water system. Under these conditions, the machine should not be started since it is possible to lose the solution charge. Consult the instructions for the machine to cover this situation.

7. **Adding Octyl Alcohol to Solution**. Once a week, about 6 ounces of octyl alcohol should be added to the solution circuit while the machine is running. This cleans the outside of the tubes in the generator and absorber and improves their efficiency in transferring heat. The procedure is as follows:

(1) Pour about 8 ounces of octyl alcohol in a glass container.

(2) Hold the container under the alcohol charging connection as shown in figure 35. The end of the charging connection must be kept close to the bottom to prevent air from entering the machine.

(3) Slowly open the charging valve and observe the alcohol level as it is drawn into the machine. Close the valve quickly so that the level of liquid remains above the end of intake tube to prevent air from entering the machine.

8. If the alcohol is drawn rapidly into the charging connection, it indicates that the conical strainer and solution spray header are clean. A progressive decrease in the rate at which alcohol is drawn shows that these units are becoming clogged. If alcohol is not drawn into the charging connection, it is an indication that the conical strainer is clogged. In this case, the conical strainer should be removed and cleaned at the next shutdown. If the condition still persists, it will be necessary to remove and clean the solution spray header.

9. **Cleaning Purge Steam Jet**. This is an important part of the maintenance since the purge unit must be kept in good operating condition to maintain efficiency of the machine. The following procedures will apply to both single- and two-stage steam jets:

(1) Check to be sure that the absorber purge valve (item 1 in fig. 36) is closed.

(2) Close the purge steam supply valve (item 2).

(3) Remove the steam jet cap.

(4) Use a piece of thin wire through the top of the steam jet to loosen any dirt in the nozzle.

(5) Open the purge steam supply valve to blow out loosened dirt and then close the valve.

(6) Replace the steam jet cap.

10. **Checking Evaporator Water Circuit for Lithium Bromide**. While the quantity of solution does not formally change, a high boiling level in the generator may force solution into the evaporator water circuit. A solution test kit must be

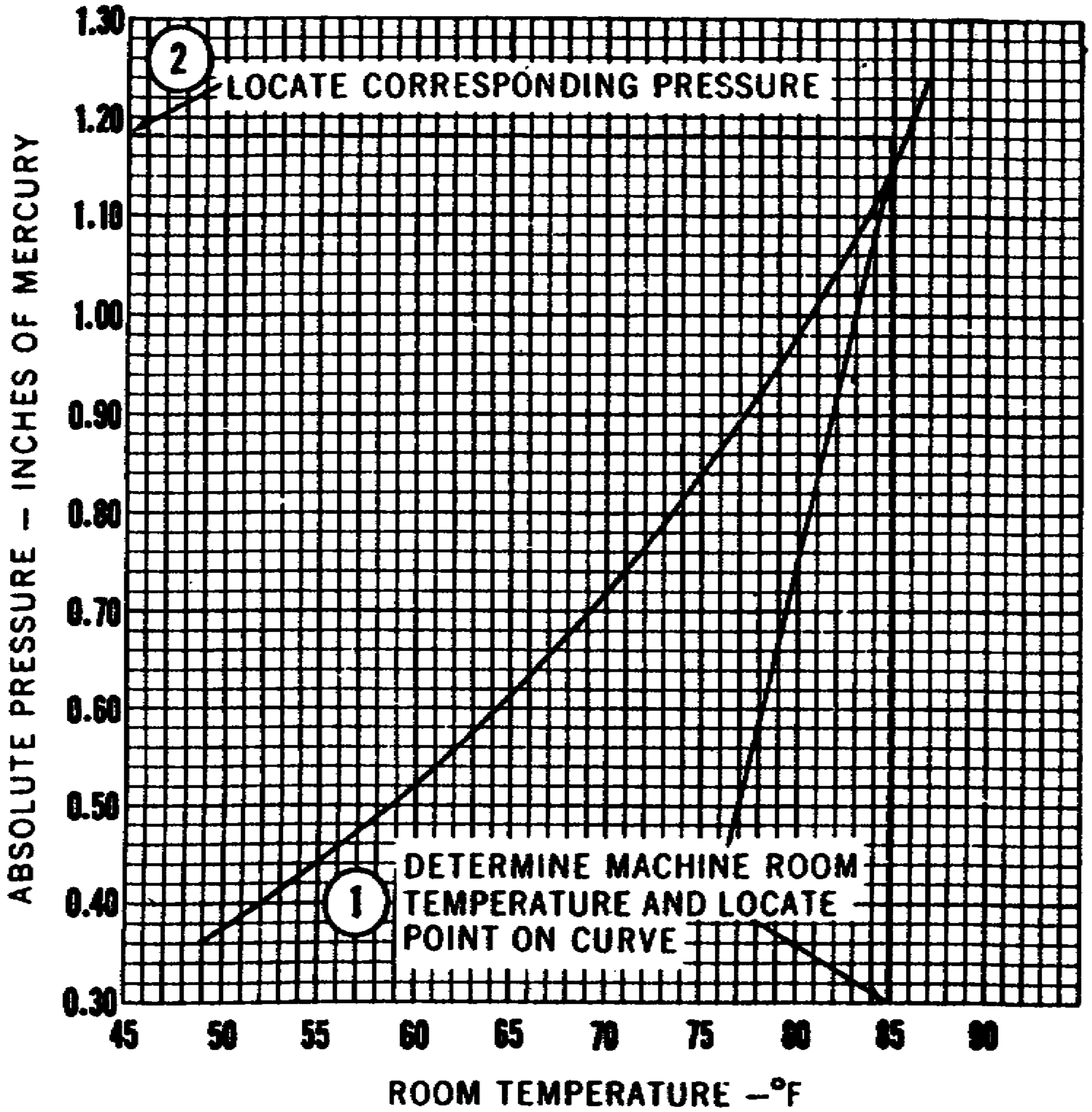


Figure 33. Pressure and temperature curve.

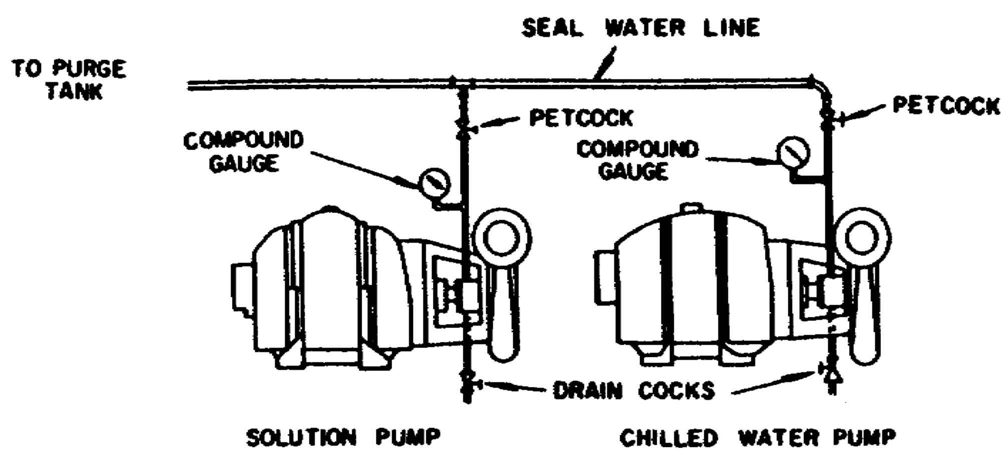


Figure 34. Seal water system.

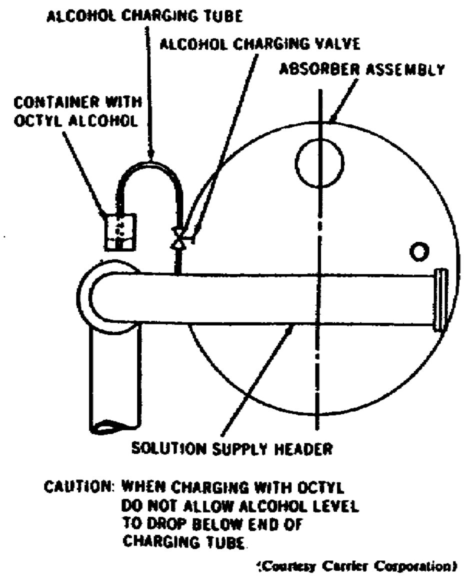


Figure 35. Octyl alcohol charging.

used to detect and measure the percentage of lithium bromide in the evaporator water. The test kit contains three bottles labeled No. 1, No. 2, and No. 3. No. 1 contains an indicator solution, No. 2 contains silver nitrate, and No. 3 is a standard solution of lithium bromide. The test kit is used as follows:

(1) Place ten drops of evaporator water sample from the system into a clean bottle.

(2) Add three drops of No. 1 to the sample.

(3) Count the number of drops of No. 2 solution necessary to turn the sample a permanent red. Record the number of drops of No. 2 used.

(4) Place ten drops of the standard solution, No. 3, in a clean bottle.

(5) Add three drops of No. 1 solution.

(6) Count the number of drops of No. 2 necessary to give a permanent red. Record the number of drops.

11. The standard sample of lithium bromide is a 1-percent solution. By comparing the number of drops of solution No. 2 required to turn the

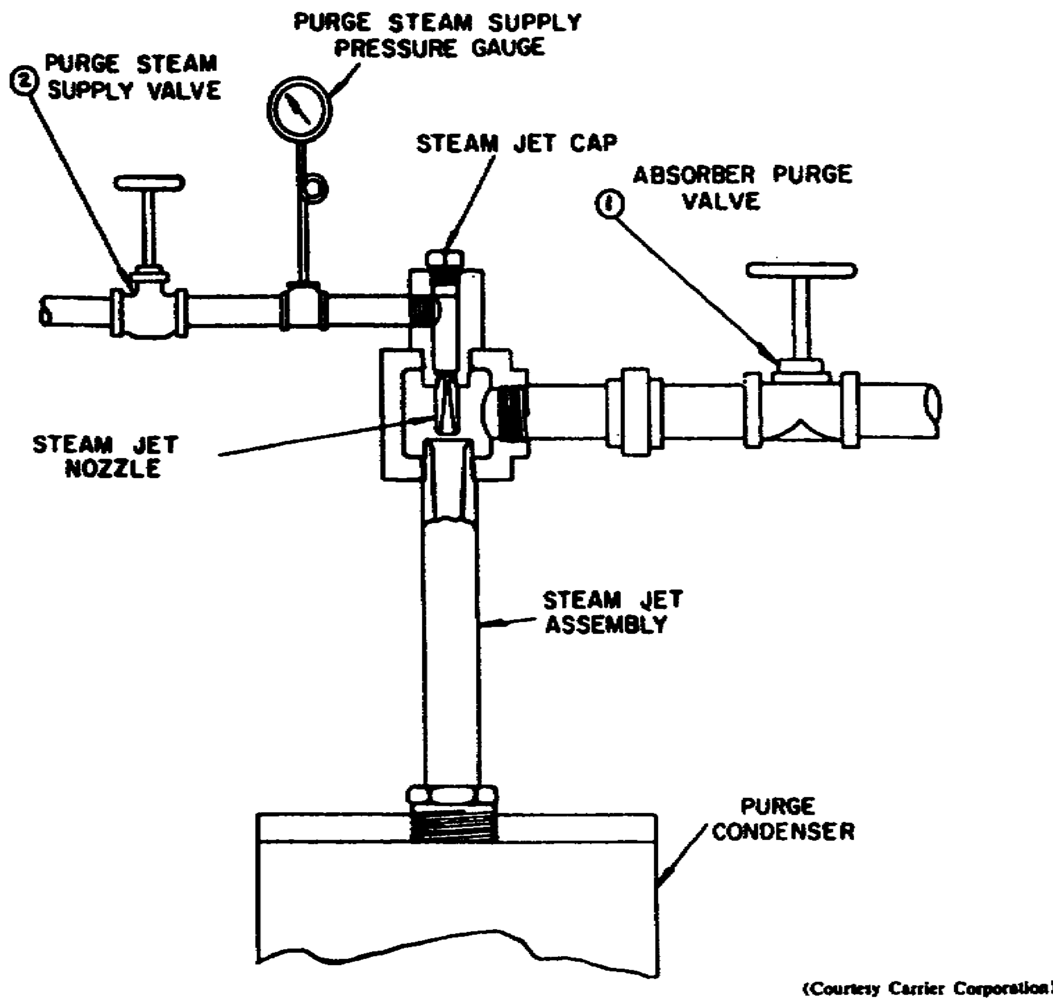


Figure 36. Steam jet purge.

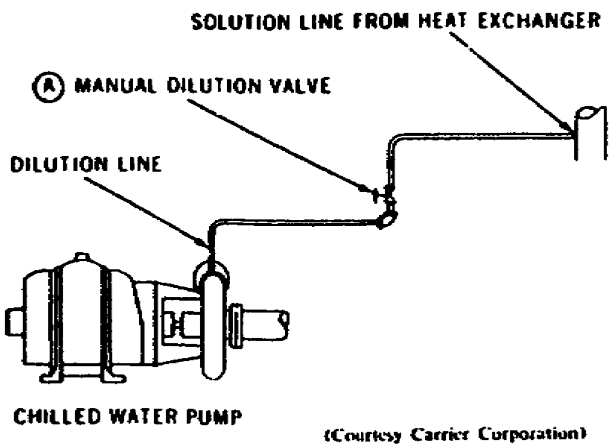


Figure 37. Manual dilution.

evaporator water sample red with the number of drops required to turn the standard red, the percentage of lithium bromide can be determined. If the evaporator water sample requires less of No. 2 than the standard, then it contains less than 1 percent of lithium bromide. If the test shows the lithium bromide content of the evaporator water to be greater than 1 percent, it should be reclaimed.

12. **Reclaiming Solution**. The lithium bromide is reclaimed by passing evaporator water into the solution circuit while the machine is in operation. The length of time required for reclamation will be determined by the amount of salt in the evaporator water circuit. The capacity of the machine will be partly reduced during this period. The process should be continued until the test shows less than one-half of 1 percent. The procedure for reclaiming solution is as follows:

(1) Crack the manual dilution valve, item A in figure 37, and feed water slowly into the solution circuit.

(2) Check the boiling level through the generator bull's-eye sight glass. If the light cannot be seen, the boiling level is too high. Bring the boiling level down by slightly closing the dilution valve until the light can be seen.

(3) Continue the process until the test shows less than one-half of 1 percent. This may take anywhere from a few hours to several days, depending on the amount of salt in the evaporator water circuit.

13. **Annual Maintenance**. Before annual maintenance is started, the machine should be shut down and charged with nitrogen as outlined in the procedure for extended shutdown. The following paragraphs are arranged in the same sequence as the work would normally be performed.

14. *Cleaning lithium bromide solution.* To clean the lithium bromide solution, it must be removed from the machine as follows:

(1) Open the valves in the solution line to and from the generator; this will drain the solution into the absorber section.

(2) Attach a suitable rubber hose to the discharge connection of the solution pump.

(3) Close the valves in the solution to and from the generator and close the valve in the vapor condensate return line. This isolates the generator from the absorber.

(4) Start the solution pump and pump the solution into drums. The pump should shut off automatically when the absorber is empty.

(5) Remove the plug in the solution inductor to drain the piping below the absorber.

NOTE: The solution in the drums should be allowed to stand for 2 or 3 days to allow the dirt to settle.

15. *Cleaning absorber sight glass.* The bull's-eye sight, evaporator tank sight and absorber reflex glasses should be carefully removed and cleaned. Cracked glasses or those with collected foreign matter that cannot be cleaned should be replaced. New gaskets should be used when the glasses are reinstalled.

16. *Cleaning solution strainer.* The procedure for removing and cleaning the conical solution strainer is as follows:

(1) Remove the nuts holding the solution supply header.

(2) Remove the nuts and bolts in the flange connection to the solution piping.

(3) Remove the solution supply header. Figure 38 illustrates the solution supply header.

(4) Remove the bolts holding the blank flange on the solution supply header.

(5) Carefully remove the strainer and clean it by flushing it with water.

(6) Replace the strainer and use a new gasket under the blank flange. Be sure that the flange faces are clean so that the flange will seal properly when bolted back in place. Do not replace the supply header until the spray header has been removed and cleaned.

17. *Cleaning solution spray header.* If the supply header has not been removed, proceed with

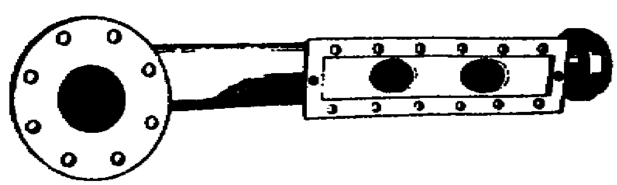


Figure 38. Solution supply header.

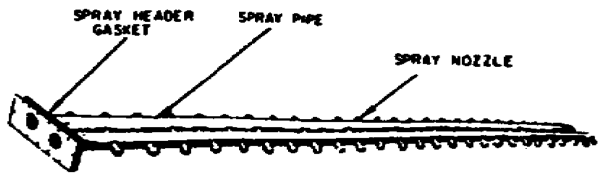


Figure 39. Solution sprayheader.

steps (1), (2), and (3) in the preceding paragraph. When this has been done, remove the solution spray header, being extremely careful that the spray nozzles do not strike the sides of the opening. Clean it by flushing. Any nozzles that are not clear should have the nozzle cap removed and cleaned individually. The old gasket material should be thoroughly removed from the spray header and a new gasket used when it is ready for reassembly. A solution spray header is shown in figure 39.

18. To install the spray header, slide it back through the opening until it is 2 inches from the far end. Remove the plug from the absorber at the end opposite to the header opening. Insert a rod through this hole and lift the end of the spray header so as to guide it through the last couple of inches into its proper position. Install the supply header, using a new gasket. Replace the plug in the far end of the absorber.

19. *Cleaning chilled water spray header.* The chilled water spray header is removed and cleaned by the same procedure as just outlined. However, even more care must be exercised in handling this header since it is possible not only to damage the nozzles but, if the header is allowed to tip, the eliminator plates may be bent. These are thin plates like the fins in an automobile radiator which when bent will lose their effectiveness. Clean off the old gasket material and install a new gasket before replacing the header on the machine. A plug must be removed from the opposite end as before so that a guide rod can be used on the far end of the header.

20. *Cleaning primary purge connections on absorber.* Clean the primary purge connections on the absorber by removing the plugs in the T connections at the primary purge line and cleaning the line with a wire or nylon brush. Only a small amount of water should be used to wash out this area. Replace the plugs after the cleaning operation is completed.

21. *Inspection of vacuum type valves.* All vacuum type valves should have their bonnets removed and the diaphragms checked for cracks or signs of wear which might indicate a future failure. Following is a list of the different vacuum type valves used in an absorption system:

Purge valves
Solution valve
Manual dilution valve
Chilled water makeup valve
Vapor condensate return valve
Absorber manometer valve
Solution charging valve
Chilled water valves

22. Although proper service will cause some diaphragms to last longer, it is considered good maintenance practice to replace all diaphragms every 2 years. This helps to prevent a breakdown or an interruption of service during the cooling seasons.

23. *Checking generator sight glasses.* The generator overflow sight glass and the generator bull's-eye sight glasses should be removed and cleaned. Glasses that are damaged should be replaced. New gaskets should always be used when the glasses are reinstalled.

24. *Cleaning water seal system.* The entire water seal system should be inspected and cleaned according to the following procedure:

(1) Open the drain connections on the bottom of the water seal tank and drain the water.

(2) Open the petcocks on the bottom of the pump seal chambers and drain the water from the lines and chambers.

(3) Disconnect the water seal lines between the water seal tank and the pump seal chambers and clean them by reverse flushing with water. Use compressed air to blow out the lines after flushing.

(4) Inspect and clean all the pipe connections.

(5) Clean the purge tank and flush it to remove the loosened dirt.

(6) Reinstall the water seal lines.

25. *Cleaning absorber and condenser tubes.* The absorber and condenser tubes should be cleaned at least once a year. More frequent cleaning may be necessary as indicated by a steady rise in vapor condensate temperature during the season. A steady decrease in temperature of the condensing water leaving the machine may also indicate scaling. This condition may be further confirmed by inspection of the thermometer well in the condenser water line leaving the machine. The presence of scale here is associated with scaling in the tubes. Cleaning should be done as follows:

(1) Remove both headers from the absorber and condenser.

(2) Inspect the tubes to determine the type of scale.

(3) Soft scale may be removed by cleaning with a nylon bristle brush. Metal brushes of any kind which might scratch the surface must never be used. Hard scale which cannot be removed

with a brush will require treatment with suitable chemicals.

26. *Cleaning condensing water system.* The procedures for cleaning the condensing water system of an absorption refrigeration system are similar to the procedures used to clean the condensing water systems on compression refrigeration systems.

27. *Cleaning salinity indicator.* The salinity indicator should be removed and the electrodes cleaned of accumulated deposits.

28. **Vacuum Testing Machine for Leaks**. After completing the maintenance work, the machine should next be tested for leaks according to the following procedures.

(1) Close all valves except the vapor condensate valve which must be left open.

(2) Start the water jet on the purge unit and open the absorber purge valve and the evacuation valve. Operate the purge unit until a vacuum of at least 25 inches of mercury is read on the manometer. Record this reading.

(3) Shut down water jet and close the valves.

(4) Check the manometer vacuum 24 hours later. The maximum allowable loss is one-tenth of an inch of mercury in 24 hours. If the loss is within limits, then charge the machine with solution. A machine that does not meet the vacuum requirements must be tested for leaks with a halide leak detector.

29. **Halide Leak Detector Test**. The procedures for testing with the halide leak detector are as follows:

(1) Make sure that all valves are closed except the vapor condensate valve.

(2) Charge the machine with Refrigerant-12 to a pressure of 5 p.s.i.g. Use the refrigerant type charging valve on the absorber. Read the charging pressure in the machine on the solution pump pressure gauge.

(3) After charging with Refrigerant-12, the machine should be further charged to 18 p.s.i.g. with nitrogen, using the procedure previously given under Extended shutdown.

(4) Test the machine for leaks with a halide leak detector. Stop all the leaks that are found.

(5) Perform another vacuum test to determine that the machine is now satisfactory.

30. **Charging the Machine**. After maintenance is completed and the machine passes a satisfactory vacuum test, the machine should be charged with solution. The machine must be kept charged with solution at all times except while maintenance is being done. Storage drums used to hold the solution should be moved as little as possible so as not to disturb dirt which has settled to the bottom. Figure 40 illustrates the method of solution charging.

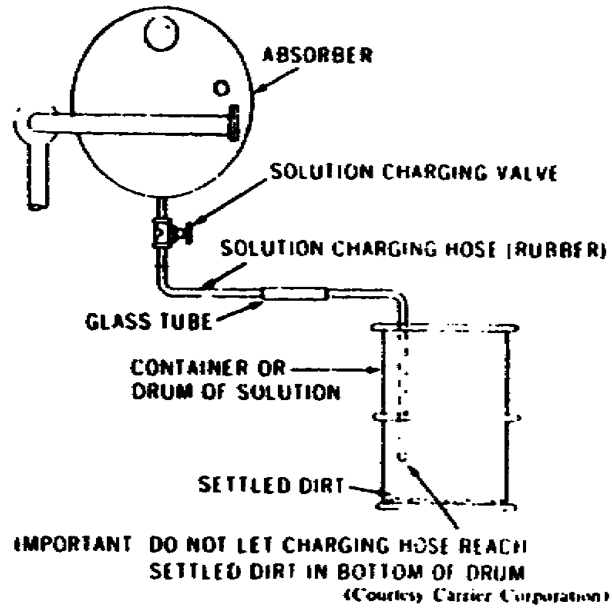


Figure 40. Solution charging.

(1) Start the water jet on the purge unit and open the purge valve on the absorber.

(2) Continue purging until a vacuum reading of 25 inches of mercury is obtained on the manometer. Close the valves and shut off the jet when the vacuum is satisfactory.

(3) Connect the hose to the solution charging valve and place the other end of the hose into the drum of solution. Do not let the hose touch the bottom of the drum since this would draw up dirt that had settled there.

(4) Open the solution charging valve and allow the solution to enter the machine.

(5) After all of the solution has been transferred into the machine, close the solution valve in the line from the generator and open the solution valve in the line to the generator.

(6) Start the solution pump which will pump all the solution up to the generator. When the pump shuts off, close the valve in the line to the generator. This last step is necessary because all of the solution should be stored in the generator.

(7) If the machine is to remain out of service, then it should be charged with nitrogen as previously outlined.

31. **Troubleshooting**. Troubleshooting and correction are two of your most important duties. We have discussed the operation and service that you perform on absorption systems. This information, coupled with that in tables 1-18, should give you the knowledge you need to carry out your assigned tasks.

TABLE 11

SOLIDIFICATION DURING STARTUP

Fault	*Cause*	*Remedy*
Lithium bromide solidifies at startup.	Condenser water too cold.	Reset cooling tower bypass valve to design conditions.
	Air in machine.	Set capacity AUTO–OFF switch to OFF position and purge machine.
	Improper purging (jet purge).	(1) Check purge valve. Must be in AUTO position. (2) Check solution temperature in purge tank. Should be 75° F. or less. If not, purge cooling coil may be fouled or not enough flow through cooling coil. Check shutoff valves and chilled waterflow.
	Failure of strong solution valve.	Replace diaphragm.

TABLE 12

SOLIDIFICATION DURING OPERATION

Fault	*Cause*	*Remedy*
Lithium bromide solidifies during operation.	Condensing water too cold.	Reset cooling tower bypass valve to design conditions.
	Steam pressure or hot water temperature above design.	Reset to design conditions.
	Too low vapor condensate temperature.	Open manual condenser bypass valve.
	Machine requires octyl alcohol.	Add octyl alcohol.
	Improper purging.	Check purge cycle; should be 1–3 hours.
	Air leakage.	Leak test machine.
	Seal leakage.	Close seal tank makeup valve and note drop of tank level overnight. If level drops, change leaky seal.

TABLE 13

LOW CAPACITY

Fault	*Cause*	*Remedy*
Low capacity.	Air in machine.	Find and repair leak. Purge the machine.
	Condenser tubes dirty. (Can be noted by continually rising vapor condensate temperature.)	Clean tubes and take corrective action in water treatment methods.
	Improper purging.	Check purge cycle; should be 1–3 hours.
	Machine needs octyl alcohol.	Add octyl alcohol.
	Improper setting of capacity control valve.	Reset capacity control valve to design temperature by turning control point adjuster down.
	Insufficient condensing waterflow or too high temperature.	(1) Reset cooling tower bypass valve to design temperature. (2) Check operation of tower fan. (3) Check condenser strainer.
	Solution temperature leaving generator below 220° F.	(1) Low steam pressure. (2) Low hot water temperature. (3) Plugged steam strainer or trap.
	Overflow tube cold.	Correct the evaporator water charge.

TABLE 14
Shutdown on Safety Control

Fault	*Cause*	*Remedy*
Machine shuts down on safety control.	Motor overloads.	Reset all motor overloads and check reason for failure.
	Shutdown on low temperature cutout.	(1) Check setting. Low temperature cutout should be 34° F. (2) Capacity control valve may be set too low. Turn up control point adjuster.

TABLE 15
Purge Shutdown

Fault	*Cause*	*Remedy*
Purge shuts down.	Capacity control valve less than ¾ open.	Normal.
	Level safety trips with red light on.	Liquid level in purge tank above high level cutout or below low level cutout. Clean 4-probe assembly and correct the level in tank.

TABLE 16
Solidification During Shutdown

Fault	*Cause*	*Remedy*
Solidification during shutdown.	Dilution cycle less than 7 minutes.	Lengthen dilution cycle. Desolidify.
	No load during dilution cycle.	Establish load while shutting down machine. If no load is available during shutdown, manually open reclaiming valve while shutting down. Desolidify.
	Condensing water pump off during dilution cycle.	Check condensing water pump. Desolidify.
	Improper closing of capacity control valve.	Check valve closure. Desolidify.

TABLE 17
Suspected Air Leak

Fault	*Cause*	*Remedy*
Suspect air leakage.	Perform standing vacuum test.	Leak test if leakage is indicated.
	Perform running vacuum test.	Close purge valve. Machine should run 3 days without solidification. If not, leak test.

TABLE 18
Loss of Vacuum at Shutdown

Fault	*Cause*	*Remedy*
Loss of vacuum at shutdown.	Purge valve failed to seat. Noted by loss of level in purge tank.	Free purge valve.
	Check valve failed to seat in seal tank makeup line.	Replace check valve ball.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. While you are performing your hourly check of the absorption system, you notice that the condenser waterflow has dropped off and that the system is operating at a reduced capacity. What component should you troubleshoot and where is the component located? (Sec. 5, Par. 2)

2. The refrigerant used in this system is _____________________ and the absorbent is ______________. (Sec. 5, Par. 3)

3. What will occur within the system when heat is not supplied to the generator? (Sec. 5, Par. 5)

4. (Agree)(Disagree) The heat exchanger heats the strong solution. (Sec. 5, Par. 5)

5. During a routine inspection you find that the supply air pressure to the chill water thermostat is 3 p.s.i.g. What component is affected? How does this component affect the operation of the system? (Sec. 5, Pars. 6 and 7)

6. A 2° chilled water temperature change will cause the branch line pressure to change _____________ p.s.i.g. (Sec. 5, Par. 7)

7. What will occur if the feeler bulb of the concentration limit thermostat is broken? (Sec. 5, Par. 8)

8. The plant operator submits the following complaint:
   (1) The chill water temperature is 57° F. (The design temperature is 45° F.)
   (2) The off-run-start switch is in the RUN position.
   (3) The solution pump is off and the last discharge pressure reading was 36 p.s.i.g.

   What has occurred within the system to cause a shutdown? How do you restart the unit? (Sec. 5, Pars. 9 and 10)

9. Why are the solution and chilled water pumps equipped with mechanical seals? (Sec. 5, Par. 14)

10. (Agree)(Disagree) The float control in the solution pump water seal tank controls makeup water to the tank automatically. (Sec. 5, Par. 15)

11. The primary difference between daily startup and startup after standby shutdown is that __________________. (Sec. 6, Par. 3)

12. The evaporator pump is surging. What caused this surging? (Sec. 7, Par. 3)

13. A solution level in the absorber of two-thirds (Sec. 7, Par. 4)

14. When is the solution boiling level in the generator set? (Sec. 7, Par. 5)

15. What will occur when air is being handled by the purge unit? (Sec. 7, Par. 7)

16. Excessive steam pressure will cause _____________________. (Sec. 7, Par. 9)

17. Where would you connect the nitrogen tank if the system did not have a nitrogen charging valve? (Sec. 7, Par. 14)

18. To dilute the solution for extended shutdown, you must put the system through ______________ dilution cycles. (Sec. 7, Par. 15)

19. How can you determine whether air has leaked in the machine during shutdown? (Sec. 8, Par. 2)

20. Air will cause the insides of the machine to (Sec. 8, Par. 2)

21. How do you check a mechanical pump seal for leaks? (Sec. 8, Par. 3)

22. Why should you flush the seal chamber after startup? (Sec. 8, Par. 4)

23. An increased water level in the evaporator after shutdown indicates that __________________. (Sec. 8, Par. 5)

24. Why is octyl alcohol added to the solution? (Sec. 8, Par. 7)

25. How would you correct the following malfunction? The octyl alcohol charging valve is open but the alcohol is not being drawn into the machine. What would you do if this situation occurred frequently? (Sec. 8, Par. 8)

26. The following complaint has been received at your shop. The steam jet purge unit on an absorption system is operating but is not purging air that is present in the absorber. What is the most probable cause and how would you correct it? (Sec. 8, Par. 9)

27. Bottle number 2 in the solution test set contains _______________. (Sec. 8, Par. 10)

28. How many drops of indicator solution do you add to the solution sample? (Sec. 8, Par. 10)

29. The standard sample (bottle No. 3) is a ________________ percent solution. (Sec. 8, Par 11)

30. During an evaporator water solution test, more silver nitrate was needed to turn the sample red than the standard solution. What does this indicate? How is this situation remedied? (Sec. 8, Pars. 10 and 11)

31. What determines the length of time needed to reclaim the evaporator water? (Sec. 8, Par. 12)

32. How long does it take for the dirt in the solution to settle out when the solution is placed in drums? (Sec. 8, Par. 14)

33. How is the conical strainer cleaned? (Sec. 8, Par. 16)

34. How is the purge connection on the absorber cleaned? (Sec. 8, Par. 20)

35. (Agree)(Disagree) The diaphragm is a vacuum type valve should be replaced yearly. (Sec. 8, Par. 22)

36. The operating log shows a steady increase in vapor condensate temperature. What maintenance is required? (Sec. 8, Par. 25)

37. How is soft scale removed from condenser tubes? (Sec. 8, Par. 25)

38. What is the maximum allowable vacuum loss during a vacuum leak test? (Sec. 8, Par. 28)

39. Which refrigerant is added to the system to perform a halide leak test? (Sec. 8, Par. 29)

40. List at least three possible causes of lithium bromide solidification at startup. (Sec. 8, table 11)

41. How can you make sure that a seal is leaking? (Sec. 8, table 12)

Centrifugal Systems

FEW PEOPLE realize the importance of the refrigeration specialist in this age of aerospace weapons systems. For them, refrigeration has nothing to do with launching a missile and reaching the moon. However, we know that without control of the environment of a launch complex the military goals of defense and space conquest would never be achieved.

2. The centrifugal refrigeration system is often used in such weapons systems as Titan, Bomarc, and SAGE. In this chapter we will discuss the operation of this system, the complete refrigeration cycle, each component of the unit, and the general maintenance requirements.

9. Refrigeration Cycle

1. The centrifugal system uses the same general type of compression refrigeration cycle used on other mechanical systems. Its features are:

- A centrifugal compressor of two or more stages.
- A low-pressure refrigerant known as Refrigerant-11. Approximately 1200 pounds of refrigerant are required for fully charging a centrifugal machine.

2. An economizer in the liquid return from the condenser to the evaporator acts as the expansion device. You can compare the economizer to the high side float (metering device) used on older model refrigerators. The use of this piece of equipment reduces the horsepower required per ton of refrigeration cycle. This increase in efficiency is made possible by using a multistage turbocompressor and piping the flash gas to the second stage.

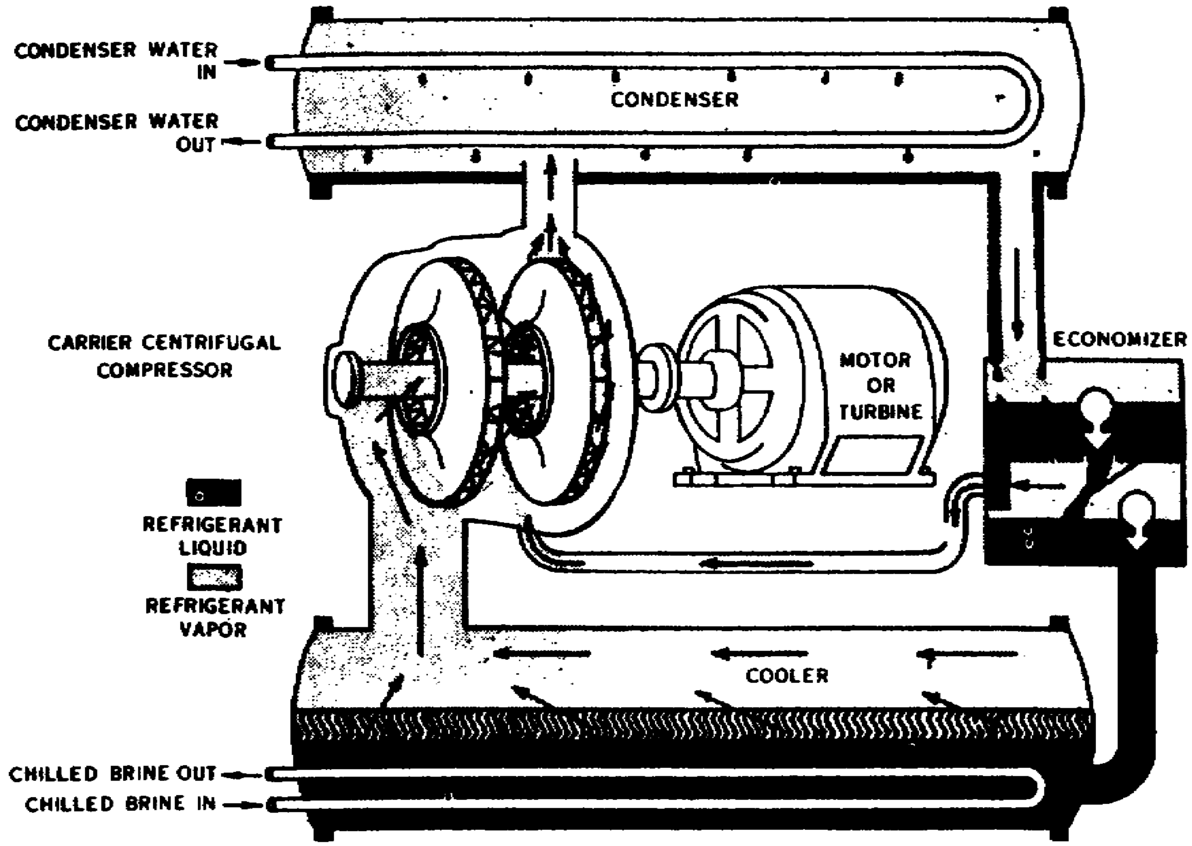
3. A schematic of the centrifugal cycle is shown in figure 41. We will begin the cycle at the evaporator. The chilled water flowing through the tubes is warmer than the refrigerant in the shell surrounding the tubes, and heat flows from the chilled water to the refrigerant. This heat evaporates the refrigerant at a temperature corresponding to the pressure in the evaporator.

4. The refrigerant vapors are drawn from the evaporator shell into the suction inlet of the compressor. The suction vapors are partially compressed by the first-stage impeller and join the flash gas vapor coming from the economizer at the second-stage impeller inlet. The refrigerant gas discharged by the compressor condenses on the outside of the condenser tubes by giving up heat through the condenser tubes to the cooler condenser water. The condensing temperature corresponds to the operating pressure in the condenser.

5. The liquefied refrigerant drains from the condenser shell down through an inside conduit into the condenser float chamber. The rising refrigerant level in this chamber opens the float valve and allows the liquid to pass into the economizer chamber. The pressure in the economizer chamber is approximately halfway between the condensing and evaporating pressures: consequently, enough of the warm liquid refrigerant evaporates to cool the remainder to the lower temperature corresponding to the lower pressure in the economizer chamber. This evaporation takes place by rapid "flashing" into gas as the liquid refrigerant passes through the float valve and the conduit leading into the economizer chamber. The flashed vapors pass through eliminator baffles and a conduit to the suction side of the second stage of the compressor.

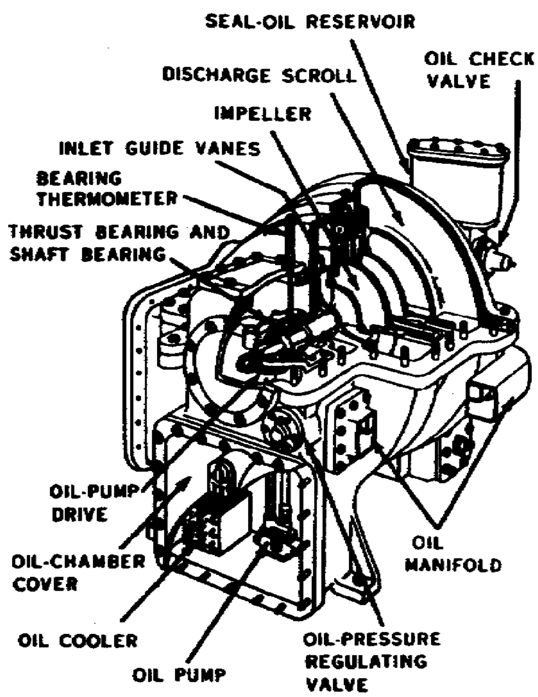
6. The cooled liquid then flows into the economizer float chamber located below the condenser float chamber. The rising level in the economizer float chamber opens the float valve and allows the liquid refrigerant to pass into the bottom of the cooler. Since the evaporator pressure is lower than the economizer pressure, some of the liquid is evaporated (flashed) to cool the remainder to the operating temperature of the evaporator. These vapors pass up through the liquid refrigerant to the compressor suction. The remaining liquid serves as a reserve for the refrigerant continually being evaporated by the chilled water. The cycle is thus complete.

7. Now that you understand the complete refrigeration



(Courtesy Carrier Corporation)

Figure 41. Centrifugal cycle.



(Courtesy Carrier Corporation)

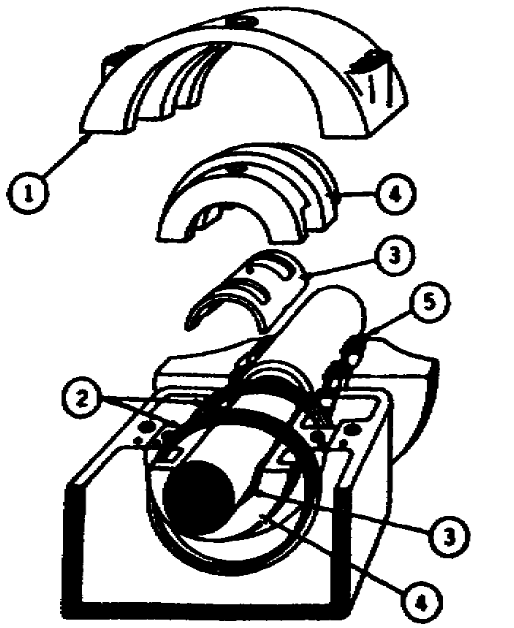
Figure 42. Compressor cutaway.

cycle, let us study the compressor in more detail.

10. Centrifugal Compressor

1. A cutaway view of the compressor is shown in figure 42. The easiest way to understand centrifugal compressor operation is to think of a centrifugal fan. Like the fan, the compressor takes in gas at the end (in line with the shaft) and whirls it at a high speed. The high-velocity gas leaving the impellers is converted to a pressure greater than the inlet. At normal speed, with R-11, the suction temperature is 65° F. below the temperature of condensation. At maximum speed, the compressor will produce a suction temperature of approximately 85° F. below the condensing temperature of R-11. Changing the speed of the compressor varies the suction temperature.

2. The compressor casing and the various stationary passages inside the compressor shaft are made of hard steel with keyways provided for each impeller. The impellers are of the built-up type. The hub disc and cover are machined steel forgings. The blading is sheet steel formed to curve backward with respect to the direction of rotation and is riveted to the hubs and covers. After assembly, the wheels are given a hot-dipped lead coating to reduce corrosion damage. The rotor



(Courtesy Carrier Corporation)

Figure 43. Bearing assembly.

assembly, consisting of the shaft and impellers, runs in two sleeve type bearings.

3. In figure 43 a thermometer is inserted in top of each bearing cover (1) for indicating temperature. Each bearing also has two large oil rings (2) to insure lubrication. The upper and lower bearing liners (3) are held in place by the upper and lower bearing retainers (4).

4. Brass labyrinths (5) between stages and at the ends of the casing restrict the flow of gas between stages and between the compressor casing and bearing chambers.

5. In operation, the pressure differential across each impeller produces an axial thrust toward the suction end of the compressor. This thrust is supported by a "kingsbury" thrust bearing at the suction end of the shaft.

6. **Compressor Lubricating System**. The entire oiling system is housed within the compressor casing and the oil is circulated through cored opening, drilled pages, and fixed copper fines. This eliminates all of the usual external lines and their danger of possible rupture, damage, or leakage. All of the oil for the lubricating system is circulated by a helical gear pump, shown in figure 44, which is submerged in the oil reservoir. The simple, positive drive insures ample oil for pressure lubricating and cooling all journal bearings, thrust bearings, and seal surfaces. The reservoir which houses the oil pump is an integral part of the compressor casing and is accessible through a cover plate on the end of the compressor. Circulating water cooling coils are fitted to the cover plate to maintain proper oil temperature.

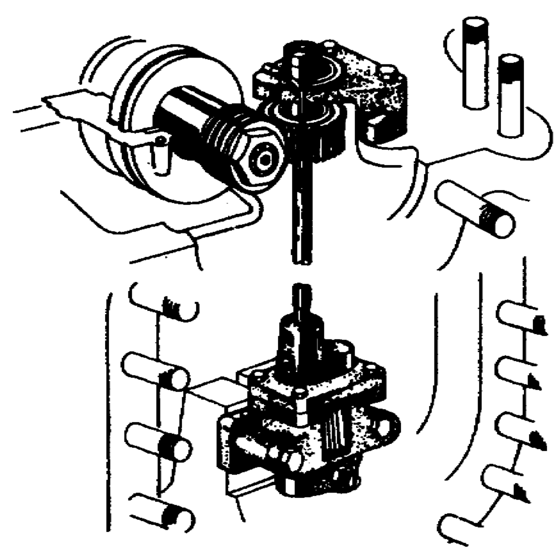
7. In general, the lubricating system (shown schematically in fig. 45) consists of the gear type oil pump, driven from the main compressor shaft and supplying oil through various connections and passages for the thrust bearing, the two shaft bearings, the oil pump worm gear drive, and for the shaft seal-with the necessary gauges and control valves to permit the system to operate automatically.

8. The oil pressure or feed circuits are as follows, according to figure 45:

- When the compressor starts, the pump (1) starts to circulate oil, which is supplied first entirely to the thrust bearing (3).
- After passing through the thrust bearing, the oiling system divides into two paths known as "A" circuit and "B" circuit.

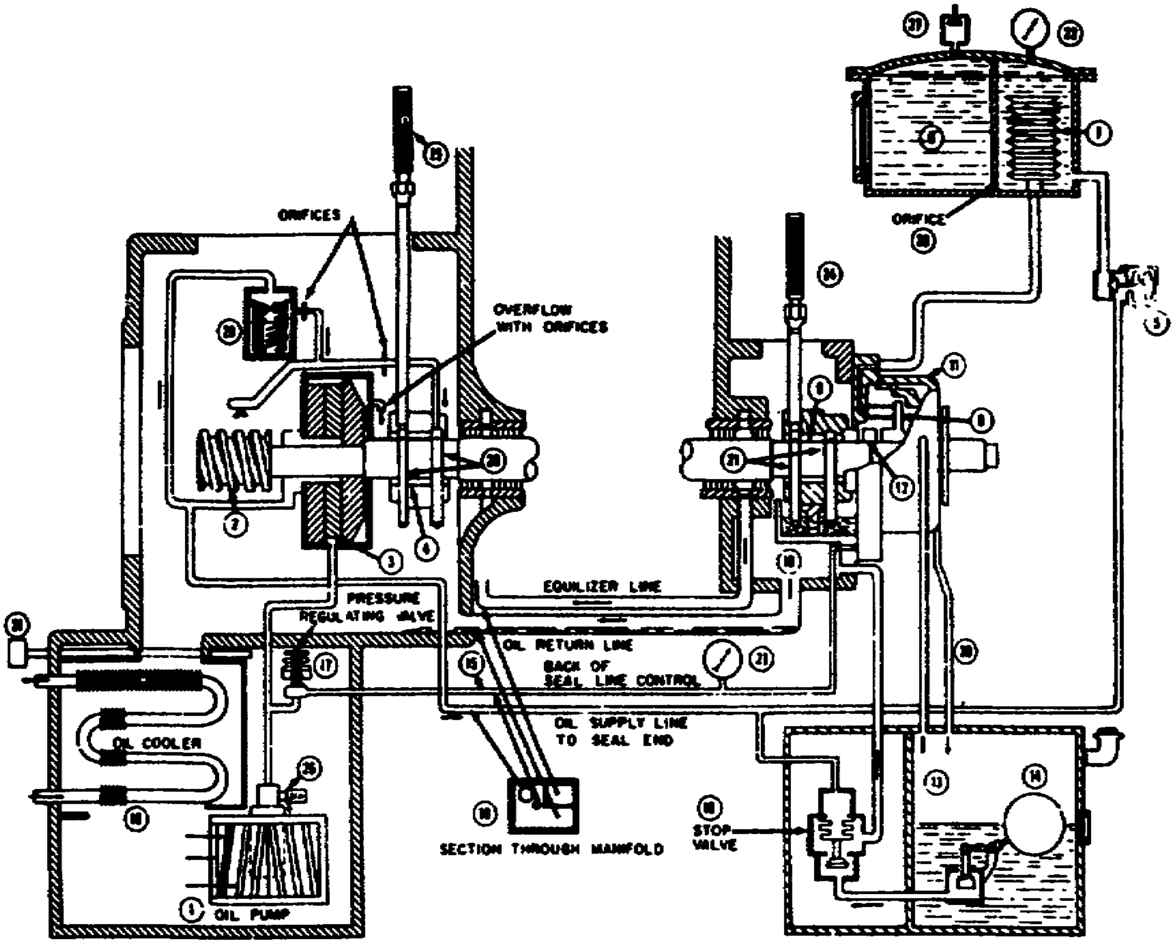
9. In the first path, the oil flows through the strainer (29) and the proper orifices to the pump gear (2) and to the rear shaft journal bearing (4). Since the thrust, rear journal bearing, and worm drive for the oil pump are all located above the oil pump chamber, the return oil merely drops back into the pump chamber from these parts.

10. In the second path, oil flows through the check valve (5) and filter (7) to actuate the shaft seal (8) and supply the front shaft journal bearing (9). Since part of the oil passes out through the front of the seal to atmospheric pressure, various valves are required in the supply lines as well as in the lines returning oil to the pump chamber. The check valve (5) does not open during compressor startup until the pump pressure reaches 8 p.s.i.g. After the valve (5) opens, the flow of oil is as described previously. If the seal oil reservoir (6) is not full, a small part of the oil passes through the orifice (28) to fill the reservoir. Oil under pressure to the seal



(Courtesy Carrier Corporation)

Figure 44. Compressor oil pump.



(Courtesy Carrier Corporation)

Figure 45. Compressor oil system schematic.

expands the seal bellows to move the stationary seal back against its stop, allowing the oil to pass through the seal in two directions: (1) inside the compressor and (2) to the atmospheric side of the shaft seal.

11. The oil passing to the compressor (vacuum) side of the seal flows to the front journal bearing (9), through two small holes in the inner floating seal ring (12) -which is located in the seal housing--to prevent unnecessary flow of oil from the vacuum side of the seal. The bearing overflow drops to the bottom of the bearing chamber (10), draining back to the oil pump chamber through the proper passage in the manifold (18).

12. The oil passing to the atmosphere is restricted by floating rings between the stationary seal and rotating seal hubs and between the housing cover and the rotating seal hub. Most of it passes directly to the atmospheric float chamber (13). The water-jacketed seal housing cover (11) cools this oil and minimizes the refrigerant loss from it. A small amount of oil passes the seal rings and is returned to the atmospheric float chamber (13) through a connection (30). From the float chamber, the oil goes through the automatic oil stop valve (16), up to the bearing chamber (10), and returns through the manifold to the oil pump chamber along with the oil overflow from the front bearing. Oil returns from the atmospheric float chamber since the pressure in the bearing chamber is always below atmospheric. This pressure, being equalized with the compressor suction through the rear shaft labyrinth, is always a vacuum during operation. From the bearing chamber, the oil flows by gravity through the manifold (18), to the oil pump chamber. The automatic stop valve (16) is provided to prevent flow of refrigerant vapor from the machine in case the pressure inside the machine during shutdown rises above atmospheric. The valve is set to open at approximately 8 pounds and is actuated by an oil pressure line taken from the oil pump discharge and, therefore, opens immediately after the compressor is started. Valve 16 also prevents outside air from entering the machine when the machine pressure is below atmospheric. This valve is necessary because the atmospheric float valve (14) is designed for level control only and is not a stop valve. Valve 17 is

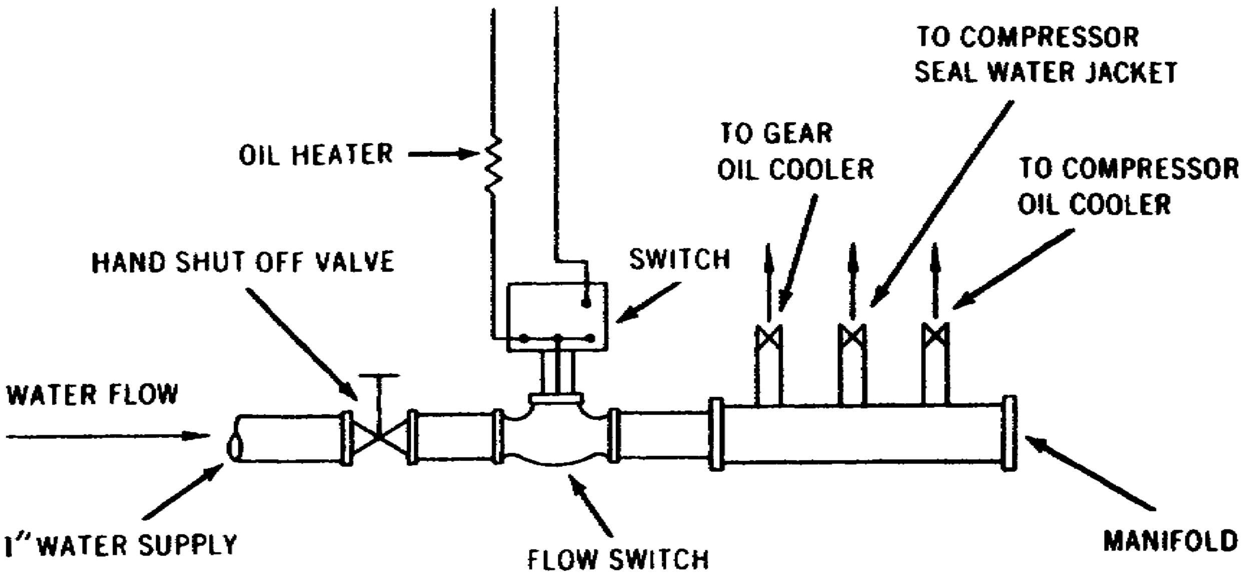


Figure 46. Compressor oil heater.

the oil pressure regulator. It is actuated by pressure "back of seal" through line 15 and controls oil pressure by returning excess oil back to the oil pump chamber.

13. Oil pressure gauges 22 and 23 on the control panel indicate the seal oil reservoir pressure and the pressure back of seal respectively. When the seal oil reservoir is full, gauge 22 indicates the pressure on the seal bellows. Gauge 23 indicates the pressure in the space between the seal and the inner floating ring or back of seal pressure which controls valve 17.

14. The air vent and vacuum breaker (27) admits atmospheric pressure during shutdown to the seal oil reservoir to maintain a head of oil on the seal. It operates as a gravity check valve.

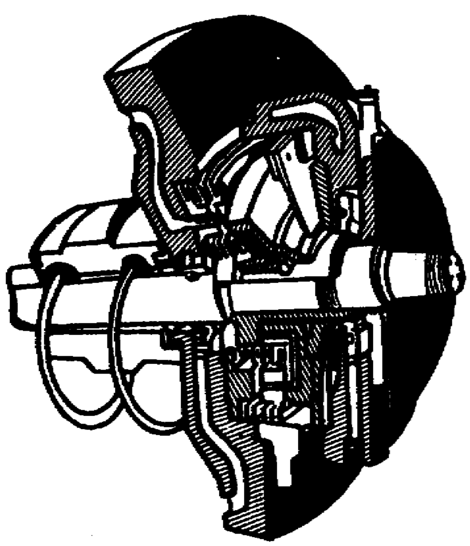


Figure 47. Shaft seal assembly.

The oil heater (31) heats the oil during shutdown to prevent excessive absorption of refrigerant by the oil. A flow switch located in the water supply to the oil cooler manifold automatically turns the heater on when the water supply is shut off by hand, and cuts the heater off when the water is turned on. A schematic diagram of the oil heater is shown in figure 46. The oil cooler (19) cools the oil as it is returned to the pump chamber during operation. Bearing thermometers 24 and 25 indicate the temperature of the shaft bearings. Oil rings 20 and 21–also shown in figure 45-bring additional oil from the bearing wells to the shaft. Relief valve 26 in the oil pump discharge line relieves any unusually high pressure that may occur accidentally, and thus protects the system against any damage.

15. **Compressor Shaft Seal**. A shaft seal is provided where the shaft extends through the compressor casing. The seal assembly is shown in figure 47.

16. The seal is formed between a ring, called the rotating scaling seat which is fitted against a shoulder on the shaft, and stationary sealing seat which is attached to the seal housing through a flexible member or bellows assembly. The contact faces on these seal seats are carefully machined and ground to make a vacuum-tight joint when in contact. A spring called the seal spring moves the stationary seal seat into contact with the rotating seal seat to make the proper seal when the compressor is shut down. A floating ring is located between the hub of the stationary sealing seat and the hub of the rotating sealing seat. A seal oil reservoir and filter chamber is attached to the compressor housing above the seal to provide oil to maintain a head of oil to the seal surfaces

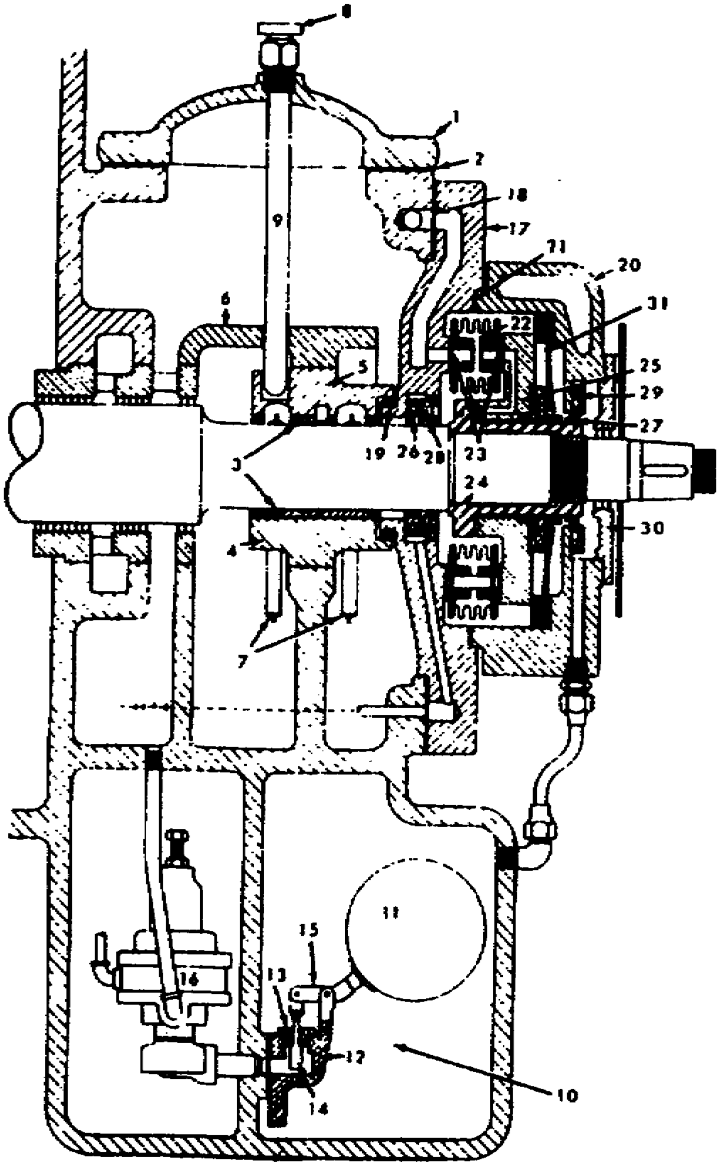


Figure 48. Diagram of compressor seal end.

during shutdown periods. The shaft seal consists of two highly polished metal surfaces which are held tightly together by a spring during shutdown, but are separated by a film of oil under pressure during operation. The positive supply of oil from the oil pump during operation and from the seal reservoir during shutdown prevents any inward leakage of air or outward leakage of refrigerant. In addition, the low oil pressure safety control will automatically stop the compressor if the oil pressure to the seal falls below a safe minimum. Figure 48 shows a cutaway diagram of the seal installed on the seal end of the compressor.

17. **Lubricant**. A high-grade turbine oil, such as DTE heavy medium or approved equal, is the type of oil recommended for centrifugal compressor usage. To be sure of specifications on grade and type of oil to use, it is advisable to refer to the manufacturer's maintenance manual.

18. If a machine is to be started for the first time or if all the oil has been drained from the unit, the following lubrication procedures are recommended:

- The machine pressure must be atmospheric.
- Remove the cover on the front bearing at the coupling end of the compressor and pour 1 gallon of oil into the front bearing level.
- Fill the seal oil pressure chamber by removing the cover.
- Remove the cover from the rear bearing and pour oil into the chamber until the indicated height is reached as recommended on the pump chamber plate.
- Fill the atmospheric float chamber through

the connection on the side of the chamber until oil shows in the sight glass.

- Pour a small amount of oil into the thrust bearing housing by removing the strainer cap and pouring oil into the strainer.

Under normal operating conditions, the following lubrication procedures are recommended:

- Replace the oil filter regularly, depending on the length of operation and the condition of the filter.
- If at any time some oil is withdrawn from the machine, replace with new oil.
- Clean and inspect the strainer in the thrust bearing at least once a year. Replace the complete oil charge at least once a year.
- After shutdown periods of more than a month, remove the bearing covers and add 1 quart of oil to each bearing well before starting.

19. To drain the oil system, allow the machine to warm up until the temperature is approximately 75° F. The machine must be at atmospheric pressure. Drain the pump chamber by removing the drain plug. Replace the plug, then drain the atmospheric float chamber in the same manner. By draining these two chambers, practically all of the oil is removed. The oil left in the bearing wells and seal reservoir is useful for keeping the bearing in satisfactory condition and as a sealing oil.

20. CAUTIONS: To keep the machine in the best operating condition, the following cautions must be observed:

- The electric heater in the oil pump chamber must be turned on during shutdown periods and must be turned off when the cooling water is turned on.
- Do not overcharge the system with oil. The oil level will fall as the oil is circulated through the system; but under normal operation, the oil level will increase approximately 7 percent in volume as the refrigerant becomes absorbed in it. The oil level in the machine will be approximately one-half glass.
- Oil can be added to the filling connection on the side of the atmospheric float chamber only while the machine is in operation and the atmospheric return valve is open.

21. Now that you have a proper knowledge of compressor operation, let's discuss the type of drive for the compressor.

11. Compressor Gear Drive

1. The gear drive is a separate component mounted between the compressor and electric motor. The gears are speed increasers required to obtain the proper compressor speed through the use of standard speed motors. The gears are of the double helical type, properly balanced for smooth operation, and pressure lubricated. The gear wheel and pinion are inclosed in an oiltight case, split at the horizontal centerline. Lubrication is from the gear type oil pump. The unit has an oil level sight glass, a pressure gauge, and an externally mounted oil strainer and oil cooler. A diagram illustrating the gear parts is shown in figure 49.

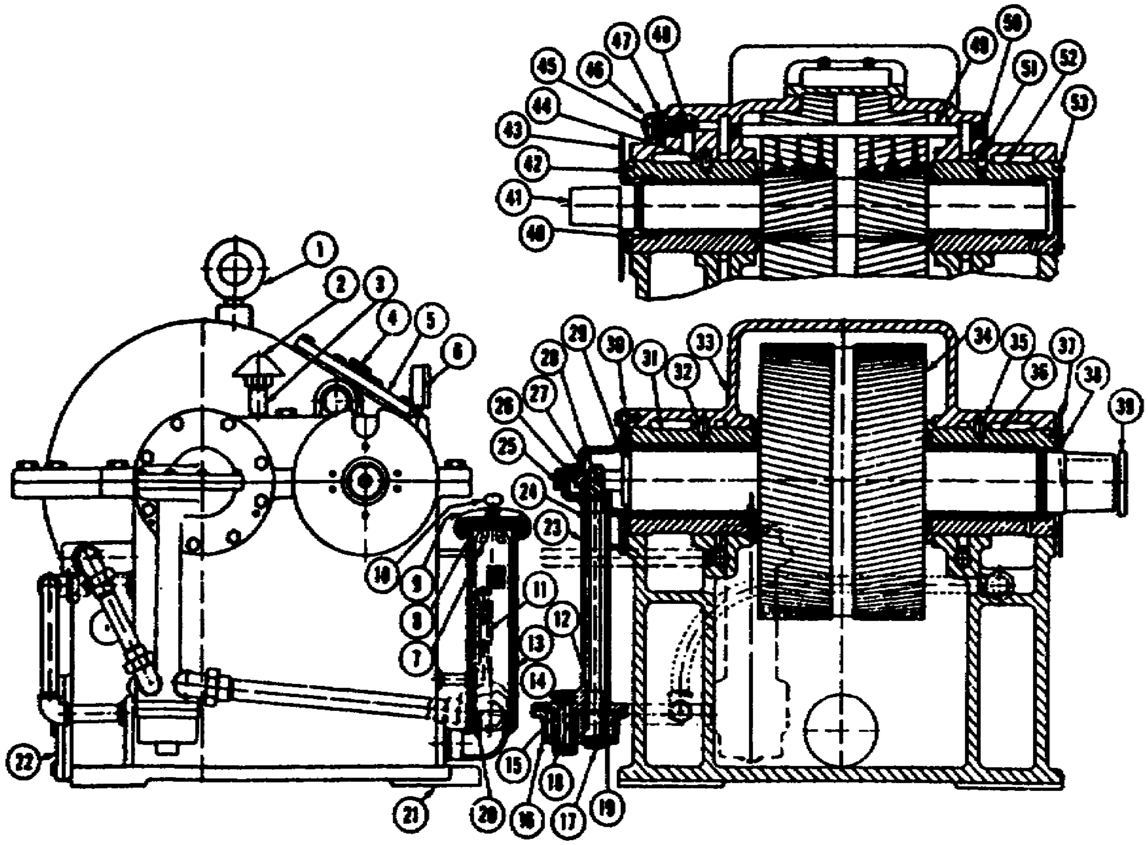
2. **Lubrication**. A good gear oil must be used for the lubrication of high-speed gears. The oil must be kept clean by filtering, and filters changed as often as possible. The temperature of the oil should be kept within the range of 130° F. to 180° F. Water cooling should be used whenever necessary to keep the temperature within these limits.

3. **Type of Oil**. The best grade of oil to use on a gear depends on journal speeds, tooth speeds, and clearances. In general, it is better to use an oil too heavy than one too light. The gears will be somewhat warmer, but the heavier oil will take care of higher temperature if it is not more than a few degrees. The heavier oil is rated at 400 to 580 seconds Saybolt viscosity at 100° F.

4. **Water Cooling of Gears**. The gears are water cooled by circulating water through water jackets cast in the ends of the gear casing or by means of either an internal or an external oil cooler. This system is connected to a supply of cool, clean water, at a minimum pressure of 5 pounds. A regulating device must be installed in the water supply line. The discharge line should have free outlet without valves to avoid possibility of excessive pressures on the system. Piping must be arranged so that all the water can be drained or blown out of the water jackets or cooler if the unit is to be subjected to freezing temperatures.

5. **Inspection**. Inspect to see that both the driving and driven machines are in line. If you are not sure that alignment is correct, check this point with gauges. Try out the water cooling system to see if it is functioning properly. When starting, see that you have sufficient oil in the gear casing and that the oil pump gives required pressure (4 to 8 pounds). When the temperature of the oil in the casing reaches 100° F. to 110° F., turn on the water cooling system. Add sufficient oil from time to time in order to maintain the proper oil level. Never allow the gear wheel to dip into the oil.

6. Regular cleaning of the lubrication system and tests of the lubricant are essential. Clean the strainer at least once a week and more often if necessary. The manufacturer recommends that the gear case should be drained and be completely cleaned out every 2 to 3 months. Refill with new filtered oil. Between oil changes, samples of oil



1. Eye bolt
2. Reservoir vent hood
3. Vent pipe
4. Inspection plug
5. Hand hole cover
6. Oil pressure gage
7. Oil strainer
8. Strainer cover
9. Strainer cover clamp
10. Clamp screw
11. Clamp screw
12. Lower drive shaft bushing
13. Strainer body
14. Idler gear shaft
15. Idler gear (driven)
16. Oil pump case
17. Oil pump case plug
18. Oil pump case plug
19. Oil pump gear (driver)
20. Oil strainer seat
21. Lower half gear case
22. Cleaning out cover
23. Oil pump bracket
24. Oil pump drive shaft
25. Drive shaft bushing
26. Spiral gear (driven)
27. Shaft extension screw
28. Spiral gear (driver)
29. Gear shaft extension
30. Oil pump cap
31. Gear shaft bearing (pump end)
32. Bearing dowel
33. Gear case cover
34. Gear
35. Bearing dowel
36. Gear bearing (driving end)
37. Air baffle spacer
38. Air baffle
39. Coupling screw
40. Pinion bearing (coupling end)
41. Pinion
42. Air baffle spacer
43. Air baffle
44. Bearing dowel
45. Relief valve stem
46. Relief valve cap
47. Spring adjusting nut
48. Relief valve spring
49. Oil spray pipe
50. Pipe plug
51. Bearing dowel
52. Pinion bearing
53. Bearing end cover

(Courtesy Terry Steam Turbine Company)

Figure 49. Gear drive components.

should be drawn off and the oil checked. If water is present, the water should be drawn off. If there is a considerable amount of water in the oil, remove all oil and separate the water from the oil before it is used again.

7. **Repair**. All working parts of the gear drive are easily accessible for inspection and repair except the oil pump. If you should have to dismantle the gears, you must take precautions to prevent any damage to gear teeth. The slightest bruise will result in noisy operation. When the gears are removed, place them on a clean cloth placed on a board and block them so that they cannot roll off. Cover the gears with a cloth to protect them from dust and dirt.

8. Bearing shells, oil slingers, etc., are marked and should be returned to their proper places. Gaskets are used between the oil pump bracket and oil pump and under handhole covers. All parts must be clean before reassembly. Make sure that no metal burrs or cloth lint is present on any part of the unit. Coat faces of flanges with shellac before bolting them together. A thin coat of shellac on the bearing supports will prevent oil leaks at these points. Before final replacement of the cover, make a careful inspection to see that all parts are properly placed and secured.

9. Worn bearings must be replaced immediately because they will cause the gears to wear. Bearings are interchangeable, and when new bearings

are installed the gears are restored to their original center distance and alignment. It is not recommended to rebabbit bearings, for the heat required to rebabbit the bearings will cause some distortion of the bearing shell. Do not renew or scrape one bearing alone, but always renew or scrape in pairs; this will help eliminate tooth misalignment. Do not adjust bearing clearances by planing the joint, thereby bringing the halves closer together, since trouble will result.

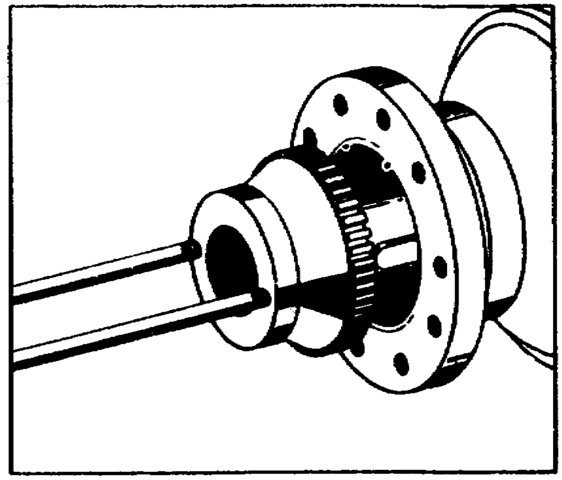
10. The oil pump is a geared type. During assembly, care must be taken to see that the paper gasket between the pump body and bracket is of the proper thickness. A gasket that is too thick will reduce the capacity and cause failure in oil pressure, while a too thin gasket will cause an excessive load to be thrown on the gears, resulting in wear and destruction of the gears. Writing paper makes a good gasket when shellacked in place. Never use a rubber gasket on any oil joint. "Cinch" fittings are used on all pipes connected to the oil pump bracket; use this type on all replacements. Threaded fittings may cause the bracket to be pulled out of line, causing noisy operation and wear on gears. Couplings should not be driven on or off the gear or pinion shafts, since hammering is liable to injure both surfaces. Provisions have been made for using a jacking device for putting on or removing couplings from shafts.

11. Gear tooth contact and wear should be uniformly distributed over the entire length of both gear and pinion helixes. If heavier wear is noted on any portion of the helixes or any part of the tooth face, it may indicate improper setting of the gear casing, misalignment of connecting shafts, vibration, excessive or irregular wear on the bearings, or poor lubricant. Should gear teeth become damaged during inspection or operation, remove burrs by use of a fine file or oil stone. Never use these tools to correct the tooth contour. Misalignment, poor lubrication, and vibration can cause pitting of tooth surfaces or flaking of metal in certain areas of the gear. If this happens, check alignment and remove all steel particles. Check the manufacturer's maintenance manual for specific maintenance procedures and instructions.

12. You now understand the drive system for the compressor, but we must learn how the drive is *coupled* to the motor and the compressor.

12. Couplings

1. The couplings used to connect the motor to the speed-increasing gears and from the gears to the compressors are self-alining coupling. They are of the flexible geared type, consisting of two externally geared hubs that are pressed on and



(Courtesy Koppers Company, Incorporated)

Figure 50. Mounting coupling on shaft.

geared to the shaft. These hubs are inclosed by a two-piece externally geared floating cover which functions as a single unit when the halves are bolted together. The cover is supported on the hub teeth during operation. A spacer or spool piece is used with the cover for the compressor coupling. The hub teeth and cover teeth are engaged around the complete circumference, and the cover and shafts revolve as one unit. The cover and each shaft is free to move independently of each other within the limits of the coupling, thus providing for reasonable angular and parallel misalignment as well as end float. The amount of misalignment that the coupling will handle without excessive stressing varies with the size of the coupling. In all cases, the coupling should be treated as a joint that will take care of only small misalignments.

2. Installation and Alignment Procedures or Coupling. Figure 50 illustrates the method used to mount each half coupling on the shaft. In reference to figure 50, place the sleeve over the shaft end and lubricate the surface of the shaft. Expand the hub with heat, using hot oil, steam, or open flame. When using a flame, do not apply the flame to the hub teeth. Use two long bolts in the puller holes to handle the war coupling. Locate the hub on the shaft with the face of the hub flush with the shaft end. Install the key with a tight fit on the sides and a slight clearance between the top of the key and the hub.

3. Check the angular alignment, as shown in figures 51 and 52. For normal hub separation, as shown in figure 51, use a feeler gauge at five points 90° apart. Recheck the angular alignment as discussed above. Figure 53 shows how to check the offset alignment by the sight method. Figure 54 illustrates the method for checking alignment by the instrument method. This method

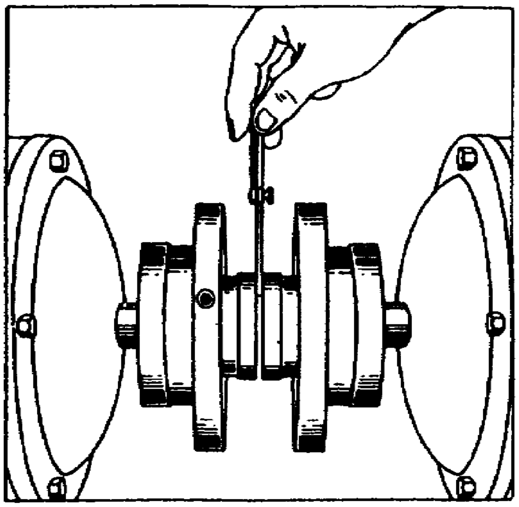


Figure 51. Checking angular alignment (normal separation).

is recommended by the manufacturer. Fasten or clamp the indicator bracket on one hub with the dial indicator button contacting the alignment surface of the opposite hub. Rotate the shaft on which the indicator is attached to the hub, and take readings at four point, 90° apart. Move either machine until readings are identical. Reverse the indicator to the opposite hub and check. Recheck the angular alignment as discussed before.

4. Figure 55 illustrates the method for checking offset alignment with wide hub separation. Use the dial indicator as discussed in checking offset alignment by the instrument method, then check the angular alignment as discussed before.

5. In checking for angular and offset alignment

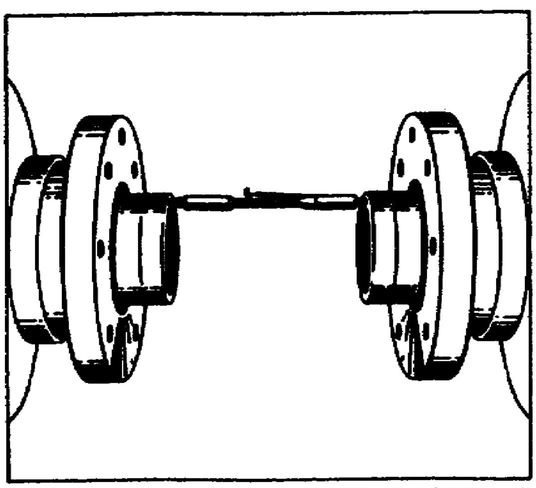


Figure 52. Checking angular alignment (wide separation).

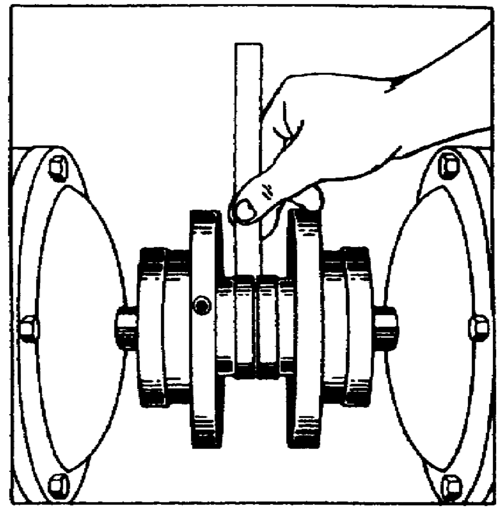


Figure 53. Checking offset alignment (sight method).

on the floating shaft arrangement, it is possible to correct both angular and offset misalignment in one operation. In reference to figure 56, position units to be coupled with the correct shaft separation. Install and assemble the coupling. Clamp the indicator bar to the flange of one coupling with the indicator button resting on the floating shaft approximately 12 inches from the teeth centerline of this coupling. Rotate the units, taking readings at four points, 90° apart. Move either machine until the readings are identical.

6. After checking and setting the offset and angular alignment, insert the gasket as shown in figure 57. Inspect to insure the gasket is not torn or damaged. Clean the coupling flanges and insert the gasket between the flanges, making sure to position the O-ring in the groove. Figure 58

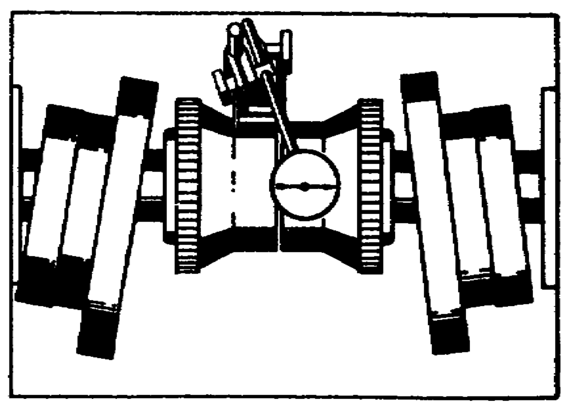
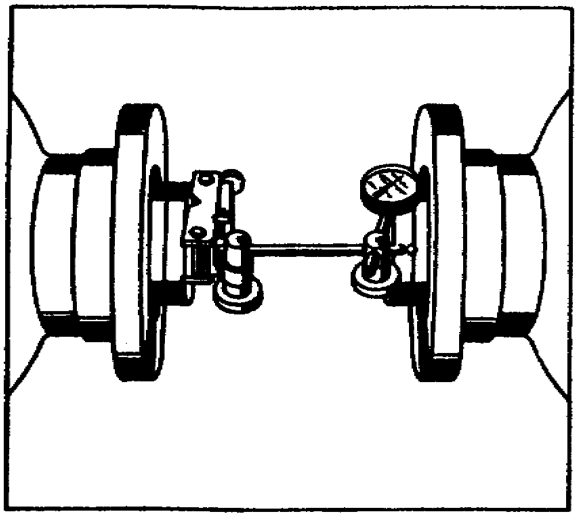


Figure 54. Checking offset alignment (instrument method).

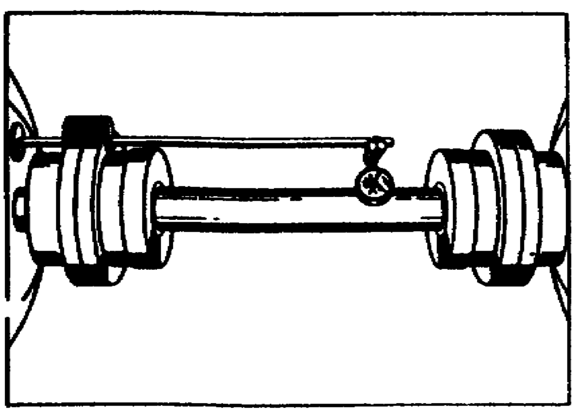


(Courtesy Koppers Company, Incorporated)

Figure 55. Checking offset alignment (wide hub separation).

illustrates the method of positioning gaskets between each set of flanges for spacer and floating shaft type coupling. Assemble the coupling as shown in figure 59. Keep the bolt holes in both flanges and gasket in line. Insert the body fitting bolts and nuts and tighten the bolts and nuts with wrenches no larger than the one furnished with the coupling until the flanges are drawn together. Using an oversize wrench on the heads of nuts and bolts may round their heads or strip the threads.

7. Lubricate the coupling as illustrated in figure 60. Remove both lubricating plugs and apply the quantity and type of lubricant as specified by the manufacturer's instruction data sheet. If grease is used, positioning of the lubrication holes is not necessary. When a fluid lubricant is used, it is recommended that the lubricating holes be positioned approximately 45° from the vertical to prevent loss of lubricant. A good oil lubricant no lighter than 150 seconds Saybolt Universal (SSU)



(Courtesy Koppers Company, Incorporated)

Figure 56. Checking angular and offset alignment.

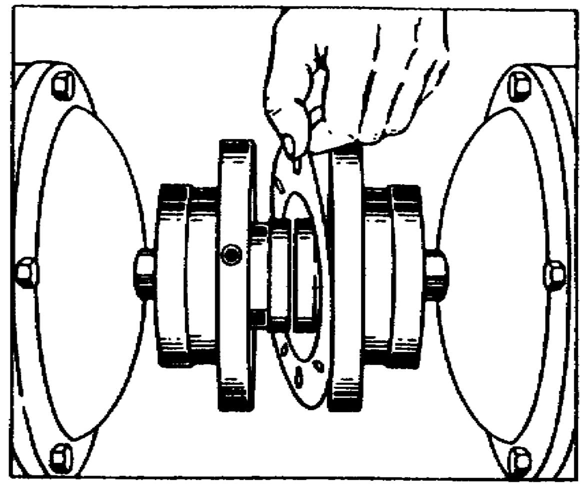


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Figure 57. Gasket insert.

or heavier than 1000 SSU at 210° F. can be used. Before replacing the lubrication plugs, check the copper ring gaskets to make sure they are in position and are undamaged. Tighten plugs with the wrench furnished with coupling as shown in figure 61.

8. The coupling must be well lubricated at all times. The couplings that use oil collector rings in the end of the cover can be lubricated while stopped or running. The compressor should not be started until the coupling has been checked for proper amount of oil. Oil will overflow the oiling ring with the coupling at rest when enough oil has been added. Other types of couplings may have sleeves attached by a gasket to the hubs with no oiling ring. The manufacturer will give specifications as to the amount of oil required to fill this unit. Unless a large amount of oil is lost from the gasketed type, it is only necessary to check the amount of oil in the coupling twice a

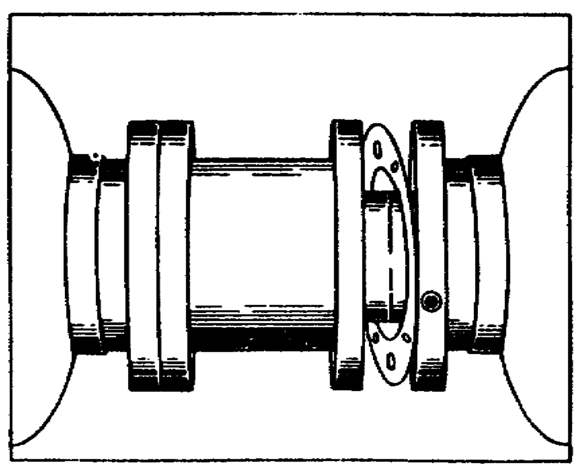

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Figure 58. Insertion of both gaskets.

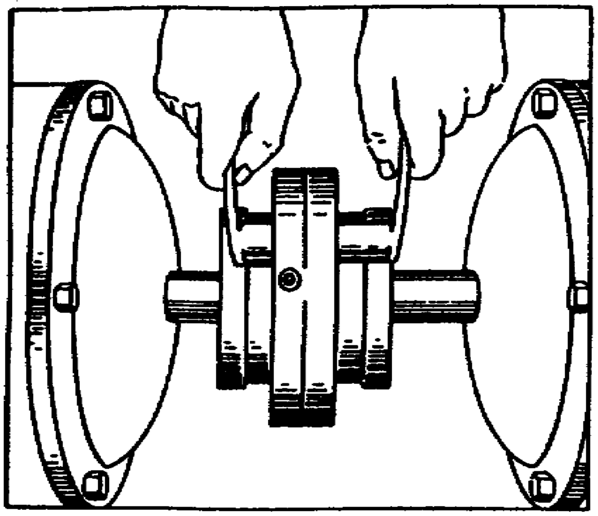

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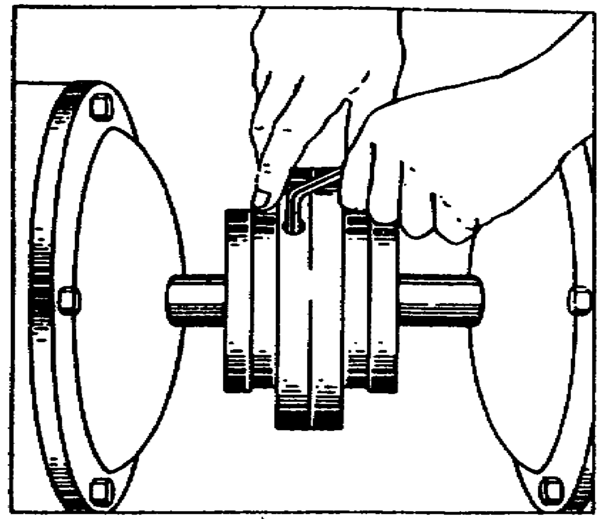
Figure 59. Assembling the coupling.

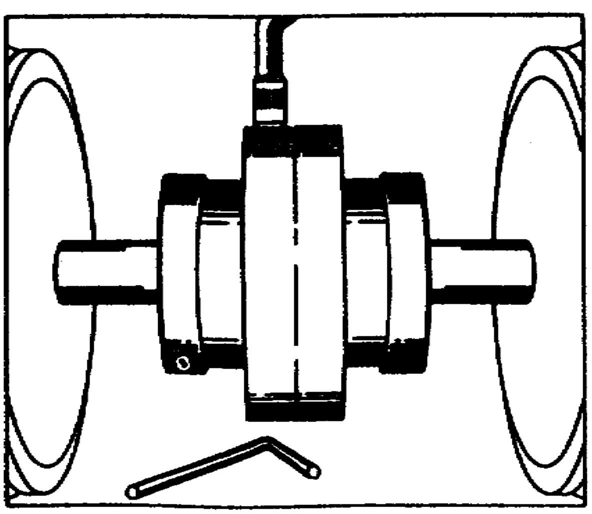


(Courtesy Koppers Company, Incorporated)

Figure 61. Tightening the coupling plug.

year by draining and refilling with the correct amount.

9. **Check of Coupling Alignment on Operating Machine**. In checking the alignment of an operating centrifugal unit, proceed as follows: Make sure the machine has operated long enough to bring the compressor gear and motor up to operating temperatures. Then stop the machine and disconnect both couplings, and with straightedge and feelers check the hubs. Check the compressor coupling for parallelism, vertically and horizontally, noticing how much it will be necessary to move the gear, vertically or horizontally, to bring the coupling within 0.002 inch tolerance for alignment. Then check the coupling for angularity by use of feelers to insure that the faces of the hubs are spaced equally apart at the top and bottom. To secure this alignment for angularity, it is necessary to shift the gear at one end either



(Courtesy Koppers Company, Incorporated)

Figure 60. Coupling lubrication.

vertically or horizontally. Caution must be used so that the parallel alignment is not disturbed. Recheck the parallel alignment to make sure that it is within its tolerance. After the coupling has been aligned, assemble the coupling. Now that we have reassembled the coupling, we shall study the drive motor and controls.

13. Drive Motor and Controls

1. The motor furnished with a centrifugal machine is an a.c. electric motor, three-phase, 60 cycle. The motor will be a general-purpose type with a normal starting torque, adjustable speed wound rotor and sleeve bearings. For wound rotor motors, the controller consists of three component parts:

- Primary circuit breaker panel
- Secondary drum control panel
- Secondary resistor grids

2. The primary circuit breaker is the main starting device used to connect the motor to the power supply. Air breakers are supplied for the lower voltages and oil breakers for 1000 volts. This breaker is a part of the control for the motor and should be preceded by an isolating switch. The breaker provides line protection (short circuit and ground fault) according to the rating of the size of breaker and is equipped with thermal overload relays for motor running protection set at 115 percent of motor rating. Undervoltage protection and line ammeter also form a part of the primary panel.

3. The secondary drum control is used to adjust the amount of resistance in the slipring circuit of the motor and is used to accelerate and regulate the speed of the motor. A resistor, which is an energy dissipating unit, is used with the drum to provide speed regulation. The maximum amount

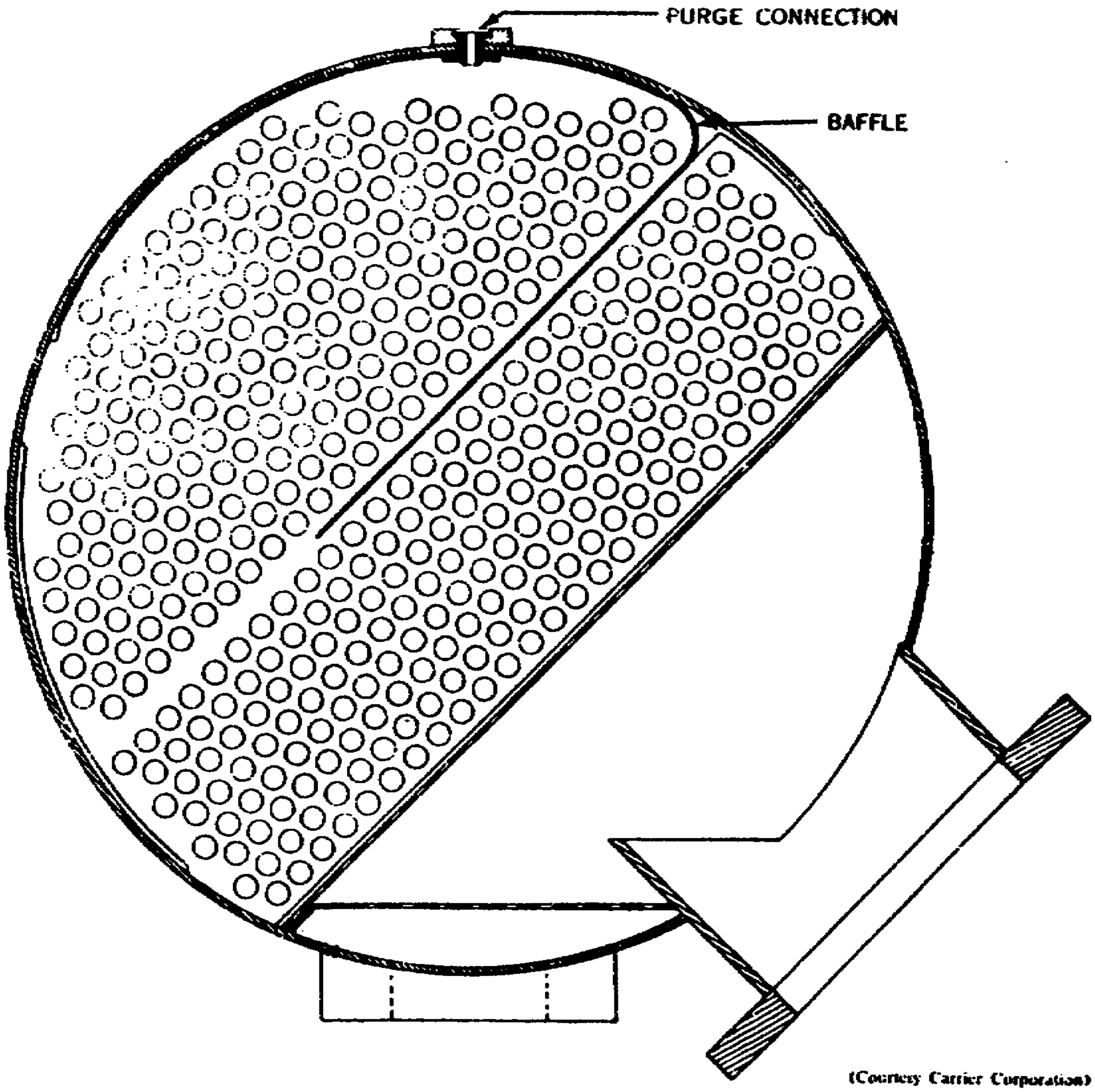


Figure 62. Cross section of the condenser.

of energy turned into heat in the resistor amounts to 15 percent of the motor rating. In mounting the resistor, allow for free air circulation by clearance on all sides and at the top.

4. Manual starting of the machine at the motor location assures you complete supervision of the unit. Interlocking wiring connections between drum controller and circuit breaker makes it necessary to return the drum to full low-speed position (all resistance in) before the breaker can be closed. The oil pressure switch is bypassed when holding the start button closed. Releasing the start button before the oil pressure switch closes will cause the breaker to trip out-hence a false start. Very large size air breakers are electrically operated but manually controlled by start-stop pushbuttons on the panel. The drum controller lever must always be moved to the OFF position before pressing the start button.

5. The motor, controlled by various automatic and manual controls propels the compressor. The compressor in turn pumps the refrigerant through the system's condenser, cooler, and economizer.

14. Condenser, Cooler, and Economizer

1. The condenser is a shell and tube type similar in construction to the cooler. The primary function of the condenser is to receive the hot refrigerant gas from the compressor and condense it to a liquid. A secondary function of the condenser is to collect and concentrate noncondensable gases so that they may be removed by the purge recovery system. The top portion of the condenser is baffled, as shown in figure 62. This baffle incloses a portion of the first water pass. The noncondensables rise to the top portion of the condenser because they are lighter than

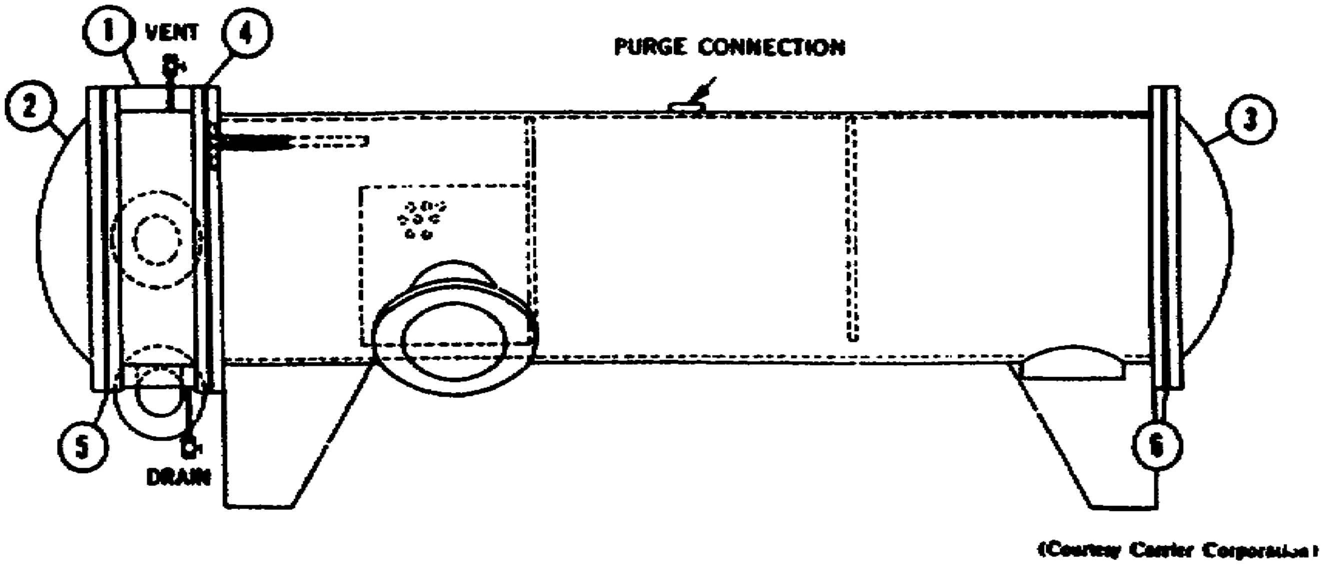


Figure 63. Condenser diagram.

refrigerant vapors and because it is the coolest portion of the condenser.

2. A perforated baffle or distribution plate, as shown in figure 62, is installed along the tube bundle to prevent direct impact of the compressor discharge on the tubes. The baffle also serves to distribute the gas throughout the length of the condenser. The condensed refrigerant leaves the condenser through a bottom connection at one end and flows it the condenser float trap chamber into the economizer chamber. The water boxes of all condensers are designed for a maximum working pressure of 200 p.s.i.g. The water box, item 1 in figure 63, is provided with the necessary division plates to give the required flow. Water box covers, items 2 and 3 in figure 63, may be removed without disturbing any refrigerant joint since the tube sheets are welded into the condenser and flange. Vent and drain openings are provided in the water circuit. The condenser is connected to the compressor and the cooler shell with expansion joints to allow for differences in expansion between them. Figure 63 is a side view of the condenser.

3. **Condenser**. The following procedures should be followed in cleaning condenser tubes:

(1) Shut off the main line inlet and outlet valves.

(2) Drain water from condenser through the water box drain valve. Open the vent cock in the gauge line or remove the gauge to help draining.

(3) Remove all nuts from the water box covers, leaving two on loosely for safety.

(4) Using special threaded jacking bolts, force the cover away from the flanges. As soon as the covers are loose from the gaskets, secure a rope to the rigging bolt in the cover and suspend from overhead. Remove the last two nuts and place on the floor.

(5) Scrape both the cover and the matching flange free of any gasket material, items 4, 5, and 6 in figure 63.

(6) Remove the water box division plate by sliding it out from its grooves. Caution should be used in removing this plate; it is made of cast iron. Penetrating oil may be used to help remove the plate.

(7) Use a nylon brush or equal type on the end of a long rod. Clean each tube with a scrubbing motion and flush each tube after the brushing has been completed. CAUTION: Do not permit tubes to be exposed to air long enough to dry before cleaning since dry sludge is more difficult to remove.

(8) Replace the division plate after first shellacking the required round rubber gasket in the two grooves.

(9) Replace the water box covers after first putting graphite on both sides of each gasket, since this prevents sticking of the gaskets to the flanges. CAUTION: Care must be taken with the water box cover on the water box end to see that the division plate matches up the rib to the flanges.

(10) Tighten all nuts evenly.

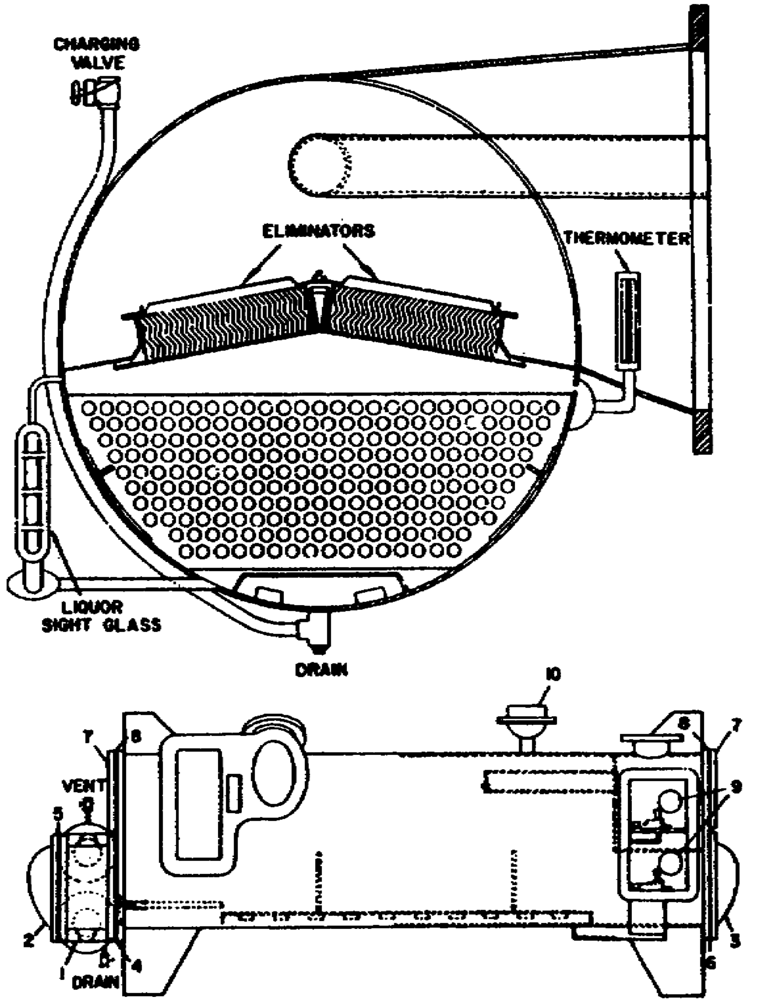
(11) Close the drain and gauge cock.

(12) Open the main line water valve and fill the tubes with water. Operate the pump, if possible, to check for leaktight joints.

4. **Cooler**. The cooler is of horizontal shell and tube construction with fixed tube sheets. The shell is low carbon steel plate rolled to shape and electrically welded. The cooler and condenser both have corrosion-resistant cast iron water boxes. They are designed to permit complete inspection without breaking the main pipe joints. Full-size separate cover plates give access to all tubes for easy cleaning. The cooler water boxes are designed for maximum 200 pounds working pressure. They are provided with cast iron division plates

1. Water box with nozzles
2. Water box cover, nozzle end
3. Water box, plain end
4. Gasket (water box to tube sheet)
5. Gasket (water box to cover), nozzle end
6. Gasket (water box to tube sheet), plain end
7. Inspection cover, either end
8. Gasket, inspection cover
9. Condenser and economizer liquid float valve assemblies
10. Rupture valve

NOTE: For three pass construction, there is a water box with nozzle on each end.



(Courtesy Carrier Corporation)

Figure 64. Cross section of cooler.

to give the required water pass flow. Both the cooler and condenser have tube sheets of cupro-nickel, welded to the shell flange. Cupronickel is highly resistant to corrosion.

5. The tubes in the cooler are copper tubes with an extended surface. The belled ends are rolled into concentric grooves in the holes of the tube sheets. Tube ends are rolled into the tube sheets and expanded into internal support sheets. The normal refrigerant charge in the cooler covers only about 50 percent of the tube bundle. However, during operation, the violent boiling of the refrigerant usually covers the tube bundle. The cooler is equipped with multibend, nonferrous eliminator plates above the tube bundle which remove the liquid droplets from the vapor stream and prevent carryover of liquid refrigerant particles into the compressor suction. Inspection covers are provided in the ends of the cooler to permit access to the eliminators. Figure 64 is a cross-section diagram of the cooler.

6. A rupture valve with a 15-pound bunting disc is provided on the cooler, and a 15-p.s.i.g. pop safety valve is screwed into a flange above the rupture disc. These items are strictly for safety, because it is highly improbable that a pressure greater than 5 to 8 p.s.i.g. will ever be attained without purposely blocking off the compressor suction opening.

7. An expansion thermometer indicates the temperature of the refrigerant within the cooler during operation. A sight glass is provided to observe the charging and operating refrigerant level. A charging valve with connections is located on the side of the cooler for adding or removing refrigerant. The connection is piped to the bottom of the cooler so that complete drainage of refrigerant is possible. A refrigerant drain to the atmosphere is also located near the charging connection and expansion thermometer.

8. A small chamber is welded to the cooler shell at a point opposite the economizer and above

the tube bundle. A continuous supply of liquid from the condenser float chamber is brought to the expansion chamber while the machine is running. The bulb of the refrigerant thermometer and the refrigerant safety thermostat bulb are inserted in this expansion chamber for measuring refrigerant temperature.

9. *Cleaning*. Depending on local operating conditions, the tubes of the evaporator should be cleaned at least once a year. Cleaning schedules should be outlined in the standard operating procedures. You will be required to make frequent checks of the chilled water temperatures in the evaporator. If these temperature readings at full load operation begin to vary from the designed temperatures, fouling of the tube surfaces is beginning. Cleaning is required if leaving chilled water temperature cannot be maintained.

10. *Repair*. Retubing is about the only major repair that is done on the evaporator (cooler). This work should be done by a manufacturer's representative.

11. **Cooler and Condenser Checkpoints**. You must check the cooler and condenser for proper refrigerant level and make sure that the tubes in the cooler and condenser are in efficient operating condition. The correct refrigerant charging level is indicated by a cross wire on the sight glass. The machine must be shut down to get an accurate reading on the sight glass. For efficient operation, the refrigerant level must not be lower than one-half of an inch below the cross wire; a refrigerant level above this reference line indicates an over-charge. Overcharging is caused by the addition of too much refrigerant. When this condition exists, the overcharged refrigerant must be removed.

12. If the machine has been in operation for long periods of time, the refrigerant level will drop due to refrigerant loss. When this condition exists, additional refrigerant must be added to the system to bring the refrigerant level up to its proper height as indicated on the cross wire. Observe all cautions and do not overcharge the cooler.

13. A method of determining if the tube bundle of either the cooler or condenser is operating efficiently is to observe the relation between the change in temperature of the condenser water or brine and the refrigerant temperature. In most cases, the brine or condenser waterflow is held constant. Under such conditions, the temperature change of chilled and condenser water is a direct indication of the load. As the load increases, the temperature difference between the leaving chilled water or condenser cooling water and the refrigerant increases. A close check should be made of the temperature differences at full load when the machine is first operated, and a comparison made from time to time during operation. During constant operation over long periods of time, the cooler and condenser tubes may become dirty or scaled and the temperature difference between leaving water or brine will increase. If the increase in temperature is approximately 2° or 3° at full load, the tubes should be cleaned.

14. Read the condenser pressure gauge when taking readings of the temperature difference between leaving condenser water and condensing temperature. Before taking readings, make sure the condenser is completely free of air. The purge unit should be operated for at least 24 hours before readings are taken.

15. **Economizer**. A complete explanation of the function of the economizer was given under the refrigeration cycle. The economizer is located in the cooler shell at the opposite end from the compressor suction connection and above the tube bundle.

16. The economizer is a chamber with the necessary passages and float valves, connected by an internal conduit passing longitudinally through the cooler gas space to the compressor second-stage inlet. This connection maintains a pressure in the economizer chamber that is intermediate (about 0 p.s.i.g.) between the cooler and condenser pressures and carries away the vapors generated in the chamber. Before entering the conduit, the economizer vapors pass through eliminator baffles to extract any free liquid refrigerant and drain it back into the chamber. (Item 9 of fig. 64 is a front view of the economizer chamber.)

17. There are two floats in separate chambers on the front end of the economizer. The top or condenser float valve keeps the condenser drained of refrigerant and admits the refrigerant from the condenser into the economizer chamber. The bottom, or economizer, float valve returns the liquid to the cooler.

18. This system is also equipped with another fine feature to assure smoother operation. Let's discuss the hot gas bypass system.

15. Hot Gas Bypass

1. The automatic hot gas bypass is used to prevent the compressor from surging at low loads. In case of low load conditions, hot gas is bypassed directly from the condenser through the cooler to the suction side of the compressor. The hot gas supplements the small volume of gas that is being evaporated in the evaporator due to low load conditions. Surging generally occurs at light load, and the actual surge point will vary with different compressors. In most instances, it usually develops at some point well below 50 percent capacity. If the leaving chilled water is held at a constant

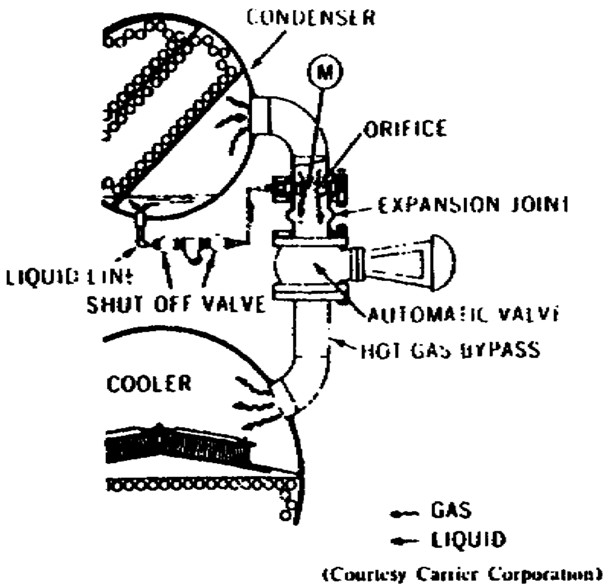


Figure 65. Hot gas bypass.

temperature, the returning chilled water temperature becomes an indication of the load. This temperature is used to control the hot gas bypass. A thermostat, set in the returning chilled water, operates to bleed air off the branch line serving the hot gas bypass valve. The thermostat is set to start opening the bypass valve slightly before the compressor hits its surge point. Figure 65 illustrates components and location of the hot gas bypass line.

2. A liquid line injection system is provided in the hot gas bypass system to desuperheat the gas by vaporization in the bypass line before it enters the compressor suction. If the gas is not desuperheated, the compressor will overheat. The automatic liquid injection system components consist of a pair of flanges in the hot gas line, an orifice, a liquid line from the condenser to one of the flanges, and a liquid line strainer with two shutoff valves.

3. The automatic valve shown in figure 65 is normally closed. When this valve is closed, there is no flow of gas through the orifice. The pressure at point M, just below the orifice, is the same as the condenser pressure; therefore, no liquid will flow through the liquid line. When the occasion arises for the need of hot gas, the valve is opened automatically and a pressure drop will exist across the orifice. The amount of pressure drop is a direct function in determining the rate of gasflow through the orifice. The larger the flow of hot gas through the bypass and orifice, the lower the pressure at point M will become in relation to the condenser pressure, and the greater will be the pressure differential to force desuperheating liquid through the liquid line. As the amount of hot bypass gas is increased or decreased by the opening or closing of the valve, the amount of desuperheating liquid forced through the liquid line is automatically increased or decreased.

4. The two shutoff valves in the liquid line are normally left wide open and are closed only to service the liquid line components. The special flange (located near the orifice) is installed at a slightly higher level than the surface of the liquid lying in the bottom of the condenser. When no hot gas is flowing through the bypass, no unbalance will exist in the liquid line. Therefore, the liquid will not flow and collect in the gas pipe above the automatic valve. This prevents the danger of getting a "slug" of liquid through the hot gas bypass line whenever the valve is opened. It also provides a means of distributing the liquid into the hot gas stream as evenly and as finely as possible. The flange is constructed with a deep concentric groove in one face for even distribution of the liquid.

5. How are undesirables such as water and air expelled from this system? The purge unit will do this important task for us.

16. Purge Unit

1. The presence of even a small amount of water in a refrigeration system must be avoided at all times; otherwise excessive corrosion of various parts of the system may occur. Any appreciable amount of water is caused by a leak from one of the water circuits. Since the pressure within a portion of the centrifugal refrigeration system is less than atmospheric, the possibility exists that air may enter the system. Since air contains water vapor; a small amount of water will enter whenever air enters.

2. The function of the purge system is to remove water vapor and air from the refrigeration system and to recover refrigerant vapors which are mixed with these gases. The air is automatically purged to the atmosphere. The refrigerant is condensed and automatically returned to the cooler as a liquid. Water, if present, is trapped in a compartment of the purge separator unit from which it can be drained manually. Thus the purge and recovery system maintains the highest possible refrigerating efficiency.

3. **Components**. The following discussion of the component items of the purge system is referenced to figure 66.

- Stop valve--on main condenser, item 1. This valve is always open except during repairs.
- Pressure-reducing valve--in suction line, item 2, to regulate the compressor suction pressure.
- Stop valve--in suction line, item 3, located in the end of the purge unit casing. This valve is to be open when the purge unit is in operation and closed at all other times.
- Pressure gauge--this gauge, item 4, indicates

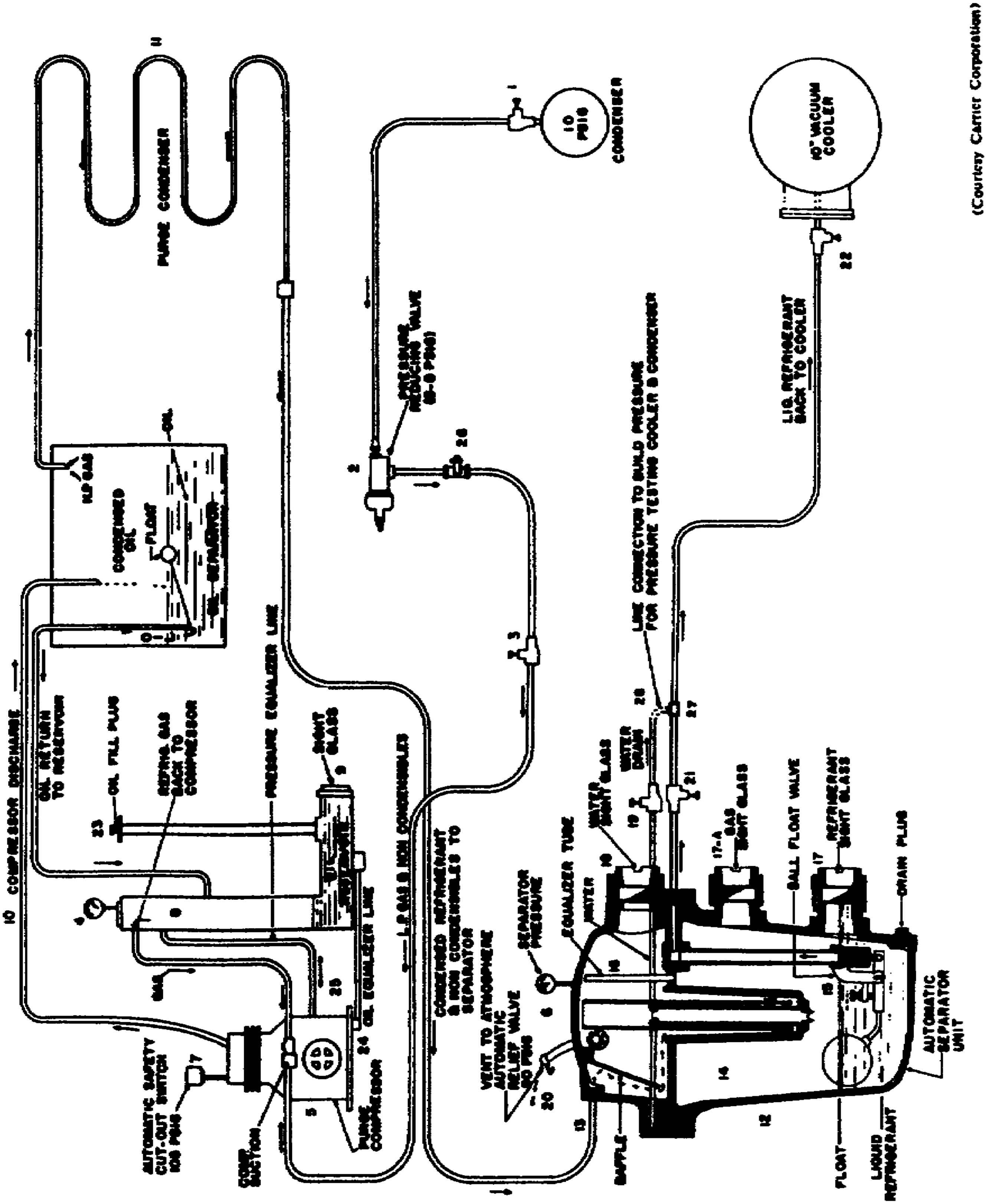


Figure 66. Purge unit schematic.

the pressure on the oil reservoir. NOTE: Before adding oil, at item 23, be sure the pressure is at zero.

- Compressor, item 5--to be operated continuously when the centrifugal compressor is operating, and before starting the machine as required by the presence of air.
- High-pressure cutout switch, item 7--connected to the compressor discharge. Adjusted to stop the compressor if the purge condenser pressure increases to about 110 p.s.i.g. because of some abnormal condition. The switch closes again automatically on the reduction of pressure to about 75 p.s.i.g.
- Auxiliary oil reservoir, item 8--this reservoir serves as a chamber to relieve the refrigerant from the compressor crankcase and also to contain extra oil for the compressor. The refrigerant vapor, which flashes from the compressor crankcase, passes up through the reservoir and into the compressor suction line. The free space above the oil level separates the oil from the refrigerant vapor before the vapor goes into the suction side of the purge compressor. The oil storage capacity of the reservoir is slightly larger than the operating charge of oil required by the compressor.
- Sight glass, item 9--for oil level in the compressor and auxiliary oil reservoir, located in front of casing.
- Compressor discharge line, item 10.
- Condenser, item 11--cooled by air from a fan on compressor motor. It liquefies most of the refrigerant and water vapor contained in the mixture delivered by the compressor.
- Evacuator chamber, item 12--for separation of air, refrigerant, and water. Chamber can be easily taken apart for inspection and repairs.
- Baffle, item 13--allows the condensate to settle and air to separate for purging. This is the delivery point for the mixture of air, water (if any), and liquid refrigerant from condenser.
- Weir and trap, item 14--located in the center of evacuation chamber. Since the water is lighter than liquid refrigerant the water is trapped above the liquid refrigerant in the upper compartment. Only refrigerant liquid can pass to the lower compartment.
- Float valve, item 15--a high-pressure float valve, opening when the liquid level rises, allows the gas pressure to force the liquid refrigerant into the economizer.
- Equalizer tube, item 16--to equalize the vapor pressure between the upper and lower compartments.
- Two sight glasses, items 17 and 17A--on lower liquid compartment, visible at the end of the casing. These glasses show refrigerant level in the separator.
- Sight glass, item 18--on upper compartment to indicate the presence of water.
- Stop valve at the end of casing, item 19--permits water to be drained from the upper compartment. The valve is marked "Water Drain" and is closed except when draining water.
- Automatic relief valve, item 20--to purge air to the atmosphere.
- Stop valve marked "Refrigerant Return" in the return liquid refrigerant line, item 21-located at the end of the casing. Open only when purge is operating.
- Stop valve, item 22--on economizer in the return refrigerant connection. Open at all times except when machine is shut down for a long period or being tested.
- Plug in oil filling connection of reservoir, item 23--pressure in the system must be balanced with the atmospheric pressure to add oil through this fitting.
- Cap, item 24--or draining oil from the compressor crankcase and oil reservoir. Oil may also be added through this connection (not shown in fig. 66) *if* (1) a packless refrigerant valve is installed in place of cap at the connection and (2) the purge compressor is operated in a vacuum.
- Connections between auxiliary reservoir and compressor crankcase, item 25.
- Motor and belt--not shown in figure 66.
- Wiring diagram inside the casing.
- Casing that completely incloses the purge recovery unit and is removable to provide a means to work on components.
- Plugged tee after pressure-reducing valve on line from condenser, item 26.
- Capped tee on line leading to cooler, item 27.
- Temporary connector pipe from water drain from separator to liquid refrigerant line to cooler, item 28.

4. **Purge Recovery Operation**. The purge recovery operation is automatic once the purge switch is turned on and the four valves listed below and referred to in figure 66 are opened:

(1) Stop valve on main condenser
(2) Stop valve in suction line
(3) Stop valve in the return liquid refrigerant line
(4) Stop valve on economizer in return refrigerant connection

5. If there should be an air leakage in the system, operation of the purge unit will remove this air. It is recommended that you stop the purge unit at intervals and shut off valves (1) an (4) listed above to check for leaks in the system. A tight machine will not collect air no matter how long the purge unit is shut off. Presence of air in the system is shown by an increase in head

Room Air Temperature	65	75	85	95	105	115
Suction Pressure (Maximum Allowable)	5 inch vacuum	0-lb gauge	3.5-lb gauge	7-lb gauge	wide open	wide open
Relief Pressure by Adjustment of Automatic Relief Valve	75-80	75-80	95-100	95-100	105-110	105-110

(Courtesy Carrier Corporation)

Figure 67. Suction and relief pressure.

pressure in the condenser. The pressure can develop suddenly or gradually during machine operation. By checking the difference between leaving condenser water temperature and the temperature on the condenser gauge, you can determine the presence of air. A sudden increase between these temperatures may be caused by air. In some instances, a sudden increase in cooler pressure over the pressure corresponding to cooler temperatures during operation may be caused by air leakage.

6. Small air leakages are very difficult to determine. It may take one or more days to detect an air leakage in the machine. A leak that shows up immediately or within a few hours is large and must be found and repaired immediately. Air pressure built up in the condenser is released to the atmosphere by the purge air relief valve. Excessive air leakage into the machine will cause the relief valve to pop off continuously, resulting in a large amount of refrigerant discharged to the atmosphere.

7. Refrigerant loss depends on operational conditions; therefore, these conditions have a determining effect on the amount of refrigerant lost. You should maintain a careful log on refrigerant charged and the shutdown level in the cooler. In this manner, you can determine the time a leak develops and the amount of refrigerant lost, find the cause, and correct the trouble.

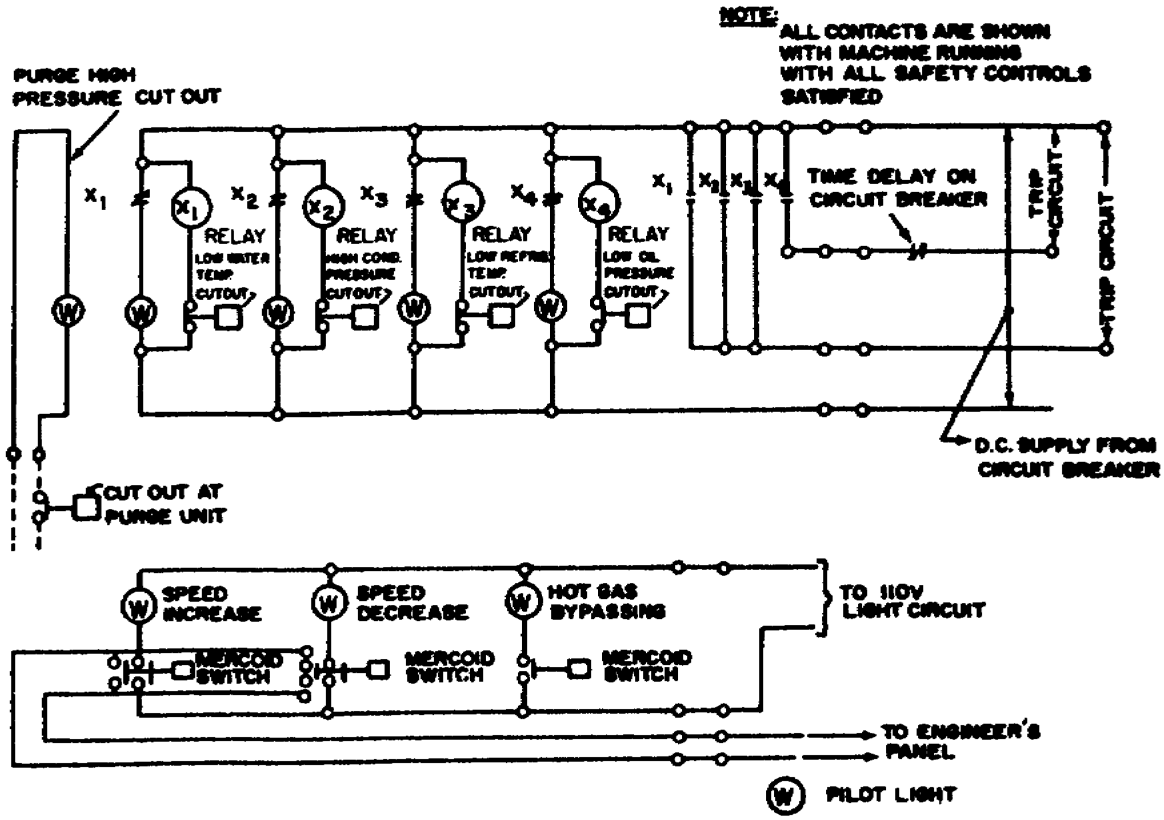
8. Moisture removal by the purge recovery unit is just as important as air removal. The moisture may enter the machine by humidity in the air that can leak into the machine or by a brine or water leak in the cooler or condenser. If there are no water leaks, the amount of water collected by the purge unit will be small (1 ounce per day) under normal operating conditions. If large amounts of water are collected by the purge unit (one-half pint per day), the machine must be checked for leaky tubes. Water can be removed more rapidly when the machine is stopped than when operating. If the machine is collecting a large amount of moisture. It is advisable to run the purge unit a short time after the machine is stopped and before it is started. Running the purge unit before the machine is started will help to reduce purging time after the machine is started.

9. The pressure-reducing valve (2), shown in figure 66, is adjusted to produce a suction pressure on the purge recovery unit and will not allow condensation in the suction line. If condensation does occur, the condensate will collect in the crankcase of the purge unit compressor, causing a foaming and excessive oil loss. The table in figure 67 can be used as a guide for setting the pressure-reducing valve. If the pressure-reducing valve is wide open, there will be a pressure drop of a few pounds across the valve and the suction pressure cannot be adjusted higher than a few pounds below the machine condensing pressure.

10. **Purge Unit Maintenance**. After repairs or before charging, it is necessary to remove large quantities of air from the machine. This can be done by discharging the air from the water removal valve (item 19, fig. 66). Caution must be observed in the removal of air, since there is some danger of refrigerant being discharged with the air and being wasted to atmosphere.

11. If the normal delivery of refrigerant is interrupted, it is usually caused by the stop valve (item 21, fig. 66) being closed or because the float valve is not operating. This malfunction is indicated by a liquid rise in the upper sight glass. Immediate action must be taken to correct this trouble. If the liquid is not visible in the lower glass, the float valve is failing to close properly.

12. Water or moisture in the system will collect on the top of the refrigerant in the evacuation chamber. If any water does collect, it can be seen through the upper sight glass and should be drained. In most normal operating machines, the water collection is small; but if a large amount of water collects quite regularly, a leak in the condenser or cooler has most likely occurred and must be located and corrected immediately.



(Courtesy Carrier Corporation)

Figure 68. Control panel electrical diagram.

13. The purge unit compressor and centrifugal compressor use the same type and grade of oil. Oil can be added to purge the compressor by closing stop valves (items 3 and 21, fig. 66), removing plug (23) in the top of the oil sight glass, and adding oil. Oil can be drained by removing the oil plug (24, fig. 66). The oil level can be checked by a showing of oil at any point in the oil sight glass while the compressor is running or shut down. The level of oil will fluctuate accordingly. The oil level should be checked daily.

14. Other components that must be closely checked in the purge recovery unit are as follows:

- Belt tension.
- Relief valve for rightness when closed to prevent loss of refrigerant.
- Condenser clean and free from air obstruction
- High-pressure cutout which shuts down if condenser pressure reaches 110 pounds.

15. CAUTION: The high-pressure cutout remakes contact automatically to startoff the purge recovery unit on 75 pounds. Single-phase motors have a built-in thermal overload to stop the motor on overload. It automatically resets itself to start the motor in a few minutes.

16. The system is running and purged. Let us now study our safety controls:

17. Safety Controls

1. Safety controls are provided to stop the centrifugal machine under any hazardous condition. Figure 68 illustrates the electrical wiring diagram. All the controls are mounted on a control panel. The safety controls are as follows:

- Low water temperature cutout
- High condenser pressure cutout
- Low refrigerant temperature cutout
- Low oil pressure cutout

2. All of the safety controls except the low oil pressure cutout are manual reset instruments. Each safety instrument operates a relay switch which has one normally open and one normally closed contactor. When a safety instrument is in the safe position, the corresponding relay is energized and the current is passed through the closed contactor to a pilot light which lights to indicate a safe operating condition. Should an unsafe condition exist, a safety control will deenergize the corresponding relay and the normally open contactor will open to deenergize the pilot light; the normally closed contactor will then close to energize the circuit breaker trip circuit.

When the circuit breaker trip circuit is energized, the circuit breaker trips open and stops the compressor motor. The pilot light will not go back on until a safe operating condition exists and the safety cutout has been manually reset. The oil safety switch operates somewhat differently. Since the oil pressure is not up to design conditions until the compressor comes up to speed, the relay for the oil pressure switch must be bypassed when the machine is started. The relay for the oil safety switch is bypassed by a time-delay relay, which keeps the trip circuit open until the compressor is up to speed. After a predetermined time interval, the time-delay relay closes the trip circuit at the circuit breaker and the oil safety switch serves its function. If the oil pressure does not build up before the time-delay relay closes, the trip circuit will be energized and the machine will stop.

3. The low oil pressure cuts out at 6 pounds and in at 12 pounds. The high condenser pressure cuts out at 15 pounds and in at 8 pounds. The low refrigerant and temperature cutout is set after operation in accordance to the job requirement. Generally, these controls should be set to cut out at 32° F. and to cut in at approximately 35° F. The low water temperature cutout should be set to cut out at 38° F. and to cut in at 43° F.

4. There are other safety controls built into the circuit breaker which are not part of the control panel, and reference should be made to the circuit breaker operating instructions for details of these controls. Such items as overload protection and undervoltage protection will be covered therein.

5. In addition to the pilot lights mentioned, a pilot light for the purge high-pressure cutout is on the safety control panel. The high-pressure cutout, which serves to protect the purge recovery compressor from high head pressure, is located in the purge recovery unit. When the high-pressure cutout functions on high head pressure, the pilot light on the control panel is lighted.

6. One or more machines at each installation are provided with two sets of starting equipment. One set is an operating controller and the other a standby controller. In order that the machine safety controls can operate the controlling breaker, a rotary selector switch is provided on the safety control panel. By means of the rotary selector switch, the machine safety controls can operate either of the controlling circuit breakers. Safety controls are used for safe operation of the system, but operating controls affect the capacity.

18. Operating Controls

1. The three methods of controlling the capacity output of a centrifugal machine are listed below:

- Controlling the speed of the compressor
- Throttling the suction of the compressor
- Increasing the discharge pressure of the compressor.

2. The three methods given are listed in order of their efficiency. At partial loads, the power requirements will be least if the compressor speed is reduced, not quite as low if the suction is throttled, and highest if the condenser water is throttled to increase the discharge pressure.

3. Where the compressor is driven by a variable-speed motor, motor speed and compressor speed are controlled by varying the resistance in the rotor circuit of the motor by means of a secondary controller.

4. **Damper Control**. Throttling the suction of the compressor is obtained by means of a throttling damper built into the cooler suction flange. By throttling the compressor suction, the pressure differential through which the compressor must handle the refrigerant vapor is increased. Suction damper control requires somewhat more power at partial loads than at variable-speed control. The increase in power consumption is overbalanced by the increased effectiveness in maintaining a nonsurging operation at lower loads. For this reason, the machines are equipped with dampers, even though the main control is variable speed. Suction damper control modulation is effected by means of a temperature controller that sends air pressure signals to the suction damper motor in response to temperature changes of chilled water leaving the cooler.

5. **Condenser Water Control**. By throttling the condenser water, the condenser pressure is increased, thereby increasing the pressure differential on the compressor and reducing its capacity. The occasion may arise where the variable-speed control cannot be adjusted low enough to meet operating conditions. In such a case, the condenser water may be throttled and the compressor speed requirement brought up into the range of speed control.

6. Speed control and suction damper control are combined to control the temperature of the chilled water leaving the cooler. The suction damper modulates to control the leaving chilled water temperature on each balanced speed step. As the refrigeration load decreases, the suction damper will gradually close in response to decreasing air pressure in the branch line from the suction damper controller. As the suction damper approaches the closed position, a light on the

control panel will indicate that the motor speed should be decreased to the next balanced step. The converse is true if the refrigeration load increases.

7. The lights for indicating a speed change are energized by mercury type pressure controls that sense branch air pressure from the suction chamber controller. The controller that energizes the "speed decrease" light also closes the light circuit on decreasing branch air pressure; the controller that energizes the "speed increase" light also closes the light circuit on increasing branch air pressure. The control system drawings give actual settings for pressure controllers; the final settings should be determined under actual operating conditions. You must determine what pressure change corresponds to a speed change and then adjust the pressure controller accordingly. Refer to the manufacturer's manual on details of adjustments. This information on operating controls will help you better understand the operation of the entire system.

19. System Operation

1. It is very difficult to give definite instructions in this text on the operating procedures for a given installation. Various design factors change the location of controls, types of controls used, and equipment location, and will have a definite effect on operational procedures. Listed below is a general description of startup and shutdown instruction. It is recommended that you follow your installation standard operating procedures for definite operating instructions.

2. **Seasonal Starting**. Listed below are the recommended steps that can be used in normal starting:

(1) Check oil levels for motor, gear, coupling, compressor, and bearing wells.

(2) Allow condenser water to circulate through the condenser. Be sure to vent air and allow the water to flow through slowly. This precaution must be observed to avoid water hammer.

(3) Allow water or brine to circulate through the cooler. Be sure to vent air and allow the liquid to flow through slowly. As explained above, this will help in preventing water hammer.

(4) Make sure that air pressure is present at all air-operated controls.

(5) Start the purge unit before starting the machine; this helps in removing air from the machine. Then move the switch on the front of the casing to the ON position. The purge recovery unit should be operated at all times while the machine is operating.

(6) Make sure all safety controls have been reset and that the control lever is in position No. 1 (all resistance in).

(7) Close the circuit breaker for all safety controls by pushing the starting switch or button in.

(8) Bring the machine up to 75 percent full load with all resistance in. Check oil gauges to make sure proper oil pressure is being developed. If proper oil pressure is not developed in approximately 10 seconds, the machine will cut out on low oil pressure.

(9) Open the valve to allow the cooling water to circulate to the compressor oil cooler, gear or turbine oil cooler, and seal jacket. The water circulating to the compressor oil cooler must be kept low enough in temperature to prevent the highest bearing temperature from exceeding a temperature of 130° F. Then adjust to give a temperature from 140° F. to 180° F. The seal bearing temperature should run approximately 160° F., while the thrust bearing temperature is running at approximately 145° F. under normal operating conditions. These temperatures should be checked closely until they maintain a satisfactory point.

(10) After starting, the machine may surge until the air in the condenser has been removed. During this surging period, the machine should be run at a high speed; this helps in the process of purging. The condenser pressure should not exceed 15 p.s.i.g., and the input current to motor-driven machines should not run over 100 percent of the full load motor rating. The machine will steady itself out as soon as all the air has been purged. After leveling out the motor speed, the damper maybe adjusted to give the desired coolant temperature. The motor should be increased slowly, point to point. Do not proceed to the next speed point until the motor has obtained a steady speed. Keep a close observation on the ammeter to make sure that the motor does not become overloaded.

3. **Normal and Emergency Shutdown**. Normal shutdown procedures are performed in the same manner as emergency shutdown procedures. The following steps are used in shutting down the centrifugal machine:

(1) Stop the motor by throwing the switch on the controller.

(2) After the machine has stopped, turn off the water valve which supplies water to the compressor oil, gear oil cooler, and seal housing.

(3) Shut down all pumps as required.

4. Shutdown periods may be broken down into two classes. The two classes are standby and extended shutdown. Standby shutdown may be machine must be available for immediate use;

extended shutdown is defined as that period of time during which the machine is out of service.

5. *Standby shutdown*. The following checks must be made during standby shutdown and corrective action taken:

(1) Maintain proper oil level in the oil reservoir and in the suction damper stuffing box.

(2) Room temperature must be above freezing.

(3) Machine must be kept free of leaks.

(4) Purge unit must be operated as necessary to keep the machine pressure below atmospheric pressure.

(5) If the machine pressure builds up in the unit due to room temperature rather than leakage of air into the machine, a small quantity of water circulated through the condenser or cooler will hold the machine pressure below atmospheric. Periodic operation of the purge unit will accomplish the same result.

(6) The machine should be operated a few minutes each week to circulate oil and lower the refrigerant temperature.

6. *Extended shutdown*. If the system is free of leaks and the purge unit holds down the machine pressure, the following instructions and corrective actions must be taken in long shutdown periods:

(1) Drain all water from the compressor, gear and turbine oil cooler, condenser, cooler, seal jacket, pumps, and piping if freezing temperatures are likely to develop in the machine room.

(2) It is possible for the oil to become excessively diluted with refrigerant, causing the oil level in the pump chamber to rise. This level should not be allowed to rise into the rear bearing chamber; if this occurs, remove the entire charge of oil.

7. **Logs and Records**. A daily operating log is maintained at each attended plant for a record of observed temperature readings, waterflow, maintenance performed, and any unusual conditions which affect an installation operation. You are held responsible for keeping an accurate log while on duty. A good log will help you spot trouble fast. A typical log sheet has spaces for all important entries, and a carefully kept log will help to make troubleshooting easier.

8. A master chart of preventive maintenance duties, each component identified, is usually prepared by the supervisor and includes daily, weekly, and monthly maintenance services. The preventive maintenance items included on the chart are applicable to a specific installation. The items on the chart must be checked accordingly. Proper sustained operation is the result of good maintenance.

20. Systems Maintenance

1. It is very difficult to set up a definite maintenance schedule since so many operational factors must be considered. You must familiarize yourself with the operating procedures at your installation and follow recommendations. We shall discuss the proper procedures for replacing oil, charging the unit, removing refrigerant, and troubleshooting.

2. **Replacing Oil**. The following procedure is used in the renewal of the oil:

(1) Pressure in the machine should be approximately 1 p.s.i.g.

(2) Drain oil from the bottom of the main oil reservoir cover.

(3) Remove the main oil reservoir cover and clean the chamber to remove all impurities.

(4) Replace the main oil reservoir cover and secure tightly.

(5) Remove the bearing access cover plates.

(6) Lift up the shaft bearing caps by reaching through the bearing access hole and removing the two large capscrews.

(7) Fill the bearing approximately three-fourths of the full charge, allowing the excess oil to flow into the main oil reservoir.

(8) Replace the bearing cap and secure with capscrews.

(9) Remove the brass plug from the thrust housing, and remove the strainer; clean and replace.

(10) Replace the plug and secure.

(11) Drain oil through the plug in back of the seal oil reservoir.

(12) Remove the cover from the seal oil reservoir.

(13) Remove the filter from the chamber; replace with a new filter.

(14) Refill the reservoir with oil.

(15) Replace the cover and secure tightly.

(16) Drain the oil through the plug at the bottom of the atmospheric oil reservoir.

(17) Remove the atmospheric oil filling plug and pour in fresh oil until the level is halfway in the atmospheric reservoir sight glass.

(18) Replace the plug and secure tightly.

(19) Operate the purge unit to remove as much air as possible.

(20) Add oil to the atmospheric float chamber, if main oil reservoir indicates under-charge after short operation.

3. **Charging the Unit**. The manufacturer ships the refrigerant (R-11) in large metal drums which weigh approximately 200 pounds. At temperatures above 74° F., the drum will be under pressure. To prevent injury or loss of refrigerant, never open the drums to the atmosphere when they are above this temperature.

It is possible to charge refrigerant from an open drum a 60° temperatures, although it is recommended that leaktight connections be made to the charging valve. The charging valve is located on the side of the cooler. To help in the charging procedure, each refrigerant drum has a special type plug installed on the side of the drum. This plug is specially engineered for charging purposes. The charging connection on the drum consists of a 2-inch plug in which is inserted a smaller 3/4-inch plug. The 3/4-inch opening inside the drum is covered with a friction cap. The cap prevents leakage into or out of the drum when the 3/4-inch plug is unscrewed.

4. *Refrigerant charging*. To charge the machine with refrigerant, proceed as follows:

(1) The machine must be under a vacuum.

(2) Fit a 3/4-inch nipple into the standard globe valve and close the valve.

(3) Remove the 3/4-inch plug inserted in the 2-inch plug from the drum.

(4) Place the valve with the nipple into the opening, making sure that it is far enough in to push off the cap inside the drum.

(5) Place the drum in a horizontal position near the cooler charging valve with the use of a hoist. The drum should be high enough to allow the refrigerant to flow as a liquid, by gravity, from the drum into the charging line. Rotate the drum so that the valve is at the bottom.

(6) Connect the two valves (drum and cooler) with a copper tube and fittings, making sure all the joints are leakproof.

(7) Open both valves and allow the refrigerant to flow into the cooler. Operate the machine to maintain a vacuum after the initial reduction to zero.

(8) When the drum is empty, close the valve on the cooler and disconnect the drum. Remove the valve for use with the next drum. Complete charging of the machine requires 1200 pounds of refrigerant.

5. *Adding refrigerant to bring refrigerant to standard level*. When adding refrigerant, use the same procedures that we have just discussed. Another method that can be used to add refrigerant is simply to allow the refrigerant to be drawn in as a gas. Let the drum rest on the floor and let the gas escape into the cooler while the machine is in operation or idle.

6. *Removing refrigerant*. In removing refrigerant from the cooler, the following procedure is recommended:

(1) By use of the purge recovery unit, inject air into the machine until the pressure is 5 pounds gauge.

(2) Connect tubing to the charging valve on the cooler and allow the refrigerant to discharge into the refrigerant drum.

(3) Less loss of refrigerant will take place if the refrigerant is cold. Always allow space in the drum for refrigerant expansion.

7. **Troubleshooting**. The steps to be taken in detecting and correcting improper operation of the centrifugal machine are outlined in table 19. Use the proper methods for making these service adjustments, repairs, and corrections as outlined in this chapter. All settings, clearances, and adjustments must be made to manufacture's specifications. The manufacturer's maintenance catalog gives definite clearances, temperatures, pressure, and positions for adjustment of component parts. These tolerances must be set as recommended for efficient operation; carelessness in these settings can cause extensive damage to the machine.

TABLE 19

TROUBLESHOOTING CENTRIFUGAL SYSTEMS

Fault	*Cause*	*Remedy*
High condenser pressure.	Low on condenser water.	Check condenser water pumps for proper operation.
	Sealed and dirty condenser tubes.	Inspect and clean condenser tubes.
	Division plate ruptures.	Replace division plate.
	Air in condenser. (Check differences between leaving water temperature and condensing temperature.)	Remove air from line.
	Condenser float valve in economizer stuck closed.	Adjust float, examine valve seat, and eliminate cause of sticking.
	Hot gas bypass valve open.	Close valve.
	Entering water temperature too low.	Regulate waterflow.
	Low charge of refrigerant.	Check refrigerant level in cooler and add refrigerant.
Loss of capacity.	Condenser not transferring enough heat.	Check items listed in "High condenser pressure."
	Hot gas bypass valve open.	Close valve.

TABLE 19-continued

Fault	*Cause*	*Remedy*
	Gradual contamination of refrigerant by oil.	Change refrigerant.
	Sudden increase in difference between refrigerant and water temperature.	Check division plates and gaskets in cooler water box for breakage.
	Gradual increase in water and refrigerant temperature.	Clean cooler tubes; remove excess oil from refrigerant; check division plates and gaskets.
Compressor surges.	Load too light.	Open hot gas bypass valve.
	Air leak.	Run purge and repair leak.
	High condenser pressure.	Check items listed in "High condenser pressure."
R-11 level too low.	Charge lost or trapped in condenser or economizer by the floats.	Find leak, check floats, add refrigerant after determining cause of loss.
	Purge leaking.	Check relief valve.
Compressor second stage frosts.	Economizer float valve stuck.	Check float operation.
	Light load with cold condenser water.	Decrease flow of condenser water.
	Suction damper closure causes circulation of condensate from economizer.	Readjust suction damper controls to give greater opening of damper.
Purge unit doesn't operate correctly.	Thermal overload on motor burned out.	Replace thermal overload on motor.
	High-pressure cutout switch contacts open.	Check settings and operation and reset if needed.
	Air-cooled condenser fouled with lint and dirt.	Claen condenser by blowing off lint with air hose.
	Shutoff valves closed.	Check valves and open if in closed position.
	No power.	Check switch, contacts, and connections.
	Broken belt on compressor.	Replace belt.
	Float valve in separator tank stuck.	Valve off unit, evaporate R-11, open tank, and repair float.
	Air relief valve stuck.	Stop unit, remove valve, and repair or replace.
	Suction line reducing valve stuck.	Valve off unit at condenser, remove valve and repair or replace.
Machine stops through action of safety controls.	High condensing pressure. (High-pressure switch indicating light will be on; also compressor and gear oil switch indicating lights.)	Check condenser performance. Check water quantity. Check cooler float valve operation. Purge air. Carefully check oil level, pressures, and temperatures for both compressor and gear when restarting machine.
	Low compressor oil pressure. (Indicating light will always be on when compressor stops; also gear oil switch.)	Check strainers in rear end and seal reservoir. Check reducing valve settings. Check oil levels, pressures, and temperatures of both compressor and gear on restarting.
	Low gear oil pressure. (Indicating light will always be on when compressor stops; also compressor oil switch.)	Check strainer. Check oil pressure switch setting. Check oil levels, pressures, and temperatures on compressor and gear.
	Low refrigerant or chilled water temperature. (Indicating light of control which opened will be on; also both oil switch indicating lights.)	Check for low load; shift load to another operating machine if required; check controls for proper adjustment and settings. Check oil levels, pressures, and temperatures of both compressor and gear on restarting.
	Condenser water or low chilled water pressure differential. (Indicating light will be on; also both oil switch indicating lights.)	Check for proper operation of pump; check for partially closed valve. Check oil levels, pressures, and temperatures of both compressor and gear on restarting.
	Compressor motor controller cutting out on thermal overload. (Motor controller white light out.)	Check load on unit; start second compressor if load is in excess of machine capacity.
High or low oil pressure.	Excessive dilution of oil with refrigerant or foaming on start.	Pump out by starting compressor momentarily several times. Remove

TABLE 19-Continued

Fault	Cause	Remedy
		diluted oil and replenish. Check previous operating logs to determine cause of dilution.
	Oil pressure regulating valve out of adjustment.	Check setting and readjust in accordance with instructions.
Low back of seal pressure with high seal pressure.	Dirty filter.	Remove, inspect, and clean filter.
	Filter cartridge improperly installed.	Check installation of filter and replace correctly.
Oil leaking out around compressor shaft while in operation or building up in atmospheric float chamber.	Atmospheric float valve sticking.	Drain oil from chamber and inspect float operation.
	Vent valve on seal chamber sticking open, causing flow of oil from reservoir.	Manually reset. Remove and clean dirt from seat.
Compressor bearing temperature high.	Insufficient flow of cooling water through oil cooler.	Open throttling cock to oil cooler.
	Excessive dilution of oil by the refrigerant upon startup, or electric oil heater off during shutdown.	Operate electric oil heater during shutdown.
	Temperature in pump chamber above 150° F. when compressor is started.	Turn on cooling water sooner on starting; check for clogged cooling coil. Check and clean.
	Thrust or shaft bearing scored.	Check bearing and shaft end clearance.
Compressor loses oil.	Worn labyrinths.	Check rotor balance and bearing wear.
	Leak in oil system.	Check oil piping and correct.

Fault	Cause	Remedy
	Oil level too high.	Drain oil.
Increasing differential between seal oil pressure and back of seal oil pressure.	Dirty filter.	Remove, inspect, clean.
	Improperly installed filter.	Check installation of filter and replace correctly.
Noisy couplings.	Misalignment.	Check at operating temperature and realign.
	Insufficient lubrication.	Add oil.
	Excessive wear.	Replace.
Cooler suction damper control not operating satisfactorily.	Control air supply off.	Check air line filter; check mechanical parts of controller.
	Damper linkage or blade binding.	Check damper movement by manually positioning the damper throughout entire range.
	Controller not functioning properly.	Check operation of control and adjust.
Refrigerant level in cooler too low.	Charge lost or trapped in condenser or economizer by the floats.	Add refrigerant. Check floats for proper operation.
	Purge unit leaking at relief valve.	Check relief valve.
Motor overloaded.	High chilled water temperature or flow.	Regulate cooling load or flow.
	Damper open.	Regulate and adjust controls.
	Refrigerant level too high.	Remove excess refrigerant.
Gear overheated.	High oil level.	Drain excess oil.
	Dirty cooler.	Clean cooler tubes.
	Low cooling water.	Increase flow.
	Misaligned coupling.	Check alignment and adjust.

Review Exercises

The following exercises are study aids. Write your answer in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text.

1. The refrigerant charge is approximately ___________ pounds. (Sec. 9, Par. 1)

2. Which component reduces the horsepower requirement per ton of refrigeration? (Sec. 9, Par. 2)

3. (Agree)(Disagree) The refrigerant flows through the tubes in the cooler. (Sec. 9, Par. 3)

4. The liquid refrigerant, from the condenser, enters the ________________. (Sec. 9, Par. 5)

5. How much pressure is there within the economizer chamber? (Sec. 9, Par. 5)

6. The suction gas is taken in by the compressor in ______________ the shaft. (Sec. 10, Par. 1)

7. How are the wheels (impellers) protected from corrosion? (Sec. 1, Par. 2)

8. Each bearing has _______________ large oil rings. (Sec. 10, Par. 3)

9. What prevents interstage leakage of gas? (Sec. 10, Par. 4)

10. Which end of the compressor will axial thrust affect? (Sec. 10, Par. 5)

11. The oil pump is driven from the ______________________. (Sec. 10, Par. 7)

12. Which component does the pump lubricate first? (Sec. 10, Par. 8)

13. How is oil returned from the oil pump drive gear? (Sec. 10, Par. 9)

14. How is the shaft seal actuated? (Sec. 1, Par. 10)

15. What purpose do the two holes in the inner floating seal ring serve? (Sec. 10, Par. 11)

16. The automatic stop valve is set to open at approximately _________________ pounds. (Sec. 10, Par. 12)

17. Which oil pressure gauges are mounted on the control panel? (Sec. 10, Par. 13)

18. How is the oil heater energized during shutdown? (Sec. 10; Par. 14)

19. (Agree)(Disagree) During operation the two polished surfaces of the shaft seal are held together with a spring. (Sec. 10, Par. 16)

20. What type oil is used in centrifugal compressors? (Sec. 10, Par. 17)

21. The compressor gear drive (increases, decreases) the motor to compressor speed. (Sec. 11, Par. 1)

22. The grade of oil to use on a gear depends on __________, ___________, and ______________.(Sec. 11, Par. 3)

23. When would you turn on the gear drive cooling water? (Sec. 11, Par. 5)

24. Worn bearings in the gear drive will cause ___________________. (Sec. 11, Par. 9)

25. Which coupling uses a spool piece? (Sec. 12, Par. 1)

26. How is the hub expanded when it is to be installed on the shaft? (Sec. 12, Par. 2)

27. The angular alignment of a coupling is checked with a _________________. (Sec. 12, Par. 3)

28. Which instrument is used to check the offset alignment of a coupling? (Sec. 12, Par. 4)

29. Which type of coupling can be lubricated while the compressor is running? (Sec. 12, Par. 8)

30. The motor furnished with the centrifugal machine is __________ phase, _________________ cycle, and has an ________________ rotor. (Sec. 13, Par. 1)

31. The secondary drum control is used to adjust the amount of resistance in the ___________________ of the motor which regulates motor ____________________ (Sec. 13, Par. 3)

32. Which switch is bypassed when the start button is held closed? (Sec. 13, Par. 4)

33. What is the secondary function of the condenser? (Sec. 14, Par. 1)

34. What prevents the discharge gas from directly hitting the condenser tubes? (Sec. 14, Par. 2)

35. What precaution would you observe while removing the water box cover? (Sec. 14, Par. 3)

36. A burst rupture disc is caused by __________________ (Sec. 14, Par. 6)

37. How can you determine the refrigerant charge of the system? (Sec. 14, Par. 11)

38. What is indicated when the temperature differential of the refrigerant and chilled water increases? (Sec. 14, Par. 13)

39. _________________ is prevented by the hot gas bypass. (Sec. 15, Par. 1)

40. Why is the liquid injector used in the hot gas bypass? (Sec. 15, Par. 2)

41. What controls the amount of liquid refrigerant flowing to the hot gas bypass? (Sec. 15, Par. 3)

42. (Agree) (Disagree) The high-pressure control on the purge unit must be reset manually. (Sec. 16, Par. 3)

43. Where is the weir and trap located on the purge unit? (Sec. 16, Par. 3)

44. High head pressure indicates that ____________________. (Sec. 16, Par. 5)

45. How is the air pressure in the condenser released to the atmosphere? (Sec. 16, Par. 6)

46. What amount of water collected by the purge unit is an indication of leaky tubes? (Sec. 16, Par. 8)

47. When will a pressure drop exist across the pressure-regulating valve? (Sec. 16, Par. 9)

48. When are large quantities of air normally purged from the centrifugal refrigeration system? (Sec. 16, Par. 10)

49. When is water drained from the separator unit? (Sec. 16, Par. 12)

50. The four safety controls that will stop the centrifugal are ________________, ________, ___________, and ________________. (Sec. 17, Par. 1)

51. Which safety control does not require manual resetting? (Sec. 17, Par. 2)

52. What is the differential for the high condenser pressure control? (Sec. 17, Par. 3)

53. How can you change (switch over) controllers? (Sec. 17, Par. 6)

54. The most efficient method of controlling the capacity of the centrifugal is to _____________________. (Sec. 18, Pars. 1 and 2)

55. What will occur if you add more resistance to the rotor circuit of the drive motor? (Sec. 18, Par. 3)

56. When is suction damper control more effective than speed control? (Sec. 18, Par. 4)

57. What is the position of the drum controller lever during startup? (Sec. 19, Par. 2)

58. What will cause the oil level to rise in the pump chamber during an extended shutdown? (Sec. 19, Par. 6)

59. The pressure within the machine during an oil replacement operation should be approximately _______________ p.s.i.g. (Sec. 20, Par. 2)

60. (Agree)(Disagree) The 2-inch plug in the refrigerant drum prevents leakage when the 3/4-inch plug is removed. (Sec. 20, Par. 3)

61. How is refrigerant charged into the system as a gas? (Sec. 20, Par. 5)

62. How do you pressurize the system to remove refrigerant? (Sec. 20, Par. 6)

63. What is one of the most probable causes of high condenser pressure? (Sec. 20, table 19)

64. Surging is caused by _________________, ________________, or ________________. (Sec. 20, table 19)

65. What would occur if the economizer float valve stuck? (Sec. 20, table 19)

66. What will cause a low "back of seal" oil pressure and a high seal oil pressure? (Sec. 20, table 19)

67. Noisy couplings are caused by ___________________, ________________, or _________________. (Sec. 20, table 19)

68. (Agree)(Disagree) A high oil level in the speed gear will cause the gear to overheat. (Sec. 20, table 19)

Water Treatment

WATER USED IN air-conditioning systems may create problems with equipment, such as scale, corrosion, and organic growths. Scale formation is one of the greatest problems in air-conditioning systems that have water-cooled condensers and cooling towers. Corrosion is always a problem in an open water recirculating system in which water sprays come in contact with air. The organic growth we are greatly concerned with is algae or slime. Since algae thrive on heat and sunlight they will be a problem in cooling towers. As a refrigeration specialist or technician you will save the military great sums of money if you test and treat your equipment water. For example, if you allowed scale to reach the thickness of a dime in a water-cooled condenser, it would cut the efficiency of the machine more than 50 percent.

21. Scale

1. When water is heated or evaporated, insolubles are deposited on metal surfaces. These deposits usually occur on the metal in the cooling towers, evaporative condensers, or inside the pipes and tubes of the condenser water system which have a recirculating water system. What causes scale? We can explain it in a simple formula:

$$Ca\,(HCO_3) + \text{heat} = CaCO_3, + CO_2 + H_2O$$

Calcium bicarbonate + heat = calcium carbonate + carbon dioxide + water

In this formula the calcium carbonate is the villain. *Calcium carbonate* is the chief scale-forming deposit found in air-conditioning systems, but *magnesium carbonate* and *calcium sulfate* can also cause some degree of scaling.

2. **Causes of Scale**. A rising temperature decreases the solubility of calcium carbonate and calcium sulfate. This is known as reverse solubility. Sodium compounds such as table salt (sodium chloride), on the other hand, have a direct solubility. Suppose you take a glass of water 80° F. and dissolve table salt into the water. Soon you will saturate the water and no amount of stirring would cause any more salt to go into solution. But if you heat the water to 100° F., more salt can be dissolved into the solution. This dissolving action is known as direct solubility. But if you reaccomplish these steps using calcium saturates instead of table salt, you would see more solids precipitate out of the solution as the heat is increased. This action is suitably called reverse solubility and occurs in a water-cooled condenser cooling tower.

3. You will find that scale will form on heat transfer surfaces when you use water containing even a small amount of hardness. The pH value of the water determines if the hard water will cause scale or corrosion. The pH scale is from 0 to 14. Neutral water has a pH value of 7.0. Any reading under 7.0 is acid, while a reading above 7.0 is base or alkaline.

4. Let us compare pH to temperature. A thermometer measures the temperature of a solution, while pH measures the intensity of acid or base in a solution. As you know, pH means potential hydrogen. When a hydrogen atom has lost its electron (H^+), it becomes a positive hydrogen ion. When a great many of these hydrogen atoms make this change, the solution will become highly acid and attack metals. When the hydrogen atom gains electrons, the solution will be base and have a pH value from 7.1 to 14. A base solution contains more hydroxyl ions (OH^-). Scale will form when a base solution is exposed to a temperature rise, providing the hardness is 200 parts per million or higher. Notice the recommended pH for cooling towers in figure 69.

5. You will find that it is very important to test for solids in the water because solid content (hardness) determines the amount of scale formation. Hardness is the amount of calcium and magnesium compounds in solution in the water. Water containing 200 p.p.m. hardness and a pH indication of 9 or above will enhance the formation of scale. To avoid scale in cooling towers, you must control hardness. The maximum p.p.m. standards for cooling towers are

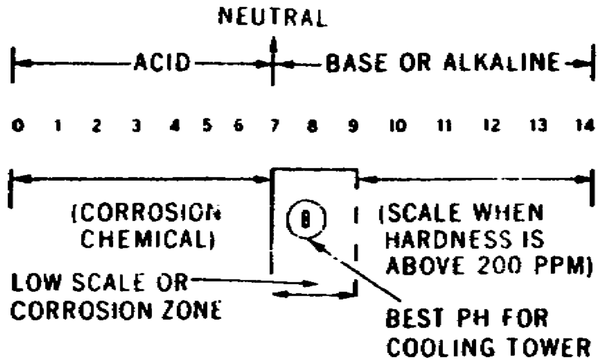


Figure 69. pH scale.

100 p.p.m. for makeup water and 200 p.p.m. for bleedoff water.

6. In cooling towers and evaporative condensers the water becomes harder due to evaporation. The term used to compare hardness to the circulating water to the makeup water is *cycles of concentration*. For example, 2 cycles of concentration indicate that the circulating water is twice as hard as the makeup water. If the makeup water contained 100 p.p.m., the circulating water would contain 200 p.p.m. To avoid this damaging concentration, you will find it is necessary to limit the cycles of concentration. Bleedoff is an effective method used for this purpose. The amount of bleedoff can be calculated by using the following formula:

Cycles of concentration

$$= \frac{\text{bleedoff hardness (circulating water)}}{\text{makeup hardness}}$$

For example: if the bleedoff (circulating water) is 150 p.p.m. and the makeup is 50 p.p.m., the cycles of concentration are 3.

7. There are many methods of treating water to prevent scale. A few of these are:

- Bleedoff-regulate the amount of bleedoff water to keep the cycles of concentration within tolerance.
- pH adjustment-maintain the pH of the water between 7 and 9, as near 8 as possible.
- Add polyphosphates-keeps scale forming compounds in solution.
- Zeolite water softening-exchanges a nonscale forming element for calcium and magnesium compounds.

Before we discuss water softening, we will introduce the soap hardness test.

8. **Soap Hardness Test**. The soap hardness test is used to measure total hardness. The presence of calcium and magnesium salts, and to a lesser degree other dissolved minerals, constitutes hardness in water. Hardness can be best determined by soap titration. Soap titration directly measures the soap-consuming capacity of a water. You will study this test in the following paragraphs.

9. To begin the soap hardness test, measure 50 milliliters of the sample water into the hardness testing bottle. Add the *standard* soap solution to the water, 0.5 ml. at a time, from the soap burette, shown in figure 70. Shake bottle vigorously after each application and place it on its side. If no lather forms, continue adding 0.5-ml. portions of soap solution to a maximum of 6 ml and place the bottle on its side. Now you must use the formula below if you have a permanent lather to complete the test. If a permanent lather does not appear, see para 10. Hardness (p.p.m.)

= 20 X (total number or ml. of standard soap solution required for permanent lather)

10. If a permanent lather does not appear after adding 6 ml. of the standard soap solution,

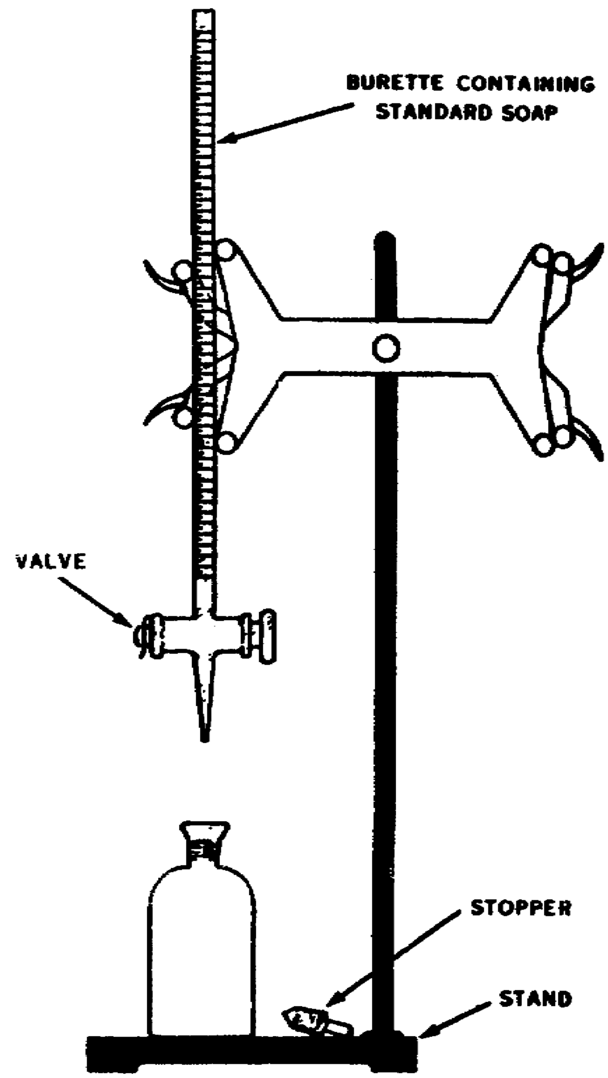


Figure 70. Soap hardness test equipment.

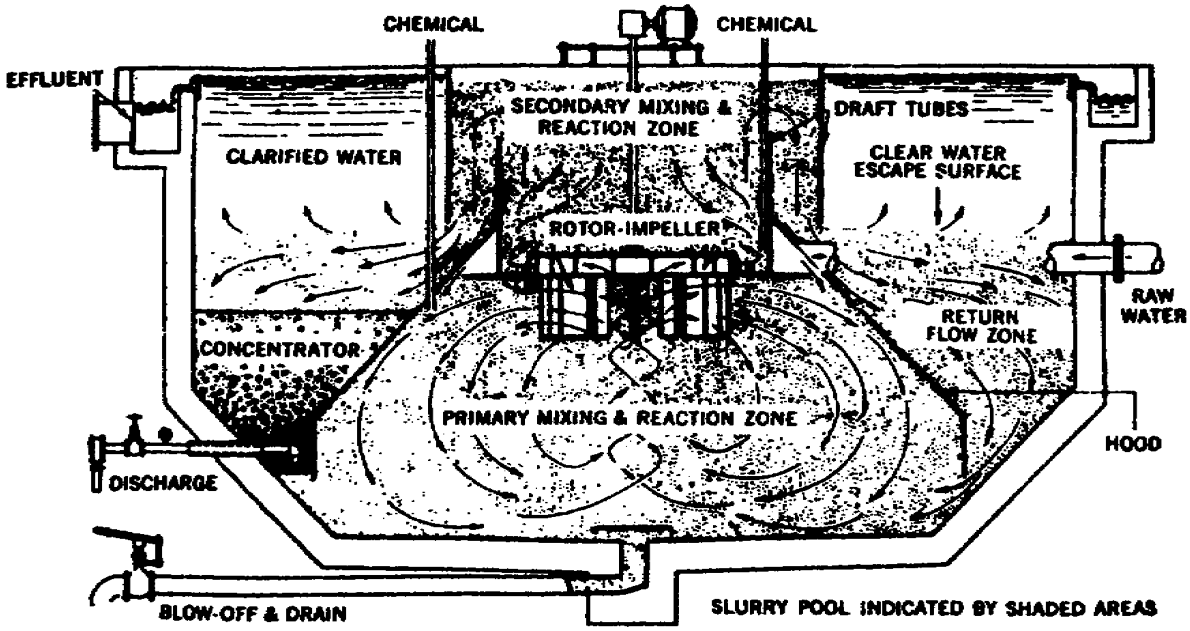


Figure 71. Accelator.

repeat the test with a new water sample. This time dilute 25 ml. of the sample water with an equal quantity of zero-hardness water (distilled water). Conduct the test as you studied previously. When a permanent lather has been obtained, calculate the hardness as follows:

= 40 X (total number of ml. of standard soap solution required for permanent lather)

11. **Water Softening**. Hard waters are potable but are objectionable because they form scale inside of plumbing and on metal system components. A temporary hardness can be caused by magnesium bicarbonate. Hard water can be softened by two different methods. The first is the lime-soda process which changes calcium and magnesium compounds from soluble to insoluble forms and then removes these insolubles by sedimentation and filtration. The second and most common is zeolite or base-exchange process. This process replaces soluble calcium and magnesium compounds with soluble sodium compounds.

12. *Lime-soda process*. Lime-soda process plants are essentially the same as water filtration plants. Lime and soda ash are added to raw water; the softening reaction occurs during mixing and flocculation. The precipitated calcium and magnesium a removed by sedimentation and filtration. An additional process, called recarbonation, which is the introduction of carbon dioxide gas, is frequently applied immediately prior to filtration. If the raw water has high turbidity, the turbidity is partial removed by sedimentation prior to the adding of the lime and soda.

13. *Zeolite process*. The zeolite process is usually used for water which has low turbidity and does not require filtration. Treatment may be given to the entire supply at one point. This system is commonly used to soften water for special uses, such as for the control of scale. In such cases, the treatment units are located at points near the equipment requiring treated water.

14. Turbidity is a muddy or unclear condition of water which is caused by suspended silt, clay, sand, or organic materials such a decaying vegetation or animal waste. Turbidity can be corrected by sedimentation, filtration, or traps. In most cases the water supply and sanitation personnel will supply you with usable, potable water.

15. *Softening devices*. Softening devices include patented equipment such as the Accelator and Spiractor. The Accelator is also used as a combined flocculation and sedimentation unit without softening. When this unit is operated before filtration to treat water with low suspended solids and low alkalinity, it may be necessary to add lime or clay to add weight and prevent rising floc.

16. The Accelator, shown in figure 71, is a suspended solid clarifier. Precipitates which are formed are kept in motion by a combination of mechanical agitation and hydraulic flow. Velocity of waterflow through the system is controlled to keep precipitates in suspension at a level where water passes through them. The accumulated

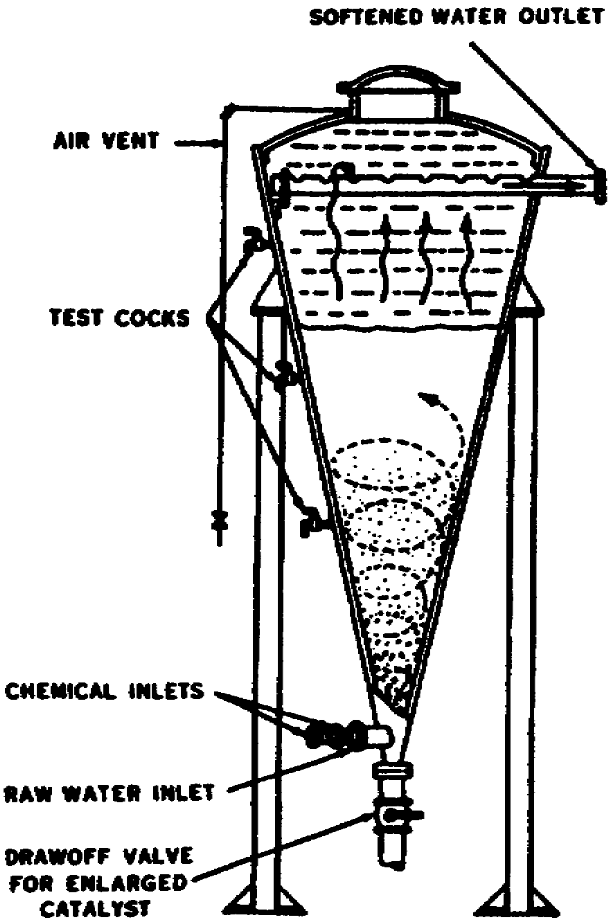


Figure 72. Spiractor

precipitate is called the sludge blanket. When the Accelator is operating properly, the water above the sludge blanket and flowing over the weirs is clear. Operation depends on balancing the lift of particles by the velocity of upward flowing water against the pull of gravity. When the velocity of the water is gradually decreased, a point is reached at which the particles are too heavy to be supported by the velocity of the water. Continuous treatment builds up the sludge blanket which is drawn off as required. Operation of the equipment is covered in detail in the manufacturer's instruction manuals.

17. The Spiractor, shown in figure 72, consists of an inverted conical tank in which the lime-soda softening reactions take place in the presence of a suspended bed of granular calcium carbonate. In operation, the tank is slightly more than half filled with 0.1 to 0.2 millimeter granules. Hardwater and chemicals enter the bottom of the unit close to each other. They mix immediately as the treated stream of water rises through the granular bed with a swirling motion. The upward velocity keeps the granular material in suspension. As the water rises, velocity decreases to a point where material is no longer in suspension. The contact time, 8 to 10 minutes, is enough to complete softening actions. Softened water is drawn off from the top of the cone. The size of calcium carbonate granules increases during the process, increasing the bulk of granules in the unit. The water level of the cone is kept down to the desired point by withdrawing the largest particles from the bottom. New material must be added, which can be produced by regrinding and screening the discharged material. Softened water is usually filtered through a sand filter to move turbidity. Advantages of the equipment are its small size, low installation cost, rapid treatment lack of moving parts and pumping equipment, and elimination of sludge disposal problems. The unit is most effective when hardness is predominantly calcium, there is less than 17 p.p.m. magnesium hardness (expressed as calcium carbonate), water temperature is about 50° F., and turbidity is less than 5 p.p.m.

18. *Zeolite (ion exchange).* Ion exchange is a chemical operation by which certain minerals that are ionized or dissociated in solution are exchanged (and thus removed) for other ions that are contained in a solid exchange medium, such as a zeolite sandbed. An example is the exchange of calcium and magnesium, in solution as hardness in water, for sodium contained in a sodium zeolite bed. The zeolites used in the process of ion exchange are insoluble, granular materials. A zeolite may be classified as follows: glauconite (or green sand), precipitated synthetic, organic (carbonaceous), synthetic resin, and clay. Various zeolites are used, depending on the type of water treatment required. Most zeolites possess the property cation, or base exchange, but anion exchangers are also available and may be used when demineralization of water is required. In the course of treating water, the capacity of the zeolite bed to exchange ions is depleted. This depletion requires the bed to be regenerated by the use of some chemical that contains the specific ion needed for the exchange. For instance, when a sodium zeolite is used to soften water by exchanging the sodium ion for the calcium and magnesium ions of hard water, the zeolite gradually becomes depleted of the sodium ion. Thus, it will not take up the calcium and magnesium ions from the water passing through the bed. The sodium ion is restored to the zeolite by uniformly distributing a salt or brine solution on top of the bed and permitting it to pass evenly down through the bed. The salt removes the calcium and magnesium taken up by the bed as soluble chlorides and restores the zeolite to its original condition. Beds may also be regenerated with acid, sodium carbonate,

sodium hydroxide, or potassium permanganate, depending on the type of zeolite being used.

19. In addition to the problem of scale, the refrigeration man knows that corrosion is a constant problem. Let us now study corrosion, its causes, its effects, and its control.

22. Corrosion

1. In the refrigeration/air-conditioning field, corrosion has long been a problem. Even in the modern missile complexes, corrosion is prevalent. Corrosion is very difficult to prevent, but it can be controlled. Before we can control corrosion, we first must understand what causes it.

2. The effects of corrosion differ as to the type of corrosion, such as uniform, pitting, galvanic, erosion-corrosion, and electrochemical. We must understand various ways of treating the system to control these types of corrosion. Corrosion is generally more rapid in liquids with a low pH factor than in alkaline solutions.

3. **Types of Corrosion**. An air-conditioning system may have several types of corrosion in the water system. Many of these types are undoubtedly familiar to you.

4. *Uniform corrosion*. One of the most common types of corrosion encountered in acid environments is known as uniform corrosion. This is caused by acids, such as carbonic, which cause a uniform loss of metal throughout the condensating water system.

5. *Pitting corrosion*. Pitting corrosion is a nonuniform type, the result of a local cell action produced when a particle, flake, or bubble of gas deposited on a metal surface. The pitting is a local accelerated attack, which causes a cavity in the metal but does not affect the surrounding metal. Oxygen deficiency under such a deposit sets up an anodic action. This area keeps producing such action until the penetration finally weakens the structure and it falls, developing a pinhole leak.

6. *Galvanic corrosion*. When dissimilar metals which are capable of carrying electric current are present in a solution, galvanic corrosion occurs. This action is similar to the electroplating process used in industry to bond or plate dissimilar metals. When two metals similar to each other are joined together, there is little reaction. But the coupling of two metals from different groups causes accelerated corrosion in one of the two metals. When using large amounts of copper in a system and a few unions of steel, the steel will corrode at a rapid rate. In such cases you should install nonferrous metal instead of steel. Corrosion inhibitors reduce the corrosion rate but will not eliminate galvanic corrosion.

7. *Erosion-corrosion*. Erosion-corrosion is caused by suspended matter or air bubbles in a rapidly moving water. The matter can be fine to coarse sand, depending on the velocity of the water. Usually the greatest *amount* of erosion-corrosion will take place at elbows and U-bends. Another place where erosion-corrosion takes place is on the impellers of centrifugal pumps.

8. Good filtration installations will remove grains of sand and other matter that are large enough to cause erosion-corrosion. To get rid of air tapped in a system, it is recommended that hand- or spring-operated bleed valves be installed in the highest point of the water system. Purging the water system gets rid of the air bubbles that enter the system in the makeup water.

9. *Electrochemical corrosion*. Electrochemical corrosion occurs when a difference in electrical potential exists between two parts of a metal in contact with an electrolyte (water). The difference in potential will cause electric current to flow. The difference in potential may be set up by two dissimilar metals, by a difference in temperature or amount of oxygen, or by the concentration of the electrolyte at the two points of contact with the metal. The *anode* is the point at which the current flow is from the metal to the electrolyte; it is here that corrosion occurs. The *cathode*, which is usually not attached, is the point of current flow from the electrolyte to the metal. This action is shown in figure 73.

10. **Corrosion Inhibitor**. The most common chemicals used as inhibitors are chromates and polyphosphates. These inhibitors alone serve only to decease the rate of corrosion, but if other water treatments are used in conjunction with them, corrosion may be nearly stopped.

11. *Chromates*. Chromates are seldom present n untreated water; however, they may occur as a result of industrial waste contamination. The chromates are used extensively to inhibit corrosion and are effective in the water air-conditioning systems in concentrations of 200-500 p.p.m. at a pH of 7.0 to 8.5. Chromates are the most commonly used corrosion inhibitors in chilled water systems. For corrosion prevention the most favorable range is with the pH from 7.5 to 9.5, but scaling becomes a problem at the higher pH range. Consequently, the pH should be held near the *lower range* where corrosion protection is excellent. Because it is more economical, sodium bichromate ($Na_2Cr_2O_72H_2O$) is the most commonly used chromate compound. Sodium chromate (Na_2CrO_4) is also used widely.

12. Chromate concentration is stated in p.p.m.

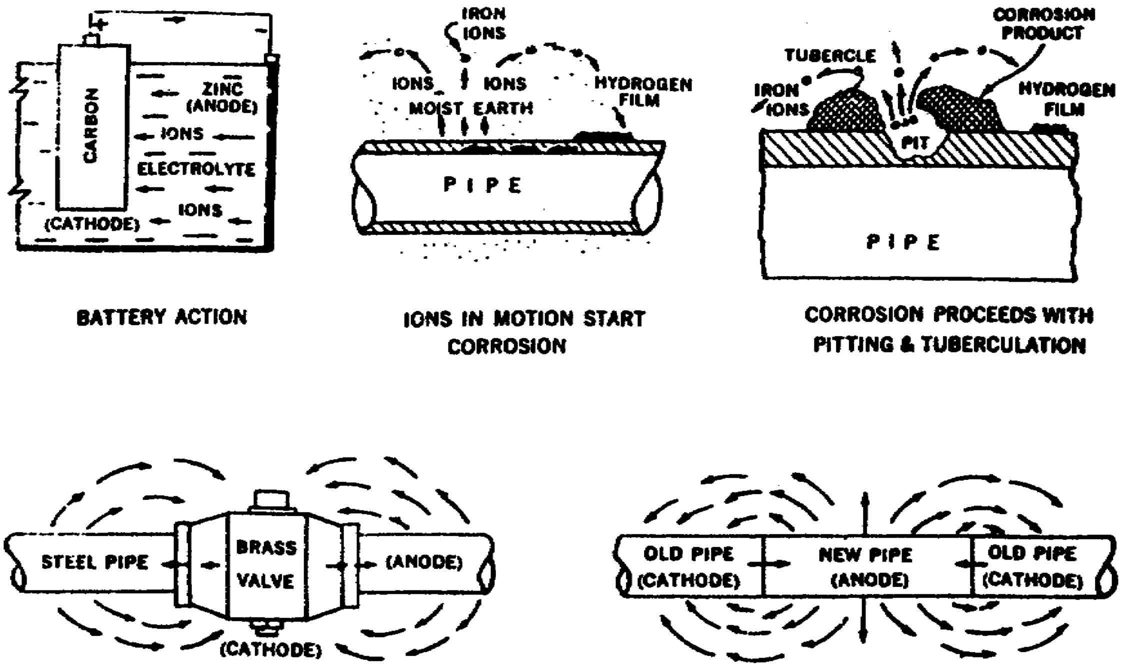


Figure 73. Causes and effects of corrosion.

Chromates are anodic inhibitors but can intensify pitting if they are used in insufficient amounts. Field tests must be performed to be sure the required amount of chromate is in the water, and to check the pH. Corrosion is greatest when the pH is between 0 to 4.5.

13. Chromate concentration is tested by color comparison. The color of the treated water is matched against a known chromate disc. For example, if the sample of treated water matches a tube known to contain 200 p.p.m. of chromate, the sample would also contain 200 p.p.m. of chromate.

14. *Polyphosphates.* Phosphates, particularly the polyphosphates, are used in cooling water treatment. The ability to prevent metal loss with polyphosphate treatment is inferior to the chromate treatment previously discussed. In addition, pitting is more extensive with polyphosphates. Unlike chromate, high polyphosphate concentrations are not practical because of the precipitation of calcium phosphate.

15. One advantage of using polyphosphates is that there is no yellow residue such as produced by chromates. This highly undesirable residue is often deposited on buildings, automobiles, and surrounding vegetation by the wind through cooling towers or evaporative condensers, when the system is treated by chromates. Also, polyphosphate treatment reduces corrosion products (sludge and rust) known as tuberculation.

16. A factor limiting the use of polyphosphates in cooling water systems is the reversion of polyphosphates to orthophosphates. Orthophosphates provide less protection than polyphosphates, and orthophosphates react with the calcium content of the water and precipitate calcium phosphate. This precipitation forms deposits on heat exchanger surfaces. The reversion of polyphosphates is increased by long-time retention and high water temperatures. Bleedoff must be adjusted on the condenser water system to avid exceeding the solubility of calcium phosphate.

17. The test used to determine the amount of polyphosphates in the system is similar the chromate color comparison test.

18. *Corrosion inhibitor feeders.* Many times a simple bag will be used to feed the chemicals into the water. The chemicals, in pellet or crystal form, are placed in nylon net bags and hung in the cooling tower sump. However, chilled water and brine systems require the use of a pot type feeder similar to the feeder shown in figure 74.

19. The chemical charge is prepared by dissolving the chemicals in a bucket and then filling the pressure tank (F) with the solution. Valves B and C are closed, and valve A is opened to drain the water out of the tank. After the water is drained, close valve A and open valves D and E. Then fill tank (F) with the dissolved chemical solution. Opening valves B and C after you have closed valves D and E will place the feeder in operation. The feedwater from the discharge

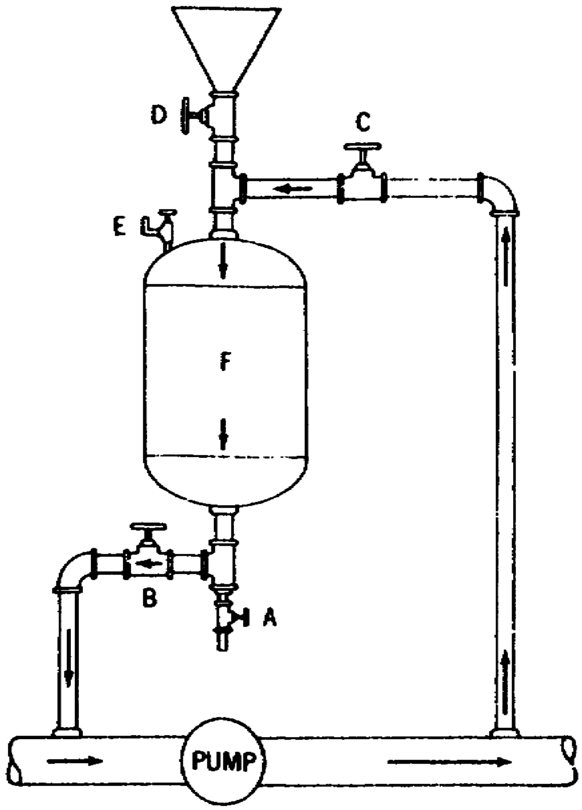


Figure 74. Pot type feeder.

side of the pump with force the solution into tie suction side of the pump. Within a few minutes, the solution will be washed out of the tank. This feeder is nonadjustable.

20. Another type of feeder you may use is the pot type proportional feeder. This type, similar to the one shown in figure 74, has an opening to permit charging with chemicals in briquette or lump form. A portion of the water to be treated is passed through the tank, gradually dissolving the chemicals.

21. The degree of proportionality is questionable at times, because there is little control over the solution rate of the briquettes or the chemical incorporated in them. Although this system is classified as proportional, it cannot be used where accuracy of feed is required. It is used successfully in our application because we have a large range in p.p.m. to control-for example, 250-300 p.p.m. chromate.

22. Now that we have studied corrosion and corrosion control, let's discuss algae.

23. Algae

1. Algae are slimy living growth of one-celled animals and plants. They may be brought by birds or high winds. Algae thrive in cooling towers and evaporative condensers, where there is abundance of sunlight and high temperatures to carry on their life's processes. Algae formations will plug nozzles and prevent proper distribution of water, thus causing high condensing pressures and reduced system efficiency. In relation to the larger subject of algae, we will study residual chlorine tests, chlorine demand tests, pH determination, pH adjustment, chlorine disinfectants, hypochlorination, and chlorination control.

2. **Residual Chlorine Test**. The growth of algae is controlled by chlorination. The residual chlorine test is the test that we make to determine the quantity of available chlorine remaining in the water after satisfaction of the chlorine demand has occurred. Orthotolidine is the solution used in making the residual chlorine test. This solution reacts with the residual chlorine, taking on a color which is matched against a standard color in the comparator disc. Readings up to 5 p.p.m. may be read from the comparator disc. One p.p.m. will control algae and 1.5 p.p.m. will kill algae.

3. The time required for full development of color by orthotolidine depends on the temperature and kind of residual chlorine present. You will find that the color will develop several times faster when water is at 70° F. than when it is near the freezing point. For this reason, you must warm up cold samples quickly after mixing the sample with orthotolidine. Simply holding the sample tube in your hand is sufficient.

4. For samples containing only free chlorine, maximum color appears almost instantly and begins to fade in a minute. You must take the reading at maximum color intensity. However, a longer period is required for full color development of chloramines which may be present. Since samples containing combined chlorine develop their color at a rate primarily dependent upon temperature and to a lesser extent on the quantity of nitrogenous material present, observe the samples frequently and use their maximum value.

5. At 70° F. the maximum color develops in about 3 minutes, while at 32° F. it requires 6 minutes. The maximum color starts to fade after about 1½ minutes. Therefore, in the orthotolidine-arsenite (OTA) test, the water temperature should be about 70° F and the sample read at maximum color and in less than 5 minutes. Preferably, permit the color to develop in the dark. Read the sample frequently to insure observation of maximum color.

6. Use enough chlorine so that the residual

in the finished water after 30 minutes of contact time will be as follows:

Concentration of Chlorine (p.p.m.)	Hydrogen Ion Concentration, pH
2.0	6.0
2.2	7.0
2.5	8.0
2.8	9.0

These residuals are effective for water temperatures ranging from 32° to 77° F. Bactericidal efficiency of chlorine increases with an increase in water temperature.

7. Two types of residual chlorine have been mentioned. The first is the free available chlorine which can be measured by the OTA test. It is valuable because it kills algae quickly. The second is the combined available chlorine, produced by the chloramines, a slower acting type and therefore one which requires a higher concentration to achieve an equivalent bactericidal effect in the same contact time.

8. The orthotolidine-arsenite (OTA) test is the preferable one in determining chlorine residuals since it permits the measurement of the relative amounts of free available chlorine, combined available chlorine, and color caused by interfering substances. The test is best performed in a laboratory because the accuracy of the results is dependent upon the quantity of available chlorine preset, the adherence to time intervals between the addition of reagents and the temperature of the sample. With water temperatures above 68° F, the accuracy decreases, whereas below this temperature, it increases.

9. The free available chlorine residual subtracted from the total residual chlorine would equal the combined available residual. You recall that the combined available residual is actually that slower acting residual created by the chloramines which have formed in the water. Since the OT test measures only the total available chlorine residual, it impossible to determine the combined available chlorine residual with this test. With the orthotolidine test, both the free and combined available chlorine are measured. If it is desired to determine whether the residual is present in either the free or combined form, it is necessary to employ the orthotolidine-arsenite test.

10. Chlorine Demand Test. The chorine demand of water is the difference between the quantity of chlorine applied in water treatment and the total available residual chlorine present at the end of a specified contact period. The chlorine demand is dependent upon the amount of chlorine applied (amount applied is dependent upon the free available and combined available chlorine), the nature and the quantity of chlorine-consuming agents present, the pH value, and the temperature of the water. Remember that the high pH and low temperature retard disinfection by chlorination. For comparative purposes, it is imperative that all test conditions be stated, such as water sample temperature or room temperature.

11. The smallest amount of residual chlorine considered to be significant is 0.1 mg/1 Cl. Some of the chlorine-consuming agents in the water are nonpathogenic, but they contribute to the total chlorine demand of the water just as other agents do.

12. Chlorine demand in most water is satisfied 10 minutes after the chlorine is added. After the first 10 minutes of chlorination, disinfection continues but at a diminishing rate. A standard period of 30 minutes of contact time is used to insure that highly resistant organisms have been destroyed, provided that a high enough dosage has been applied.

13. The chlorine demand test is used as a guide in determining how much chlorine is needed to treat a given water. Briefly, the test consists of preparing a measured test dosage of chlorine, adding it to a sample of the water to be treated, and adding the resultant residual after 30 minutes of contact time. The required dosage is then computed; it is the chlorine needed to equal the sum of the demand plus the minimum contact residual.

14. To determine the chlorine demand, calcium hypochlorite, containing 70 percent available chlorine, is used for the test. Mix 7.14 grams of calcium hypochlorite ($Ca(OCL)_2$) with 1000 cc. of the best water available to produce 5000 p.p.m. chlorine solution. One milliliter of this standard solution (reagent), when added to 1000 cc. of the water to be tested, equals 5 p.p.m. chlorine test dosage. Thus, with 1 milliliter of the reagent equaling 5 p.p.m., any proportionate test dosage may be arrived at by using one-fifth, 0.2 ml., of the reagent in 1000 cc. of the water for each p.p.m. of chlorine dosage desired. After adding a test dosage of a known strength of a 1000-cc. sample of the water to be tested (5 p.p.m., or 1 ml. of the reagent is normally used), wait 30 minutes and run a chlorine residual test. You subtract the chlorine residual from the test dosage to obtain the chlorine demand.

15. If you do not obtain a residual after a 30-minute period, the test is invalid and must be repeated. You increase the reagent by 5 p.p.m. each time until a residual is obtained. If, for example, the test were repeated two times, the results would be recorded as follows:

Test dosage 2×5	= 10.0 p.p.m. Cl_2
Cl_2 residual	= -5.0 p.p.m. Cl_2
	= 5.0 p.p.m. Cl_2

16 **pH Determination**. The pH determination

and residual chlorine tests are both made with the color comparator. Knowing the pH value of water is important for several reasons. First, the pH value influences the amounts of chemicals used for coagulation. Second, the disinfecting action of chlorine (to control algae) is retarded by a high pH. If pH is above 8.4, the rate of disinfection decreases sharply. Third, the corrosion rate is lowest at a pH of 14, increases to a pH of 10, and remains essentially uniform until a pH of 4.3 is reached, when it increases rapidly.

17. But, how do you determine the pH value of water with the comparator? Three indicator solutions are supplied for making pH determinations with the comparator. Bromcresol purple green is used for the pH range from 4.4 to 6.0. Bromthymol blue is used for pH values from 6.0 to 7.6. Cresol red-thymol blue is used for pH values from 7.6 t 9.2. Standard color discs covering each range are supplied with the comparator. Generally, the bromthymol blue indicator is used first since most pH values fall within its range. The readings for pH are made immediately after adding the indicator. You should keep in mind that clorimetric indicators provide sharp changes in readings over a short span of the pH range, but once the end of the range has been reached, little change in color is noted even though a considerable change in pH takes place. For this reason readings of 5.8 to 6.0, obtained when using the bromcresol purple green indicator, should be checked by taking a reading with bromthymol blue. Similarly, pH readings of 7.6 to 7.8 on the cresol red-thymol blue disc should be checked on the bromthymol blue disc.

18. To determine the pH value, fill the tubes to the mark with the water sample. Add the indicator solution to one tube in the amount specified by the manufacturer, usually 0.5 ml. (10 drops) for a 10-ml. sample tube and proportionally more for larger tubes. Mix the water and indicator and place the tube in the comparator.

19. After you place the tube in the comparator, you match for color and read pH directly. If the color is at either the upper or lower range of the indicator selected, repeat the test with the next higher or lower indicator.

20. If a color comparator is not available, methyl orange and phenolphthalein indicators may be used to make an approximate pH determination. These indicators are used primarily for alkalinity determinations, but they can be used for a rough check of pH values.

21. To determine a low pH that is around 4.3, fill a test bottle to the 50-ml. mark with a sample of the water to be tested and add 2 drops of methyl orange indicator. Observe the test bottle against a white background and interpret the color thus: pinkish red, pH below 4.3; yellow, pH above 4.3.

22. To determine a high pH that is around 8.3, fill a test bottle to the 50-ml. mark and add 2 drops of phenolphthalein indicator. Observe the test bottle against a white background and interpret thus: pink, pH above 8.3; colorless, pH below 8.3.

23. **pH Adjustment**. Caustic soda, soda ash, and sodium hydroxide can be added to water to increase the pH. The caustic soda or sodium hydroxide treatment uses a solution feeder to add the chemical. This is the type of feeder used to chlorinate water for algae control. Soda ash is added by means of a proportioning pot type feeder. The amount you would add depends upon the pH of the water. Test the water frequently while adding these chemicals and stop the treatment when the desired pH level is reached.

24. Acids are added to lower the pH. The types used are sulphuric, phosphoric, and sodium sulfate. They are added through solution feeders. Add only enough acid to reduce the pH (alkalinity) to the proper zone. The zone is usually 7-9 pH, *preferably a pH of 8*.

25. **Chlorine Disinfectants**. Chlorine disinfectants are available in a number of different forms. The two forms that we will use are calcium and sodium hypochlorite.

26. *Calcium hypochlorite*. Calcium hypochlorite, Ca $(OCl)_2$, is a relatively stable, dry granule or powder in which the chlorine is readily soluble. It is prepared under a number of trade names, including HTH, Perchloron, and Hoodchlor. It is furnished in 3- to 100-pound containers and has 65 to 70 percent of available chlorine by weight. Because of its concentrated form and ease of handling, calcium hypochlorite is preferred over other hypochlorites.

27. *Sodium hypochlorite*. Sodium hypochlorite, NaOCl, is generally furnished as a solution that is highly alkaline and therefore reasonably stable. Federal specifications call for solutions having 5 and 10 percent available chlorine by weight. Shipping costs limit its use to areas where it is available locally. It is so furnished as powder under various names, such as Lobax and HTH-I5. The powder generally consists of calcium hypochlorite and soda ash, which react in water to form sodium hypochlorite.

28. **Hypochlorinators**. Hypochlorinators, or solution feeders, introduce chlorine into the water supply in the form of hypochlorite solution. They are usually modified positive-displacement piston or diaphragm mechanical pumps. However, hydraulic displacement hypochlorinators are also used. Selection of a feeder depends on local

conditions, space requirements, water pressure conditions, and supervision available. Fully automatic types are actuated by pressure differentials produced by orifices, venturis, valves, meters, or similar devices. They can also be used to feed chemicals for scale and corrosion control. Common types of hypochlorinators are described below.

29. *Proportioneers Chlor-O-Feeder.* The Proportioneers Chlor-O-Feeder is a positive-displacement diaphragm type pump with electric drive (fig. 75) or hydraulic operating head (fig. 76). Maximum capacity of the most popular type, the heavy-duty midget Chlor-O-Feeder, is 95 gallons of solution in 24 hours.

30. *a*. Semiautomatic control. The motor-driven type may be cross connected with a pump motor for semiautomatic control. The hydraulic type can be synchronized with pump operation by means of a solenoid valve.

31. *b*. Fully automatic control. Motor-driven types are made fully automatic by use of a secondary electrical control circuit actuated by a switch inserted in a disc or compound-meter gearbox. This switch closes momentarily each time a definite volume of water passes through the meter, thus starting the feeder. A timing element in the secondary circuit shuts off the feeder after a predetermined number of feeder strokes; the number of strokes is adjustable. In the hydraulic type, shown in figure 77, the meter actuates gears in a Treet-O-Control gearbox which in turn controls operation of a pilot valve in the water or air supply operating the feeder. The dosage rate is controlled by waterflow through the meter, thus automatically proportioning the treatment chemical. Opening and closing frequency of the valve thus determines frequency of operation of the Chlor-O-Feeder.

32. *Wilson type DES hypochlorinator.* The Wilson type DES hypochlorinator is a constant-rate, manually adjusted, electric-motor-driven, positive-displacement reciprocating pump for corrosive liquids, and is shown in figure 78. Maximum capacity is 120 gallons of solution per day. This unit is a piston pump with a diaphragm and oil chamber separating the pumped solution from the piston to prevent corrosion of working parts.

33. *Model S hypochlorinator (manufactured by Precision Chemical Pump Corporation).* The Model S hypochlorinator, shown in figure 79, is a positive-displacement diaphragm pump with a manually adjustable feeding capacity of 3 to 60 gallons per day. A motor-driven eccentric cam reciprocates the diaphragm, injecting the solution into the main supply. Use of chemically resistant plastic and synthetic rubber in critical parts contributes to long operating life.

34. **Chlorination Control**. To estimate dosage when no prior record of chlorination exists or where chlorine demand changes frequently:

(1) Determine chlorine demand, or start chlorine feed at a low rate and raise feed by small steps; at the same time make repeated residual tests until a trace is found. Observe rate of flow treated and rate of chlorine feed at this point. Chlorine demand then equals dosage and is determined from the following equation:

$$\text{Dosage in p.p.m.} = \frac{\text{rate of feed in pounds per day}}{8.34 \times \text{flow in millions of gallons per day}}$$

(2) Add the minimum p.p.m. required residual to the p.p.m. demand in order to estimate the p.p.m. dosage required to obtain a satisfactory residual. Then set chlorinator rate of feed in accordance with the above estimated p.p.m dosage. Further upward adjustment after making residual tests is usually required because the demand increases as the residual is increased.

35. Rate of feed of hypochlorinators is found from the loss in volume of gallons of solution by determining change in depth of solution in its container. Knowing the solution strength, the pounds of chlorine used can be calculated:

$$\text{Rate of feed} = \frac{\text{loss in weight} \times 24}{\text{check period in hours}}$$

36. Available chlorine content of the chlorine compound used must be known in order to calculate the rate of hypochlorite-solution feed. Available chlorine is usually marked on the container as a percentage of weight. Values generally are as follows:

Calcium hypochlorite ....70 percent
Sodium hypochlorite (liquid) ....10 percent (varies)

(1) To find the actual weight of chlorine compound to be added, use the equation:

$$\text{Pounds of chemical required} = \frac{\text{pounds of chlorine required} \times 100}{\text{percent available chlorine}}$$

(2) To find the amount of 1-percent dosing solution needed to treat a given quantity of water with desired dosage, use the equation:

$$\text{Gallons dosing solution} = \frac{\text{Gallons water treated} \times \text{desired chlorine dosage in p.p.m.}}{10{,}000}$$

(3) To prepare various quantities of 1-percent dosing solution, use the amounts given table 20.

(4) To find the rate of feed of chlorine in gallons per day, use the equation:

$$\text{Chlorine rate of feed in gallons per day} = \frac{\text{m.g.d. flow} \times \text{p.p.m. dosage}}{\text{percent strength of dosing solution} \times 10{,}000}$$

TABLE 20

Amounts of Chlorine Compounds Used To Prepare 1-Percent Dosing Solution

Gallons of Dosing Solution	*Calcium Hypochlorite 70%*		*Chlorinated Lime 35%*		*Gallons of Hypochlorite Stock Solution*			
	Pounds	**Ounces**	**Pounds**	**Ounces**	**15%**	**10%**	**6%**	**5%**
5	0 —	9½	1 —	3	⅓	½	⅚	1
10	1 —	3	2 —	6	⅔	1	1⅔	2
15	1 —	12½	3 —	9	1	1½	2½	3
20	2 —	6	4 —	12½	1⅓	2	3⅓	4
25	2 —	15½	5 —	15½	1⅔	2½	4⅙	5
30	3 —	9	7 —	2½	2	3	5	6

(5) To feed the pounds of chlorine compound needed to prepare dosing solution of a desired strength, use the equation:

Pounds of compound required

$$= \frac{\text{(percent strength of solution)} \times \text{(gallons of solution required)} \times (8.34)}{\text{percent available chlorine in compound}}$$

(6) To find the gallons of hypochlorite stock solution needed to prepare dosing solution of a required strength, use the equation:

Gallons stock solution required

$$= \frac{\text{(percent strength of dosing solution)} \times \text{(gallons of dosing solution required)}}{\text{percent strength of stock solution}}$$

37. CAUTION: Make dosing solutions strong enough so that the hypochlorinator can be adjusted to feed one-half its capacity per day or less. Avoid using a calcium hypochlorite dosing solution stronger than 2 percent, even if it is necessary to set the machine to feed its full day capacity. If calcium hypochlorite solution stronger than 2 percent is required when the feed is set a maximum, small amounts of sodium hexametaphsphate in the solution will permit maximum concentrations up to 5 percent. Solutions of sodium hypochlorite may be fed in greater concentrations.

38. Another problem area besides algae is turbid water, so let's now study turbidity.

24. Turbidity

1. Turbidity in water is caused by suspended matter in a finely divided state. Clay, silt, organic matter, microscopic organisms, and similar materials are contributing causes of turbidity.

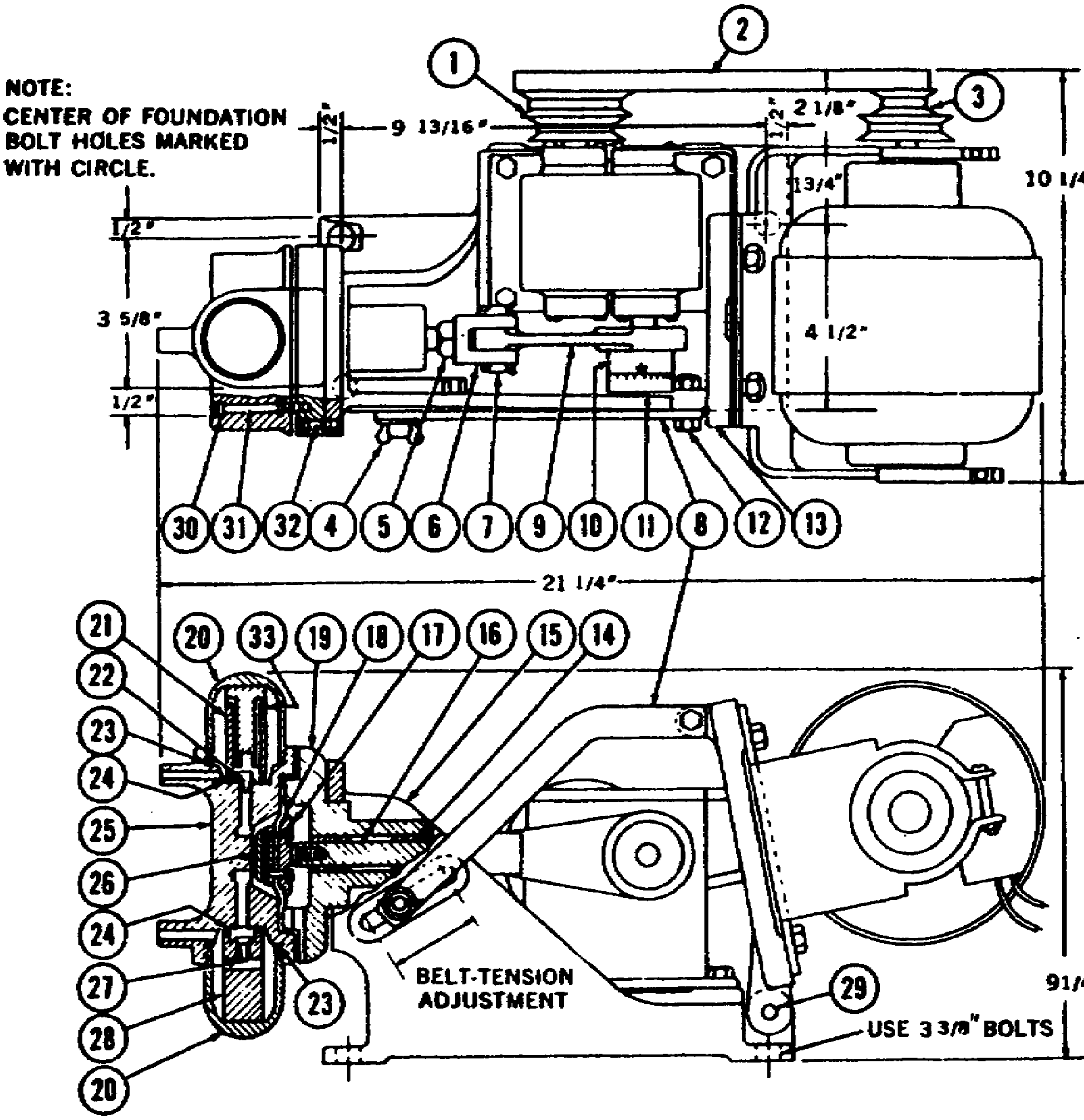
2. While the terms "turbidity" and "suspended matter" are related, they are not synonymous. Suspended matter is the amount of material in a water that can be removed by filtration. Turbidity is a measurement of the optical obstruction of light that is passed through a water sample.

3. Turbid makeup water to cooling systems may cause plugging and overheating where solids settle out on heat exchanger surfaces. Corrosive action is increased because the deposits hinder the penetration of corrosion inhibitors. We will cover the Jackson turbidity test and turbidity treatment.

4. **Turbidity Test**. The Jackson candle turbidimeter is the standard instrument used for making turbidity measurements. It consists of a graduated glass tube, a standard candle, and a support for the candle and tube. The glass tube and the candle must be placed in a vertical position on the support so that the centerline of the glass tube passes through the centerline of the candle. The top of the support for the candle should be 7.6 centimeters (3 inches) below the bottom of the tube. The glass tube must be graduated, preferably to read direct in turbidities (p.p.m.), and the bottom must be flat and polished. Most of the tube should be enclosed in a metal or other suitable case when observations are being made. The candle support will have a spring or other device to keep the top of the candle pressed against the top the support. The candle will be made of beeswax and spermaceti, gauged to burn within the limits of 114 to 126 grains per hour.

5. Turbidity measurements are based on the depth of suspension required for the image of the candle flame to disappear when observed through the suspension. To insure uniform results, the flame should be kept a constant size and the same distance below the glass tube. This requires frequent trimming of the charred portion of the candle wick and frequent observations to see that the candle is pushed to the top of its support. Each time before lighting the candle, remove the charred part of the wick. Do not keep the candle lit for more than a few minutes at a time, for the flame has a tendency to increase in size.

6. The observation is made by pouring the suspension into the glass tube until the image of the candle flame just disappears from view. Pour slowly when the candle becomes only faintly visible. After the image disappears, remove 1 percent of the suspension from the tube; this should make the image visible again. Care should be taken to keep the glass tube clean on both



1 THREE-STEP V-BELT PULLEY (1/2" BORE)
2 V-BELT
3 THREE-STEP V-BELT PULLEY 1/2" BORE)
4 5/16"—18 X 1" LONG, SQUARE HEAD BOLT AND WING NUT
5 CLEVIS NUT
6 CLEVIS
7 CLEVIS PIN
8 MOTOR ADJUSTING BAR
9 ECCENTRIC LINK
10 OUTER ECCENTRIC (COMPLETE)
11 INNER ECCENTRIC (COMPLETE)
12 5/16"—18 X 1" LONG, ROUND-HEAD SCREW AND NUT
13 MOTOR BASE
14 PUSH-ROD BUSHING
15 SUPPORT FRAME
16 PUSH ROD
17 REAGENT-DIAPHRAGM PUSH PLATE
18 REAGENT DIAPHRAGM
19 DIAPHRAGM BASE
20 CHECK-VALVE CAP
21 UPPER CHECK-VALVE SOCKET
22 WEIGHTED VALVE TIT
23 CHECK-VALVE-CAP GASKET
24 CHECK-VALVE-SOCKET WASHER
25 REAGENT-DIAPHRAGM CAP
26 REAGENT-DIAPHRAGM CLAMP
27 CHECK-VALVE TIT
28 LOWER-CHECK-VALVE SOCKET
29 MOTOR-BASE PIVOT PIN
30 DIAPHRAGM CAP-SCREW WASHER
31 10-32 X 1 3/4" LONG ROUND-HEAD MACHINE SCREW
32 No 10-32 X 3/4" LONG FILISTER-HEAD MACHINE SCREW
33 SIGHT-FEEDER INTENSIFIER

Figure 75. Proportioneers heavy-duty midget Chlor-O-Feeder.

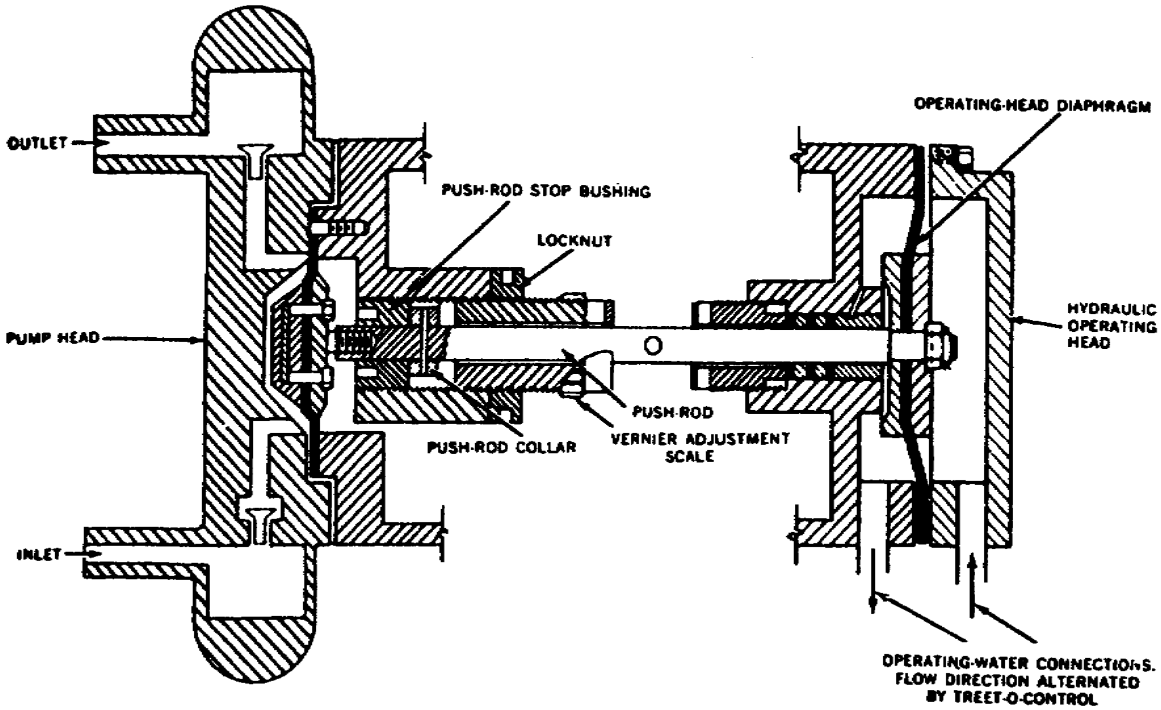


Figure 76. Hydraulically driven hypochlorinator.

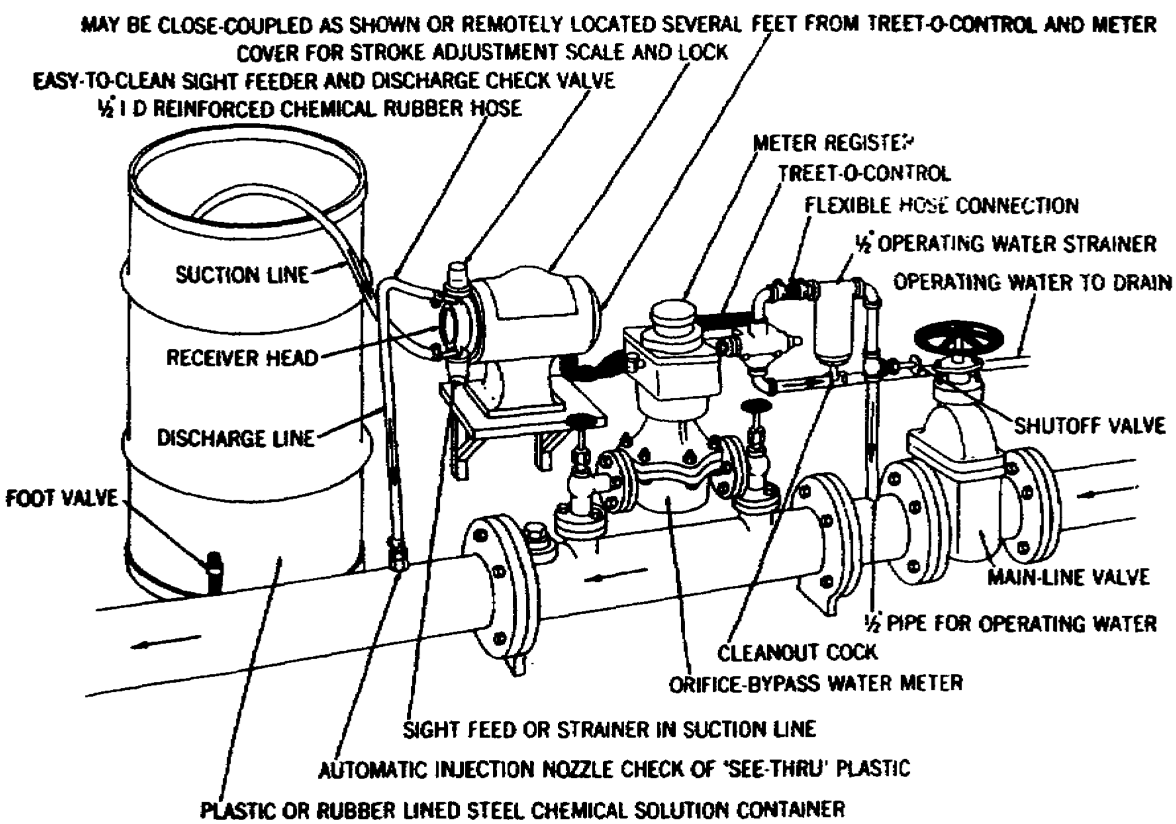


Figure 77. Motor-driven hypochlorinator.

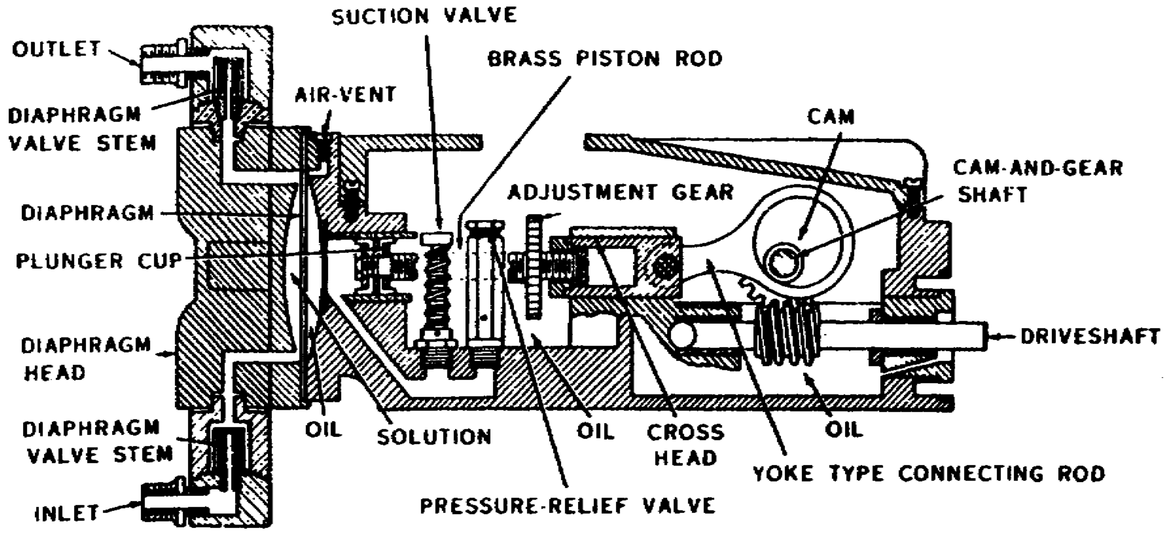


Figure 78. Wilson type DES hypochlorinator.

the inside and the outside. The accumulation of soot or moisture on the bottom of the tube may interfere with the accuracy of the results. The depth of the liquid is read in centimeters on the glass tube, and the corresponding turbidity measurement is recorded in parts per million.

7. **Turbidity Treatment**. Filtration is the most common method for removing suspended matter that you will encounter. Coagulants, flocculators, and sedimentation basins are also used but are more common to large water treatment facilities.

8. Sand and anthracite coal are the materials commonly used as filter media. The depth of the filter bed can range up to 30 inches, depending upon the type of filter you will be using. You will find that quartz sand, silica sand, and anthracite coal are used in most gravity and pressure type filters.

9. *Gravity filters*. As the name implies, the flow of water through the filter is obtained through

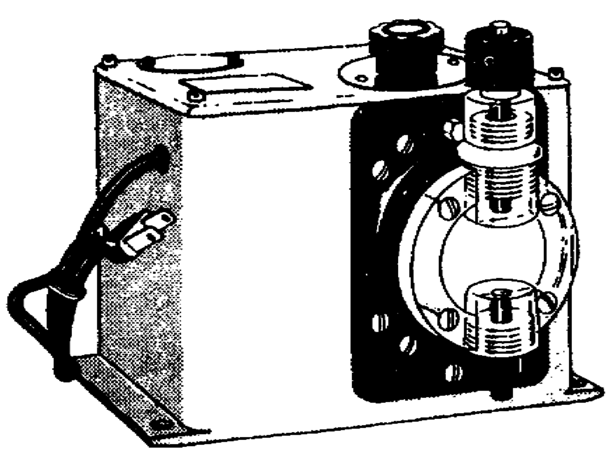


Figure 79. Model S hypochlorinator.

gravity. These filters are not common to our career field because coagulants and flocculation are required before effective filtration can occur.

10. *Pressure filers*. Pressure filers are more widely used because they may be placed in the line under pressure and thus eliminate double piping.

11. Pressure filters may be of the vertical or horizontal type. The filter shells are steel, cylindrical in shape; with dished heads. Vertical filters range in diameter from 1 to 10 feet, with capacities from 2.4 g.p.m. to 235 g.p.m. at a filtering rate of 3 gals/sq.ft/min. Horizontal filters, 8 feet in diameter, may be 10 to 25 feet long, with capacities from 210 g.p.m. to 570 g.p.m.

12. *Filter operation*. When you initially operate, or operate the filter after backwashing it, you should allow the filtered water to waste for a few minutes. This procedure rids the system of possible suspended solids remaining in the underdrain system after backwashing and also permits a small amount of suspended matter to accumulate on the filter bed. As soon as the filter produces clear water, the unit is placed in normal service.

13. During operation, the suspended matter removed by the filter accumulates on the surface of the filter. A loss-of-head gauge indicates when backwashing is necessary. Backwashing is necessary when the gauge reads 5 p.s.i.g.

14. Backwashing rates are much higher than filtration rates because the bed must be expanded and the suspended matter washed away. This backwashing is continued for 5 to 10 minutes; then the filter is returned to service.

15. We have discussed the testing and treatment of water to be used in our systems. To make

valid tests and prescribe proper treatment, you must understand the proper methods of water sampling.

25. Sampling

1. Frequent chemical and bacteriological analyses or tests of raw and treated water are required to plan and control treatment and to insure a safe and potable water. Facilities needed for water analysis depend on the type of supply and treatment. They vary from a simple chlorine residual and pH comparator to a fully equipped laboratory. Our discussions here are not concerned with analysis as such, since the term "analysis" implies that we completely disassemble water into its elementary composition. In complete water analysis your required task is to obtain valid samples to be forwarded to the proper laboratories. The sampling and testing with which you personally are concerned are simple and consist only of routine type tests that can be made in the field or in a base laboratory with simple chemicals and comparator equipment.

2. **Sampling Methods**. Sampling is an extremely important operation in maintaining quality of water supply. Unless the water sample is representative, test results cannot be accurate. You must be very careful to obtain a sample that is not contaminated by any outside source, such as dirty hands, dirty faucets, dirty or unsterilized containers. Do not sabotage the entire operation before it gets a good start. Follow approved, correct sampling methods like those outlined here and use only chemically clean sample containers.

3. *Chemical analysis*. The following precautions and actions are necessary when samples for chemical analysis are taken:

a. Wells. Pump the well until normal draw-down is reached. Rinse the chemically clean sample container with the water to be tested and then fill it.

b. Surface supplies. Fill chemically clean raw water sample containers with water from the pump discharge only after the pump has operated long enough to flush the discharge line. Take the water sample from the pond, lake, or stream with a submerged sampler at the intake depth and location.

c. Plant. Take samples inside a treatment plant from channels, pipe taps, or other points where good mixing is obtained.

d. Tap or distribution system. Let tap water run long enough to draw the water from the main before taking samples.

e. Sample for dissolved gas test. Take care to prevent change in dissolved gas content during sampling. Flush the line; then attach a rubber hose to the tap and let the water flow until all air is removed from the hose. Drop the end of the hose to the bottom of a chemically clean sample bottle and fill gently, withdrawing the hose as the water rises. Test for dissolved gas immediately.

4. *Bacteriological analysis*. In obtaining samples for bacteriological analysis, contamination of the bottle, stopper, or sample often causes a potable water supply to be reported as nonpotable. Full compliance with all precautions listed in the paragraphs below is necessary to assure a correct analysis.

a. Bottles. Use only sterilized bottles with glass stoppers. Cover the stopper and the neck of the bottle with a square of wrapping paper or other guard to protect against dust and handling. Before sterilizing the sample bottle to be used to test chlorinated water, place 0.02 to 0.05 gram of sodium thiosulfate, powdered or in solution, in each bottle to neutralize chlorine residual in sample. Keep the sterilization temperature under 392° F. to prevent decomposition of the thiosulfate.

b. Sampling from a tap. After testing for chlorine residual, close the tap and heat the outlet with an alcohol or gasoline torch to destroy any contaminating material that may be on the lip of the faucet. Occasionally, extra samples may be collected without flaming the faucet to determine whether certain faucet outlets are contaminated. Flush the tap long enough to draw water from the main. Never use a rubber hose or other temporary attachment when drawing a sample from the tap. Without removing the protective cover, remove the bottle stopper and hold both cover and stopper in one hand. Do not touch the mouth of the bottle or sides of the stopper. Fill the bottle three-quarters full. Do not rinse the bottle, since thiosulfate will be lost. Replace the stopper and fasten the protective cover with the same care.

c. Sampling from tanks, ponds, lakes, and streams. When collecting samples from standing water, remove the stopper as previously described and plunge the bottle, with the mouth down and hold at about a 45° angle, at least 3 inches beneath the surface. Tilt the bottle to allow the air to escape and to fill the bottle. When filling the bottle, move it in a direction away from the hand holding it so water that has contacted the hand does not enter the bottle. After filling, discard a quarter of the water and replace the stopper.

d. Transporting and storing samples. Biological changes occur rapidly. Therefore, if the test is to be made at the installation, perform the test within an hour if possible or refrigerate it and test within 48 hours. If the sample is to be tested at a laboratory away from the installation, use the fastest means of transportation to get to the laboratory.

e. Sample data. You must identify each sample. Note the sampling point, including building number and street location for sample of distribution system; source of water, such as installation water supply; and the date of collection.

5. **Laboratory Methods and Procedures for Testing**. As you were told earlier in this section, analysis is an involved process beyond the scope of your responsibility. However, nonstandard testing, either in a laboratory or in the field, may comprise a part of your daily work. Since you are probably going to be working in a base laboratory part of the time, laboratory technique are required knowledge. Some of the basic rules are outlined in the following paragraphs.

6 *Cleanliness*. Chemical and bacteriological tests can easily be invalidated by impurities introduced into the test by dirty hands, clothing, or equipment. Set up a regular daily schedule for cleaning laboratory equipment, furniture, and floors.

7. *Personal safety*. Keep hands away from your mouth or eyes, especially when working with poisonous chemicals or bacteriological cultures. Keep a diluted solution of lysol or mercuric chloride and a bicarbonate of soda solution at or near the laboratory sink at all times. Rinse hands with this solution immediately after washing any bacteriological-culture glassware or acid containers. Then wash thoroughly with soap and water. Never smoke or eat in the laboratory. Drinking from laboratory glassware may result in serious illness if a contaminated beaker is used. Do not use laboratory to prepare food or use incubators or refrigerators to store food.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. What is the main scale-forming compound found in condensing water systems? (Sec 21, Par. 1)

2. Scale will form when the pH value is _________ ________to _________________ and the p.p.m. is __________________ or higher. (Sec. 21, Par. 4)

3. What are the cycles of concentration if the makeup water is 100 p.p.m. and the circulating water is 200 p.p.m.? (Sec. 21, Par. 6)

4. Give four methods of preventing scale. (Sec. 21, Par. 7)

5. During the soap hardness test you use 10 ml. of standard soap solution to obtain a permanent lather. What is the hardness of your sample? (Sec. 21, Par. 9)

6. Which softening process changes calcium and magnesium from a soluble to an insoluble state? (Sec. 21, Par. 11)

7. How does the zeolite process soften water? (Sec. 21, Par. 11)

8. Why is it necessary to add lime or clay to the Accelator? (Sec. 21, Par. 15)

9. What factors would limit the use of the Spiractor? (Sec. 21, Par. 17)

10 What is used to restore the sodium ions in a zeolite softener? (Sec. 21, Par. 18)

11. In what type of liquid is corrosion more rapid? (Sec. 22, Par. 2)

12. What is the most common type of corrosion in an acid liquid? (Sec. 22, Par. 4)

13. Which type of corrosion is characterized by cavities and gradually develops into pinhole leaks? (Sec. 22, Par. 5)

14. If a system contains an abundance of copper and a few unions of steel, and the steel unions are corroding at a very high rate, what type of corrosion is taking place? (Sec. 22, Par. 6)

15. What causes erosion-corrosion and what is used to control this type of corrosion? (Sec. 22, Pars. 7 and 8)

16. What are the two most common chemical corrosion inhibitors? (Sec. 22, Par. 10)

17. Chromates are most effective in air-conditioning water systems when the concentration is ______________ to ____________ and the pH is _____________________. (Sec. 22, Par. 11)

18. What is the most common chromate used and why? (Sec. 22, Par. 11)

19. How is the chromate concentration of treated water measured? (Sec. 22, Par. 13)

20. Why shouldn't high concentrations of polyphosphates be used? (Sec. 22, Par. 14)

21. Give two advantages using polyphosphates over chromates. (Sec. 22, Par. 15)

22. Why must bleedoff be adjusted on condenser water systems when polyphosphates are used? (Sec. 22, Par. 16)

23. In what two forms may chemical corrosion inhibitors be that are placed in a nylon net bag, which in turn is placed in a cooling tower? (Sec. 22, Par. 18)

24. What type of corrosion inhibitor feeders are required on chilled water and brine systems? (Sec. 22, Par. 18)

25. What are the effects of algae on the operation of an air-conditioning system? (Sec. 23, Par. 1)

26. How many p.p.m. of chlorine are needed to eliminate algae growth in a cooling tower? (Sec. 23, Par. 2)

27. (Agree)(Disagree) During the performance of the residual chlorine test, you must heat the sample to 70° F. before adding the orthotolidine. (Sec. 23, Par. 3)

28. Why is chlorination an effective method of algae control in cooling towers and evaporative condensers? (Sec. 23, Par. 6)

29. Why is the orthotolidine-arsenite test preferred to the orthotolidine test? (Sec. 23, Par. 8)

30. What is the combined available chlorine residual when the free available chlorine residual is 2.5 p.p.m. and the total residual chlorine is 3.25 p.p.m.? (Sec. 23, Par. 9)

31. Describe the procedure used to perform the chlorine demand test. (Sec. 23, Pars. 13, 14, and 15)

32. As the result of a pH determination with a color comparator, you have found the pH to be 7.7. How would you have reached this solution? (Sec. 23, Pars. 17, 18, and 19)

33. After you have added two drops of phenolphthalein indicator to the sample, the sample turned pink. The sample is (acid, alkaline). (Sec. 23, Par. 22)

34. Which acids are used to lower the pH and how are they added to the water? (Sec. 23, Par. 24)

35. Why is calcium hypochlorite used more often than sodium hypochlorite? (Sec. 23, Pars. 26 and 27)

36. Which hypochlorinator would you select if the water to be treated required 100 gallons of chlorine solution per day? Why? (Sec. 23, Par 32)

37. The dosage of chlorine added to the 0.5 million gallons of water, when 20 pounds of chlorine is added per day, is approximately _______________ p.p.m. (solve to the nearest p.p.m.). (Sec. 23, Par. 34)

38. How many pounds of HTH would you have to add to treat water which requires 30 pounds of chlorine? (Solve to the nearest pound). (Sec. 23, Pars. 35 and 36)

39. How many gallons of chlorine is added per day to treat 2 million gallons of water when the dosage is 1.5 p.p.m. and the strength of the dosing solution is 10 percent? (Sec. 23, Par. 36)

40. What precautions must be followed while you are performing the Jackson turbidimeter test? (Sec. 24, Pars. 4, 5, and 6)

41. How many gallons of water can be filtered through a vertical type pressure filter in 1 hour? The diameter of the filter is 4 feet. (Sec. 24, Par. 11)

42. What precautions for taking water samples is common to both chemical and bacteriological analysis? (Sec. 25, Pars. 3 and 4)

43. How is a bottle sterilized when it is to be used for chlorine testing? (Sec. 25, Par. 4, *a*)

44. How far below the surface of the water in a tank should you hold the bottle when taking a sample? (Sec. 25, Par. 4,*c*)

45. What type of solution should you wash your hands with after making water tests? (Sec. 25, Par. 7)

Centrifugal Water Pumps

IF YOU SWING a bucket of water around your head, the water does not spill out because centrifugal force presses it toward the bottom of the bucket. If a number of bottomless buckets were whirled around inside a pipe, and there were only one hole where water could leave the pipe, each pail would throw out some of its water as it passed this hole. It would also suck up more water at the center. This is exactly how the centrifugal pump works. Instead of buckets, however, a centrifugal pump has vertical ribs, or vanes, mounted on a revolving disc. The water takes up the space between the vanes, or ribs. The disc, as it revolves, forces water through the pump outlet to the various components the water serves.

2. In this chapter we will study installation, operation, and maintenance of centrifugal water pumps.

26. Installation

1. The installation of a centrifugal water pump includes laying a concrete foundation and aligning each component. The foundation should be sufficiently substantial to absorb any vibration and to form a permanent rigid support for the baseplate. Figure 80 shows a foundation and baseplate. This type of concrete foundation is important in maintaining the alignment of a directly driven unit. A mixture of 1 part cement, 3 parts sand, and 6 parts gravel or crushed rock is recommended. In building the foundation, you should leave the top approximately 1 inch low to allow for grouting. You should roughen and clean the top of the foundation before placing the unit on it. Foundation bolts of the proper size should be embedded in the concrete before it sets. Use a template or drawing to locate the bolts. A pipe sleeve about 2 diameters larger than the bolt is used to allow movement for the final positioning of the bolts. Place a washer between the bolthead and the inner surface of the pipe to hold the bolt in position.

2. Be sure the foundation bolts are long enough to project through the nuts one-fourth of a inch after allowance has been made for grouting, for the thickness of the bedplate, and for the thickness of the foundation bolt nut. We are now ready to install the pump unit.

3. Place wedges at four points, two below the approximate center of the pump and two below the approximate center of the motor. Some installations may require two additional wedges at the middle of the bedplate. By adjustment of the wedges you can bring the unit to an approximate level and provide for the proper distance above the foundation for grouting. By further adjustment of the wedges you can bring the coupling halves in reasonable alignment by tightening down the pump and motor holddown bolts.

4. Check the gap and angular misalignment on the coupling. The coupling shown in figure 81 is the “spider insert” type. The normal gap is one-sixteenth of an inch. The gap is the difference in the space between the coupling halves and the thickness of the spider insert. Angular misalignment may be checked by using calipers at four points on the circumference of the outer ends of the coupling hubs, at 90° intervals, as shown in figure 81.

5. The unit will be in angular alignment when the measurements show the ends of the coupling hubs to be the same distance apart at all four points. Gap and angular alignment is obtained by loosening the motor holddown bolts and shifting or shimming the motor as required. Tighten down the holddown bolts after adjustments have been made.

6. After the wedges have been adjusted, tighten the foundation bolts evenly but only finger-tight. Be sure you maintain the level of the bedplate. Final tightening of the foundation bolts is done after the grout has set 48 hours.

7. To grout the unit on the foundation, build a wooden dam around the foundation, as shown in figure 80, and wet the top surface of the concrete thoroughly. Now force the grout under the bedplate. The grout should be thin enough to level out under the bedplate, but not so wet that the cement will separate from the sand and float

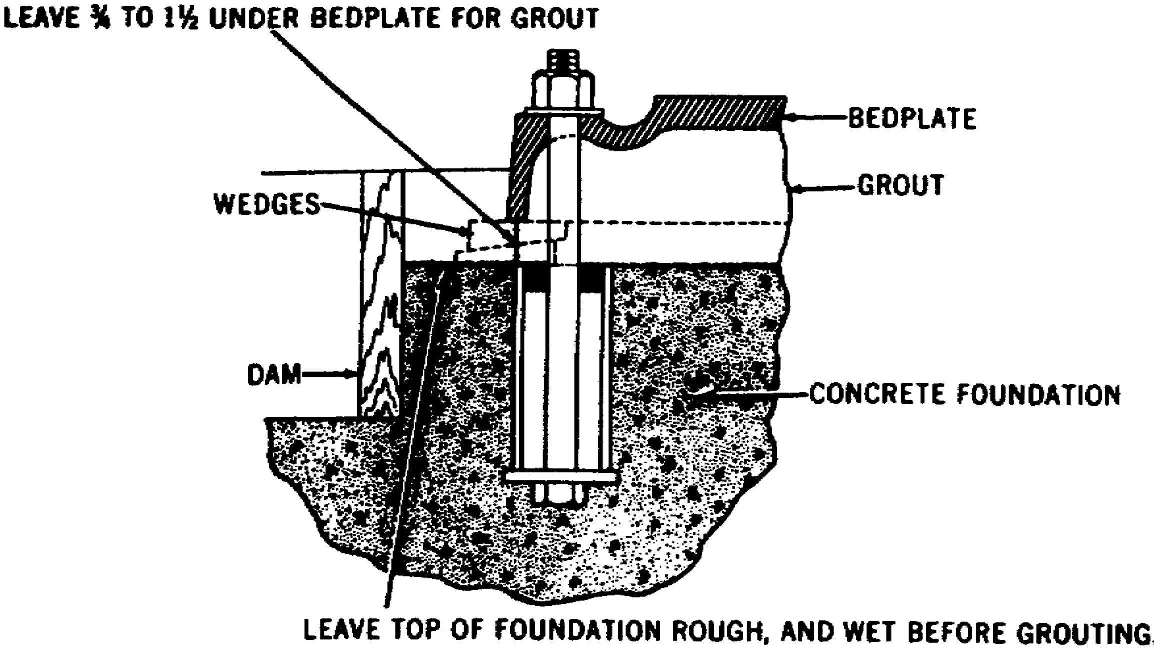


Figure 80. Pump foundation.

to the surface. The recommended mixture for grout is 1 part of Portland cement to 3 parts of sharp sand. The grout should completely fill the space under the bedplate. Allow 48 hours for the grout to harden.

8. **Alignment**. Alignment of the pump and motor through the flexible coupling is of extreme importance for double-free mechanical operation. The following steps must be followed to establish the initial alignment of the pumping unit:

(1) Tighten the foundation bolts.

(2) Tighten the pump and motor holddown bolts.

(3) Check the gap and angular adjustment as discussed previously.

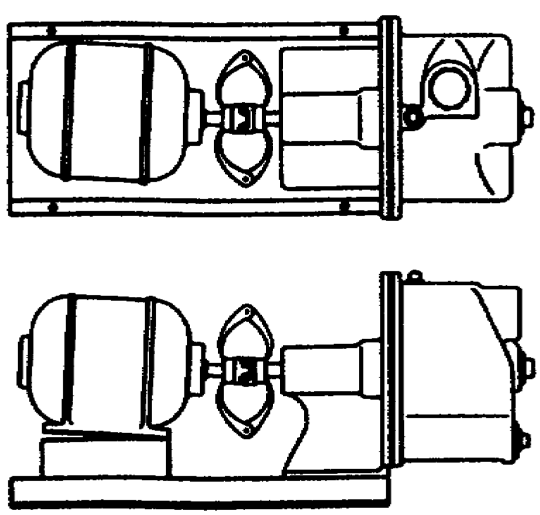


Figure 81. Checking angular alignment.

(4) Check parallel alignment by laying a straightedge across both coupling rims at the top, bottom, and both sides, as shown figure 82. The unit will be in horizontal parallel alignment when the straightedge rests evenly on both halves of the coupling at each side. In some special services a wide differential will prevail between the operating temperatures the pump and motor. Adjustment of alignment to satisfy such operating conditions must be governed by the specific application. The vertical difference of the shafts should be measured with a straightedge and feelers. To establish parallel alignment, thin shim stock is placed under the motor base. Occasionally, shims may be required under the pump base.

(5) Remember, alignment in one direction may alter the alignment in another. Check through each alignment procedure after making an alignment alteration.

9. The unit should be checked periodically for alignment. If the unit does not stay in line

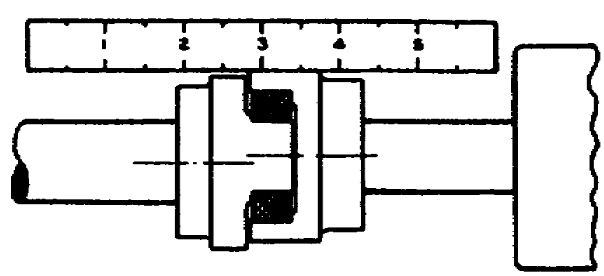


Figure 82. Checking parallel alignment.

after being properly installed, the following are possible causes:

- Settling, seasoning, or springing of the foundation
- Pipe strains distorting or shifting the pump
- Shifting of the building structure
- Spring of the baseplate

10. **Piping**. Connect the suction to the suction opening in the pump casing. Be sure that all suction connections are airtight. Use a good pipe joint compound on all threaded joints and airtight, packed unions. Suction piping smaller than the casing tapping may be used if necessary. Larger size suction piping than the casing tapping is not recommended. A strainer should be installed in suction line to protect the pump from foreign matter that may be present in the water.

11. The discharge piping is connected to the discharge threaded opening. This opening is larger than the suction opening. Smaller size discharge ping may be used, but the will be a loss of head and capacity.

12. Both pipes must be properly supported so that there will not be a strain set up. The strain could cause breakage of the pump casing or misalignment.

13. Now that you have installed the pump you are ready to check its operation. To check the operation, you must know the operating characteristics of the pump.

27. Operation

1. This centrifugal pump may be used as a cooling or chilled water pump. Whichever application it serves, the method of operation remains the same. The pump must be filled through the priming opening before it is started. Prime the pump by removing the priming plug on top of the pump casing and filling the pump with the liquid to be pumped. Be sure that all the plugs in the pump casing are screwed in tightly. Rotate the pump shaft by hand in the direction of the arrow on the casing to be sure that it moves freely. The pump is now ready to be started. Remember, after the pump is started, you must check to insure that the direction of rotation agrees with the arrow on the casing.

2. After the pump is up to speed, the priming time will depend on the size and length of the suction line. If for any reason the pump is stopped during the priming period, be sure to check the liquid level in the pump before restarting it.

3. If a newly installed pump fails to prime, you must be sure that the following conditions exist:

(1) All the plugs on the pump casing are airtight.

(2) The liquid level of the pump is at least to the priming level.

(3) All suction line joints are airtight.

(4) The motor direction matches the arrow on the pump casing.

(5) The motor reaches its rated nameplate speed.

(6) Suction strainer is clean.

4. Insufficient pump discharge can be caused by improper priming, air leaks in the suction line or pump stuffing box, low motor speed, plugged impeller or suction opening, wrong direction of rotation, worn stuffing box packing, and mechanical pump defects. These faults can also be related to low pump pressure and excessive power consumption. Proper operation of the pump is the result of good maintenance policies.

28. Maintenance

1. If the internal components of the pump become worn, you should replace the entire pump with another of the same size to insure the same pumping capacity. After the new pump is installed, it must be aligned as previously discussed.

2. **Stuffing Boxes**. In repacking be sure that sufficient packing is placed back of the lantern ring, shown in figure 83, so that the liquid for sealing is brought in at the lantern ring and not at the packing.

3. The piping supplying the sealing liquid should be tightly fitted so that no air enters. On suction lifts, a small quantity of air entering the pump at this point may result in loss of suction. If the liquid being pumped is dirty, gritty, or acidic, the sealing liquid should be piped to the stuffing box from a clean source of water. This procedure will help prevent damage to the packing and shaft sleeve.

4. Packing should not be pressed too tight, since this may result in burning the packing and scoring the shaft sleeve. A stuffing box is not properly packed if friction in the box is so great that the shaft cannot be turned by hand.

5. Always remove and replace all of the old packing. Do not reuse any of the old packing rings. In placing the new packing each packing ring should be cut to the proper length so that the ends come together but do not overlap. The succeeding rings should be placed in the stuffing box so that the joints of the rings are staggered 180° apart for two-ring packing, 120° for three-ring, and so on.

6. If the pump is packed with metallic packing and stored for a great length of time, it may be necessary to apply leverage to free the rotor. When first starting the pump, the packing should be slightly loose, without causing an air leak. If the gland leaks, put some heavy oil in the stuffing

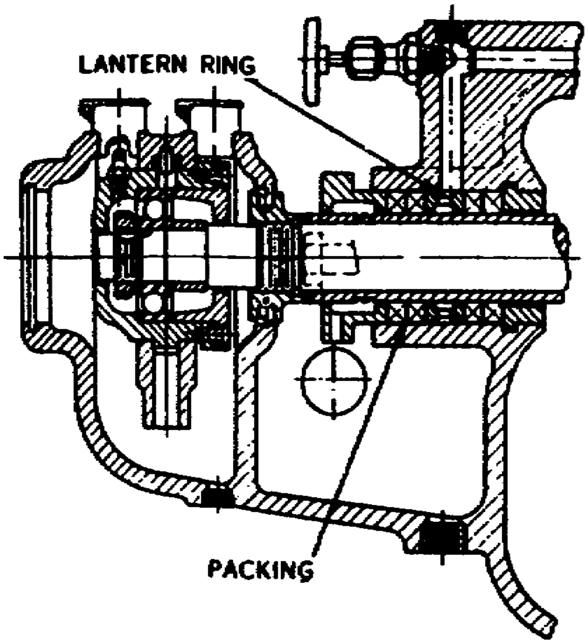


Figure 83. Cutaway of bearing and stuffing box.

box until the pump works properly. Then gradually tighten the gland.

7. When stuffing boxes are water sealed, you must be sure the water seal valves are opened sufficiently to allow a slight leakage of water. The leakage is piped away to a sump or sewer. Many pump failures occur because personnel observe liquid dripping from a gland and endeavor to stop it by tightening the gland bolts. Excessive tightening will cause the packing to burn and also may score the shaft.

8. All general-service pumps are shipped with the highest grade of soft, square asbestos packing, impregnated with oil and graphite.

9. **Mechanical Seals**. A mechanical seal is used in place of a stuffing box. This seal requires no adjustments, but it may be necessary to replace certain items should they become scored or broken. Let us discuss dismantling and assembling the mechanical shaft seal assembly.

10. *Dismantling*. Back off the gland bolts to free the gland plates. Then remove the rotating element from the pump and take off the bearings and shaft nuts. Let us follow the remaining steps as illustrated in figure 84.

11. Remove the floating seat and sealing washer. Do not disturb the bellows unless it needs replacement. The bellows becomes adhered to the sleeve if the seal has been in use for any length of time and will be damaged if moved. If it requires replacement, it must be forced off the sleeve. After the bellows is removed, the remaining parts-spring, spring holder, retainer shell, and driving band-may be taken off. If the seal uses a set collar, you must measure its location on the shaft before removing it so as to correctly relocate it during assembly.

12. **Assembly**. In assembling a mechanical seal, clean up all the parts and lightly oil the surface of the floating seat and the shaft sleeve. Use light oil-not grease.

13. Make sure that the synthetic rubber seat is tight against the shoulder of the floating seat with the rounded outer edge to the rear to facilitate insertion. Push this assembly firmly into the cavity in the gland plate and seat it squarely. Do not push on the lapped face of the floating seat.

14. The next step is to put the spring holder or set collar in place. If a set collar is used you must locate the collar in a position on the shaft determined by the measurement taken during dismantling.

15. Place the remainder of the seal parts on the shaft as an assembly. When the extended length of the seal assembly is longer than the undercut portion of the sleeve or than the distance from the collar to the end of the sleeve, the spring must be compressed beforehand and tied

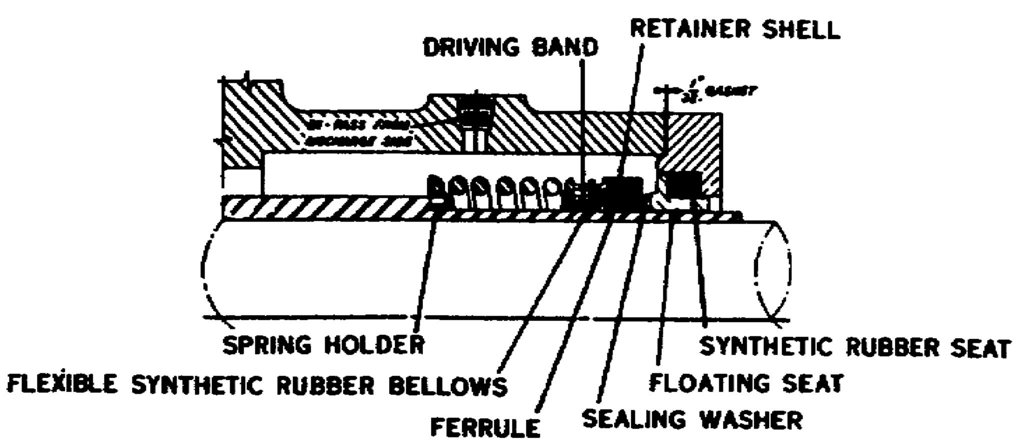


Figure 84. Cutaway of a mechanical seal.

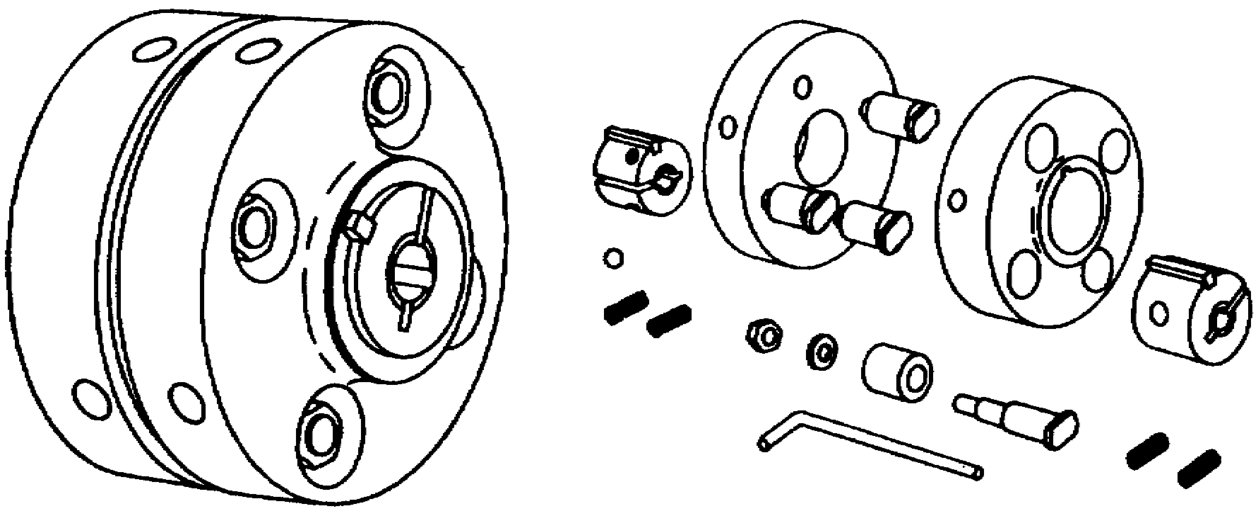


Figure 85. Flexible coupling.

together with string. The string should be removed after installation and after partial tightening of the gland bolts. Be sure there are no burrs on the sleeve that would harm the bellows. The new bellow is pushed straight on the sleeve.

16. The casing joint gasket should be cut at least one-eighth of an inch oversized and trimmed after the upper half-casing is bolted down.

17. **Bearings**. The four types of bearings found in centrifugal pumps are grease-lubricated (1) ball and (2) roller bearings, (3) oil-lubricated sleeve bearing, and (4) oil-lubricated ball bearings. The importance of proper lubrication cannot be overemphasized. The frequency of lubrication depends upon the conditions of operation. Overlubrication is the primary cause of overheated bearings. For average operating conditions it is recommended that grease be added at intervals of 3 to 6 months.

18. The housing should be kept clean, for foreign matter will cause the bearing to wear prematurely. When you clean the bearing, use clean solvent and wipe it with a clean cloth. Do not use waste to wipe the bearing because it will leave lint.

19. A regular ball bearing grease must be used. A number 1 or 2 grease is satisfactory for most chill or cooling water pump applications. Mineral greases with a soda soap base are recommended. Greases made from animal or vegetable oil should not be used because of the danger of deterioration and the formation of acid. Most of the leading oil companies have special bearing greases that are satisfactory. For specific information of lubricant recommendations you should consult the manufacturer's service bulletins.

20. The maximum operating temperature for ball bearings is 180° F. If the temperature rises above 180° F.,
the pump should be shut down and the cause determined.

21. The oil-lubricated ball bearing is filled with a good grade of filtered mineral oil (SAE 10) of approximately 150 Saybolt viscosity a 100° F. The oil should be changed when it becomes dirty, and the bearing should be cleaned at the same time. The bearing should be checked for wear frequently. Make sure that the oil rings are turning freely when the pump is first started. They are observed through the oil holes in the bearing caps.

22. The maximum operating temperature for babbitted sleeve bearings is 150° F. If the bearing temperature exceeds 150° F, shut down the pump until the cause is determined and corrected. Before the pump is started, the bearing should be flushed thoroughly with a light grade of oil to remove any dirt or foreign matter that may have accumulated during storage or installation. The bearing housing should then be filled to the indicated level with a good grade filtered mineral oil (SAE 10) of approximately 150 Saybolt viscosity at 100° F.

23. **Couplings**. We have already discussed the "spider insert" coupling. Another coupling you will come in contact with is the "Magic-Grip."

24. The "Magic Grip" coupling, shown in figure 85, consists primarily of two cast iron discs and two bushings. The bushing is split, which allows it to slide easily on the shaft. The outer diameter of the bushing and the inside diameter of the coupling are tapered. There a four drilled recesses in the bushing which accommodate the OFF and ON positions of the setscrew holes of the coupling. The recesses in the bushings are offset so that when the setscrews are tightened the bushing will either draw in on the taper and

tighten on the shaft or push out of the taper and loosen on the shaft.

25. The coupling is not intended to be a universal joint. It is capable of taking care of minor angular misalignment, but you must be sure to carefully align the coupling during installation.

26. To install the coupling, slide the bushing on the pump or motor shaft with the recess holes away from the pump. Next place the coupling over the bushing. Insert both setscrews in the ON position and tighten them alternately until the coupling is tight on the shaft.

27. To remove the coupling, remove both setscrews from the ON position and insert them in the OFF position. Turn the setscrews until the coupling is free on the busing; then loosen the setscrews and remove the coupling from the bushing. The bushing will now slide off the shaft.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the test. Do not submit your answers for grading.

1. How many pounds of cement would you have to mix with 12 pounds of sand and 24 pounds of crushed rock to form the concrete foundation for a pump? (Sec. 26, Par. 1)

2. Why is a 1-inch space left between the concrete foundation and the baseplate? (Sec. 26, Par. 1)

3. How large a pipe sleeve would you use with a baseplate bolt measuring three-fourths of an inch in diameter? (Sec. 26, Par. 1)

4. Where do you place the wedges to level the baseplate? (Sec. 26, Par. 3)

5. How do you check the angular alignment of a "spider" coupling? (Sec. 26, Par. 4)

6. How is angular alignment accomplished? (Sec. 26, Par. 5)

7. Explain the procedure used to grout the pump unit on the foundation. (Sec. 26, Par. 7)

8. How many parts of Portland cement to sharp sand are used to make grout? (Sec. 26, Par. 7)

9. How long should you allow the grout to harden? (Sec. 26, Par. 7)

10. Explain the steps you must follow to establish the initial alignment of the pumping unit. (Sec. 26, Par. 8)

11. Why would alignment be necessary after the unit has been operating for a period of time? (Sec. 26, Par. 9)

12. A ________________ is installed in the suction line to protect the pump from foreign matter. (Sec. 26, Par. 10)

13. What will occur if you install a smaller discharge pipe than the threaded discharge opening in the pump? (Sec. 26. Par. 11)

14. How is the pump primed? (Sec. 27, Par. 1)

15. Explain what you should do after the pump is primed and before it is stared. (Sec. 27, Par. 1)

16. List at least four causes for failure of a newly installed pump to prime. (Sec. 27, Par. 3)

17. A pump that uses a stuffing box takes liquid in for sealing at ____________________. (Sec. 28, Par. 2)

18. When is it necessary to pipe water from a clean water source to the stuffing box? (Sec. 28, Par. 3)

19. Why is exact packing tightening important? (Sec. 28, Par. 4)

20. How would you stagger the packing joints in the stuffing box that uses five rings? (Sec. 28, Par. 5)

21. The first step to perform when dismantling a mechanical seal is to __________________. (Sec. 28, Par. 10)

22. Which item shouldn't you disturb when dismantling a mechanical pump unless it is to be replaced? (Sec. 28, Par. 11)

23. Name the four types of bearings commonly found in centrifugal pumps. (Sec. 28, Par. 17)

24. What occurs when a bearing is lubricated too often? (Sec. 28, Par. 17)

25. What type of grease is recommended for grease-lubricated bearings? (Sec. 28, Par. 19)

26. Why aren't vegetable and animal greases used to lubricate pump bearing? (Sec. 2, Par. 19)

27. The maximum operating temperature for grease-lubricated bearings is ___________________. (Sec. 28, Par. 20)

28. The maximum operating temperature for an oil-lubricated babbitted sleeve bearing is ____________________. (Sec. 28, Par. 22)

29. What are the four drilled recesses in the bushing of a "Magic-Grip" coupling used for? (Sec. 28, Par. 24)

30. (Agree)(Disagree) During installation of a "Magic-Grip" coupling, the recessed holes should be facing the pump. (Sec. 28, Par. 26)

Fundamentals of Electronic Controls

A MISSILE STREAKS across the sky. The missile's flight is controlled electronically from a command post. The success of the launch and flight of the "bird" depends largely upon how well the electronic technicians performed their tasks.

2. Let us compare the missile launch to an electronic control system. The missile can be compared to the controlled variable-humidity, temperature, airflow, etc. The movable rocket motor is the controlled device. The controlled device is the component within the system that receives a signal from the control to compensate for a change in the variable. Last, but not least, we have the guidance system. Our controllers thermostats, humidistats, etc. -perform in much the same way as a guidance system. A change in the controlled variable will cause the controller to respond with a corrective signal.

3. In this chapter we will discuss vacuum tubes, amplification, semiconductors, transistor circuits, bridge circuits, and discriminator circuits. We will relate amplifier, bridge, and discriminator circuits to electronic controls. Electronic controls are becoming popular in the equipment cooling area of your career field because of their sensitivity and reaction time.

29. Vacuum Tubes

1. Electricity is based entirely upon the electron theory--that an electron is a minute, negatively charged particle. Atoms consist of a positively charged nucleus around which are grouped a number of electrons. The physical properties of any atom depend upon the number of electrons and the size of the nucleus; however, almost all matter has free electrons. The movement of these free electrons is known as a current of electricity. If the movement of electrons is in "one" direction only, this is direct current. If, however, the source of voltage is alternated between positive and negative, the movement of electrons will also alternate; this is alternating current.

2. The vacuum tube differs from other electrical devices in that the electric current does not flow through a conductor. Instead, it passed through a vacuum inside the tube. This flow of electrons is only possible if free electrons are somehow introduced into the vacuum. Electrons in the evacuated space will be attracted to a positively charged object within the same space because the electrons are negatively charged. Likewise, they will be repelled by another negatively charged object within the same space. Any movement of electrons under the influence of attraction or repulsion of charged objects is the current in a vacuum. The operation of all vacuum tubes depends upon an available supply of electrons. Electron emission can be accomplished by several methods--field, thermionic, photoelectric and bombardment-but the most important is thermionic emission.

3. Thermionic Emission. To get an idea of what occurs during thermionic emission you should visualize the Christmas sparkler. When you light the sparkler it burns and sparks in all directions. The filament in a vacuum tube reacts the same way when heated to a high temperature. Millions of electrons leave the filament in all directions and fly off into the surrounding space. The higher the temperature, within limits, the greater the number of electrons emitted. The filament in a directly heated vacuum tube is commonly referred to as a cathode. Refer to figure 86 for the symbol of a filament in a vacuum tube with heating sources.

4. The cathode must be heated to a high temperature before electrons will be given off. However this does not mean that the heating current must flow through the actual material that does the emitting. You can see in figure 87 that the part that does the heating can be electrically separate from the emitting element. A cathode that is separate from the filament is an indirectly heated cathode, whereas an emitting filament is a directly heated cathode.

5. Much greater electron emission can be

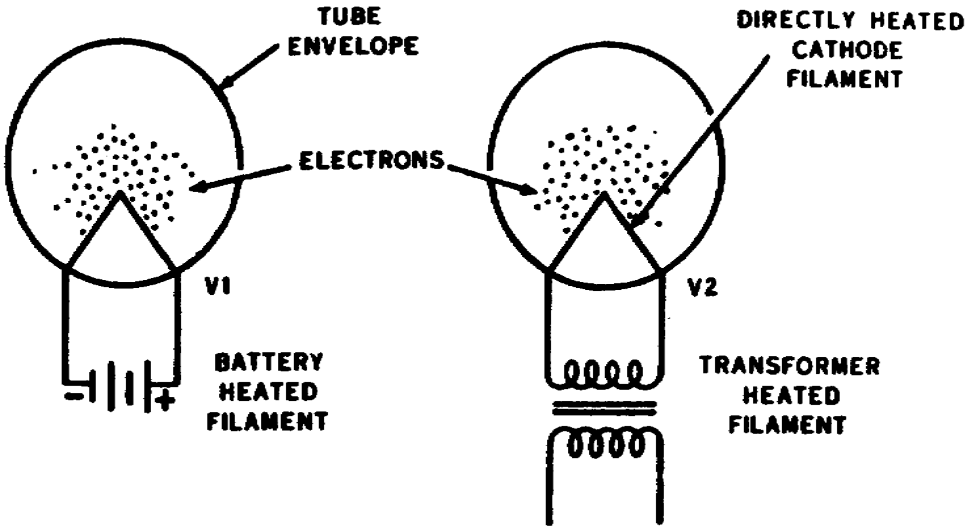


Figure 86. Thermionic emission.

obtained, at lower temperatures, by coating the cathode with special compounds. One of these is thoriated tungsten, or tungsten in which thorium is dissolved. However, much greater efficiency is achieved in the oxide-coated cathode, a cathode in which rare-earth oxides form a coating over a metal base. Usually this rare-earth oxide coating consists of barium or strontium oxide. Oxide-coated emitters have a long life and great emission efficiency.

6. The electrons emitted by the cathode stay in its immediate vicinity. These form a negatively charged cloud about the cathode. This cloud, which is called a space charge, will repel those electrons nearest the cathode and force them back in on it. In order to use these electrons, we must put a second element within the vacuum tube. This second element is called an anode (or plate), and it gives us our simplest type of vacuum tube, the diode.

7. **Diode Vacuum Tube**. Each vacuum tube must have at least two elements or electrodes: a cathode and an anode (commonly called a plate). The cathode is an emitter of electrons and the plate is a collector of electrons. Both elements are inclosed inside an envelope of glass or metal. This discussion centers around the vacuum tube diode from which the air as much possible has been removed. However, it should be understood that gaseous diodes do exist. The

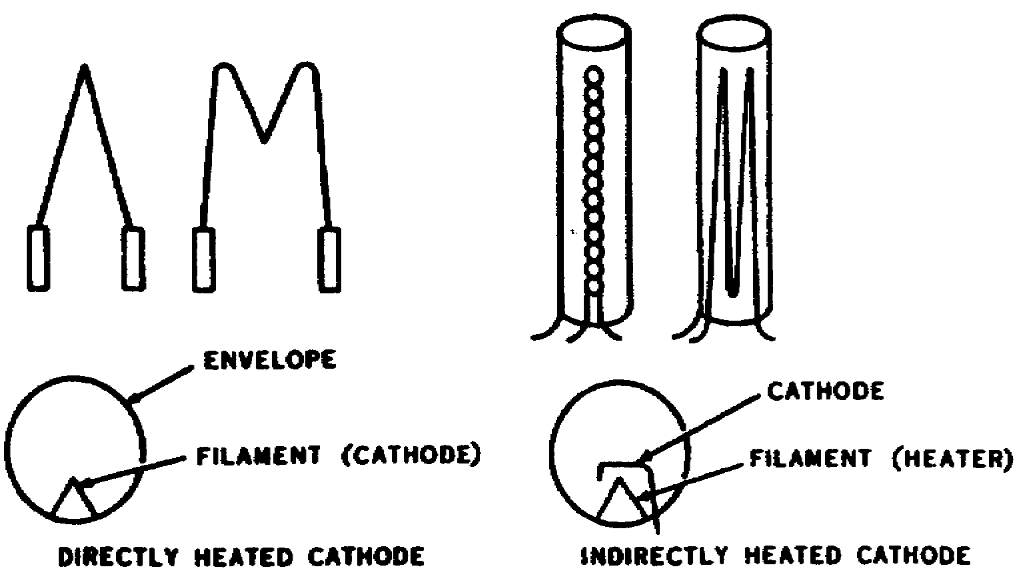


Figure 87. Indirectly and directly heated cathodes.

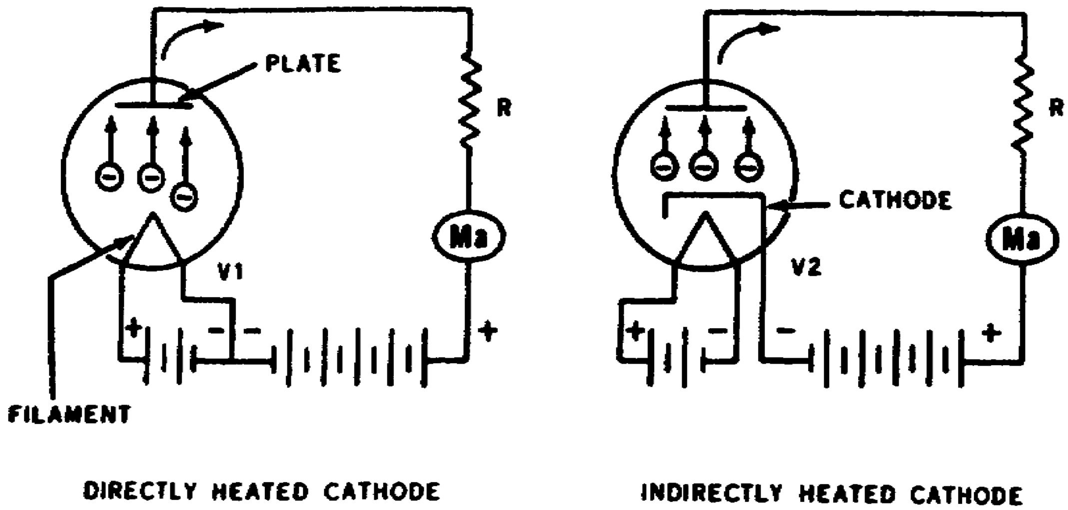


Figure 88. Electron flow in a diode.

term "diode" refers to the number of elements within the tube envelope (*di* meaning two) rather than to any specific application, as shown in figure 88.

8. The operation of the diode depends upon the fact that if a positive voltage is applied to the plate with respect to the heated cathode, current will flow through the tube. When the plate is negative with respect to the cathode, current will not flow through the tube. Since current will pass through a vacuum tube in only one direction, a diode can be used to change a.c. to d.c.

9. *Diode as a half-wave rectifier.* Experiments with diode vacuum tubes reveal that the amount of current which flows from cathode to plate depends upon two factors: the temperature of the cathode, and the potential (voltage) between the cathode and the plate. Refer to figure 89, a diagram of a simple diode rectifier circuit.

10. When an a.c. source is connected to the plate and cathode such a circuit, one-half of each a.c. cycle will be positive and the other half will be negative. Therefore, alternating voltage from the secondary of the transformer is applied to the diode tube in series with a load resistor, R. The voltage varies, as is usual with a.c., but current passes through the tube and R only when the plate is positive with respect to the cathode. In other words, current flows only during the half-cycle when the plate end of the transformer winding is positive. When the plate is negative, no current will pass.

11. Since the current through the diode flows in one direction only, it is direct current. This type of diode rectifier circuit is called a half-

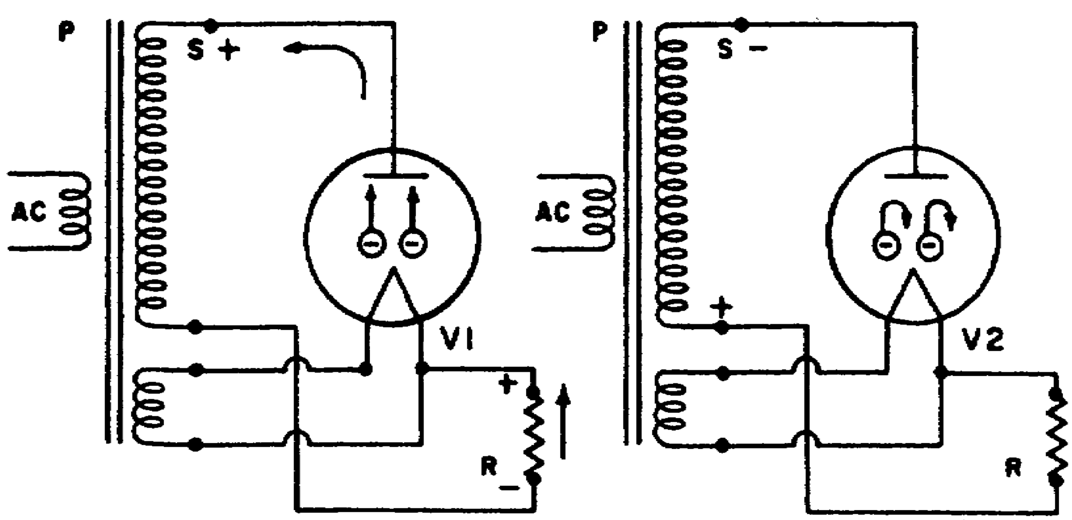


Figure 89. Simple half-wave rectifier circuit.

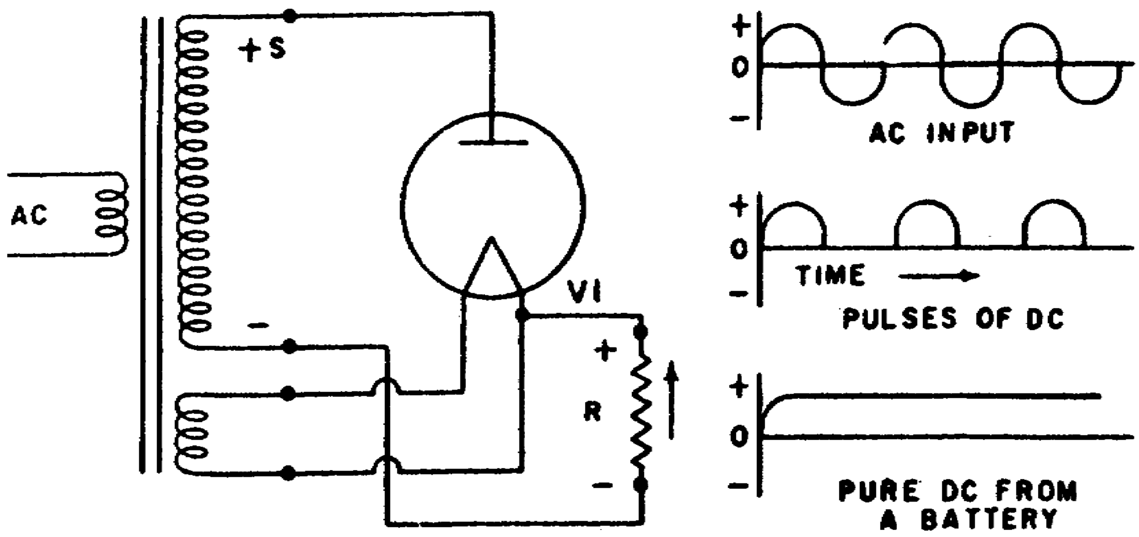


Figure 90. Output of a half-wave rectifier.

wave rectifier, because it rectifies only during one-half of the a.c. cycle. As a result, the rectified output will be pulses of d.c., as shown in figure 90. You can see from figure 90 that these pulses of direct current are quite different from pure direct current. It rises from zero to a maximum and returns to zero during the positive half-cycle of the alternating current, but does not flow at all during the negative half-cycle. This type of current is referred to as pulsating direct current to distinguish it from pure direct current.

12. In order to change this rectified alternating current into almost pure direct current, these fluctuations must be removed. In other words, it is necessary to cut off the humps at the tops of the half-cycles of current and

fill in the gaps caused by the negative half-cycle of no current. This process is called "filtering" '

13. Look at the complete electrical circuit of figure 91. Filtering is accomplished by connecting capacitors, choke coils (inductors), and resistors in the proper manner. If a filter circuit is added to the half-wave rectifier, a satisfactory degree of filtering can be obtained. Capacitors C_1 and C_2 have a small reactance at the a.c. frequency, and they are connected across the load resistor, R. These capacitors will become charged during the positive half-cycles as voltage is applied across the load resistor. The capacitors will discharge through R and L during the negative half-cycles, when the tube is not conducting, thus tending to smooth out, or filter out, the

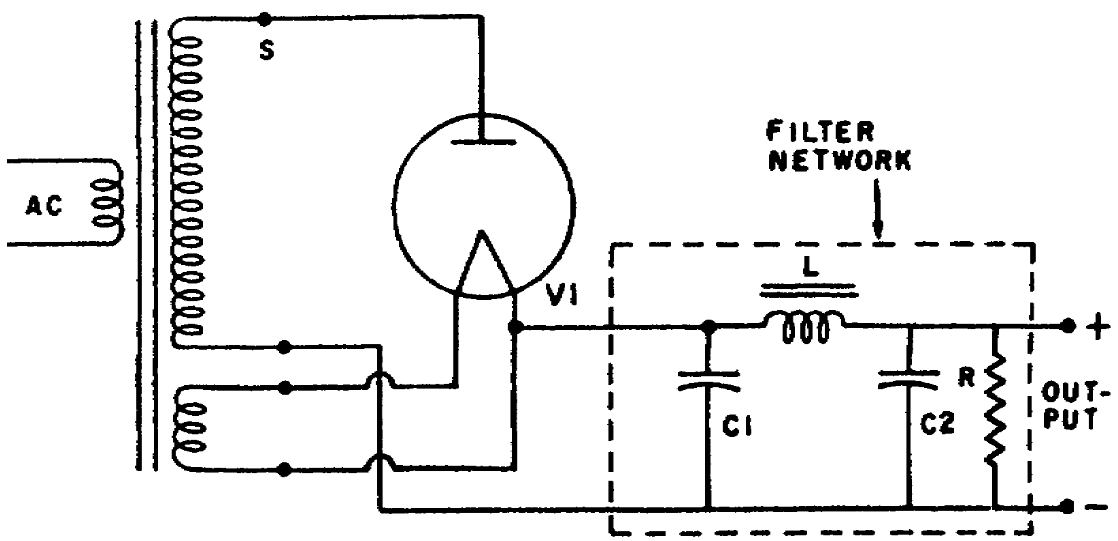


Figure 91. Filter network added to a half-wave rectifier.

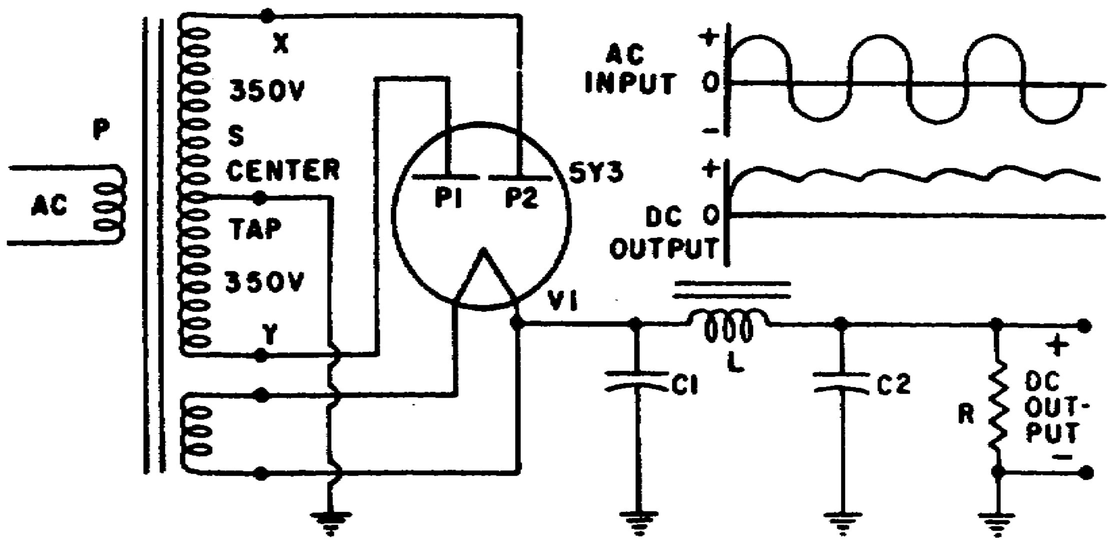


Figure 92. Full-wave rectifier.

pulsating direct current. Such a capacitor is known as a filter capacitor.

14. Inductor L is a filter choke having high reactance at the a.c. frequency and a low value of d.c. resistance. It will oppose any current variations, but will allow direct current to flow almost unhindered through the circuit. In order use both alternations of a.c., this circuit must be converted to a full-wave rectifier.

15. *Diode used or full-wave rectification*. One disadvantage of the half-wave rectifier is that no current is available from the transformer during the negative half-cycle. Therefore, some of the voltage produced during the positive half cycle must be used to filter out the voltage variations. This filtering action reduces the average voltage output of the circuit. Since the circuit is conducting only half the time, it is not very efficient. Consequently, the full-wave rectifier, which rectifies both half-cycles, was developed for use in the power supply circuits of modern electronic equipment.

16. In a full-wave rectifier circuit, two diodes may be used. However, in many applications, the two diodes are included in one envelope and the tube is referred to as a duo-diode. A typical example of a full-wave rectifier circuit is shown in figure 92. In this circuit a duo-diode is used, and the transformer's secondary winding has a center tap. Notice that the center tap current is turned to ground and then through R and inductor L to the cathode (filament) of V1. The voltage appearing across X and Y is 700 volts a.c. The center tap is at zero potential with 350 volts on each side.

17. Point X of the high-voltage winding is connected to plate P_2, and Y is connected to P_1. The plates conduct alternately, since at any given instant, one plate is positive and the other is negative. During one half-cycle, P_1 will be positive with respect to the center tap of the transformer secondary winding while P_2 will be negative. This means that P_1 will be conducting while P_2 is nonconducting.

18. During the other half-cycle, P_1, will be negative and nonconducting while P_2 will be positive and conducting. Therefore, since the two plates take turns in their operation, one plate is always conducting. Current flows through the load resistor in the same direction during both halves of the cycle, which is called full-wave rectification. The circuit shown in figure 92 is the basis for all a.c. operated power supplies that furnish d.c. voltages for electronic equipment. Notice that the heater voltage for the duo-diode is taken from a special secondary winding on the transformer.

19. The next tube you will study is the triode. The triode is used to amplify a signal.

30. Amplification

1. With the invention of the triode vacuum tube, the amplification of electrical power was introduced. Technically speaking, amplification means slaving a large d.c. voltage to a small varying signal voltage to make the large d.c. voltage have the same wave shape as the signal voltage. As a result, the wave-shaped d.c. voltage will do the same kind of work as the signal voltage will do, but in a larger quantity. After the triode came the tetrode, pentode, etc., to do a much better job of amplification than the triode. Amplification by use of the triode and other multi-element

vacuum tubes will be discussed in this section.

2. **Triode Vacuum Tube**. In the diode tubes previously described, current in the plate circuit was determined by cathode temperature and by the voltage applied to the plate. A much more sensitive control of the plate current can be achieved by the use of a third electrode in the tube. The third electrode (or element), called a control grid, is usually made in the form of a spiral or screen of fine wire. It is physically located between the cathode and plate, and is in a separate electrical circuit. The term "grid" comes from its early physical form.

3. The control grid is placed much closer to the cathode than to the plate, in order to have a greater effect on the electrons that pass from the cathode to the plate. Because of its strategic location the grid can control plate current by variations in its voltage. The operation of a triode vacuum tube is explained in the following paragraphs.

4. If a small negative voltage (with respect to the cathode) is applied to the grid, there is a change in electron flow within the tube. Since the electrons are negative charges of electricity, the negative voltage on the grid will tend to repel the electrons emitted by the cathode, which tends to prevent them from passing through the grid on their way to the plate. However, the plate is highly positive with respect to the cathode and attracts many of the electrons through the grid. Thus, many electrons pass through the negative grid and reach the plate in spite of the opposition offered them by the negative grid voltage.

5. A small negative voltage on the grid of the vacuum tube will reduce the electron flow from the cathode to the plate. As the grid is made more and more negative, it repels the electrons from the cathode, and this in turn decreases plate current. When the grid bias reaches a certain negative value, the positive voltage on the plate is unable to attract any more electrons and the plate current decreases to zero. The point at which this negative voltage stops all plate current is referred to as cutoff bias for that particular tube.

6. Also, as the grid becomes less and less negative, the positive plate attracts more electrons and current increases. However, a point is reached where plate current does not increase even though the grid bias is made more positive. This point, which varies with different types of tubes, is called the saturation level of vacuum tubes. So you can see that the control grid acts as a valve controlling plate current. One other thing must be made clear at this point. If the positive plate voltage is increased, the negative grid voltage must be increased if you need to limit current through the tube.

7. **Control Grid Bias**. Grid bias has been defined as the d.c. voltage (potential) on the grid with respect to the cathode. It is usually a negative voltage, but in some cases the grid is operated at a positive potential. Generally when the term "bias" is used, it is assumed to be negative. There are three general methods of providing this bias voltage.

8. The first is fixed bias. Figure 93 shows how the negative terminal of a battery could be connected to the control grid of a tube, and the cathode connected to ground to provide bias. If you say that the bias is 5 volts, you mean that the grid is 5 volts "negative" with respect to the cathode. Two methods of obtaining a bias of 5 volts are shown in figure 93. In diagram X the battery is connected with its negative terminal to the grid, while its positive terminal and the cathode are grounded. Diagram Y shows the positive terminal of the battery connected to the cathode, while its negative terminal and the grid are grounded. In either case, the grid is 5 volts negative with respect to the cathode. If the grid and the cathode are at the same potential, there is no difference in voltage and the tube is operating at zero bias (diagram Z).

9. The second method of obtaining grid bias is called cathode bias. The cathode bias method uses a resistor (R_k) connected in series with the cathode, as shown in figure 94. As the tube conducts, current is in such a direction that the end of the resistor nearest the cathode is positive. The voltage drop across R_k makes the grid negative with respect to the cathode. This negative grid bias is obtained from the steady d.c. across R_k. The amount of grid bias on the triode tube is determined by the voltage drop (IR) across R_k.

10. Any signal that is fed into the grid will change the amount of current through the tube, which in turn will change the grid bias, due to the fact that current also changes through the cathode resistor. To stabilize this bias voltage, the cathode resistor is bypassed by a condenser, C_1, that has low resistance compared with the resistance of R_k. Here's how this works.

11. As the triode conducts, condenser C_1, will charge. If the tube, due to an input signal, tends to conduct less, C_1, will discharge slightly across R_R, and keep the voltage drop constant. The voltage drop across the cathode resistor is held almost constant, even though the signal is continually varying.

12. Our third method of getting grid bias is called contact potential, or grid-leak bias. This type of bias depends upon the input signal. Two circuits using contact potential or grid-leak bias,

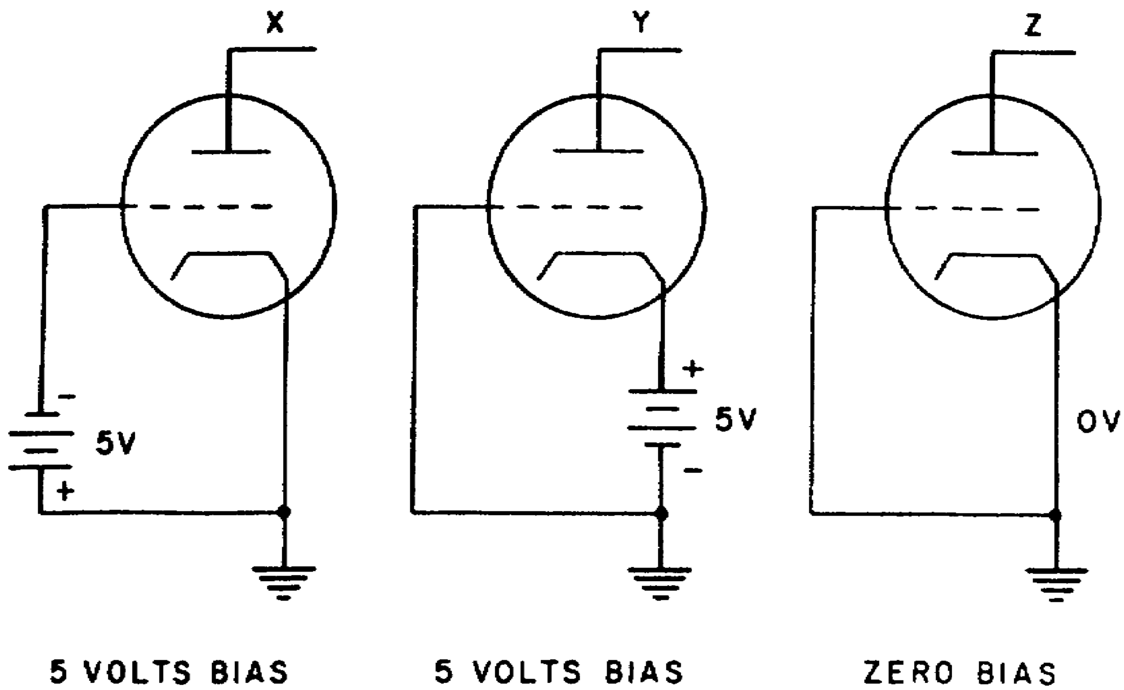


Figure 93. Using a battery to get fixed or zero bias.

are shown figure 95. The action in each case is similar-that is, when an a.c. signal is applied to the grid, it draws current on the positive half-cycle. This current flows in the external circuit between the cathode and the grid. This current flow will charge condenser C_1, as shown by the dark, heavy lines. One thing to keep in mind at this time is the ohmic value of the grid resistor. It is very high, in the order of several hundred thousand ohms.

13. As the signal voltage goes through the negative half-cycle, the condenser C_1, starts discharging. The control grid cannot discharge through the tube since it is not an emitter of electrons. The only place to can start discharging is through the grid resistor, R_g,. This discharge path is flown by the dotted arrows. A negative voltage is developed across R_g, which biases the tube. Since the resistor, R_g, has a very high value (500,000 ohms to several megohms), the condenser only has time to discharge a small amount before a new cycle begins. This means that only a very small current flows, or leaks through. However, because of the large value of R_g, C_1

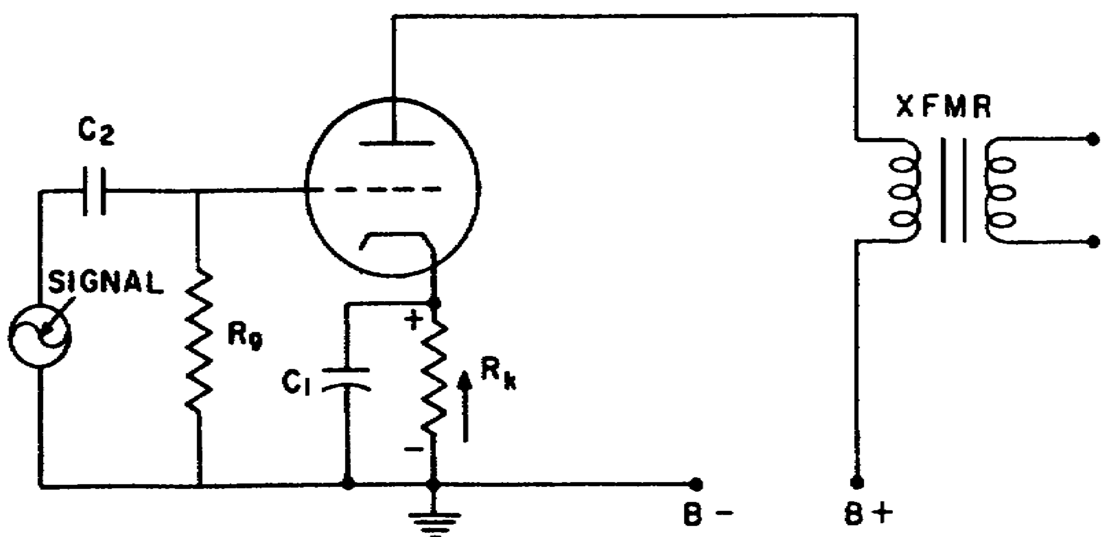


Figure 94. Cathode biasing with a cathode resistor.

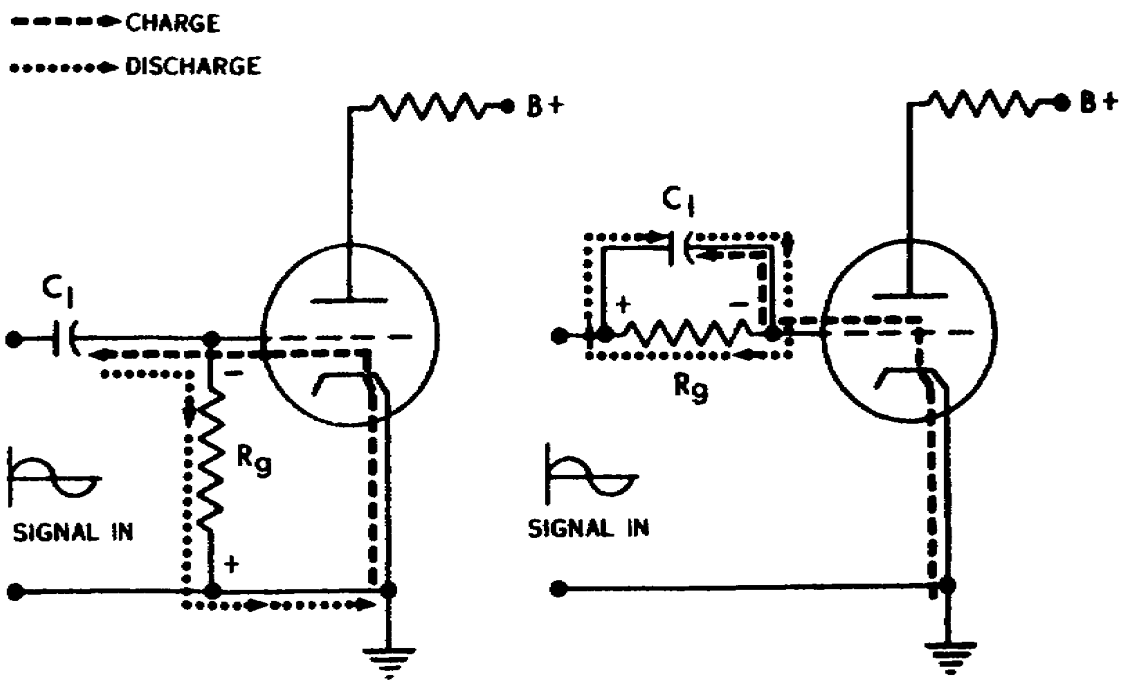


Figure 95. Connect potential bias.

will remain continuously charged to some value as long as a signal is applied.

14. One of the main disadvantages of this type of bias is the fact that bias is developed only when a signal is applied to the grid. If the signal is removed for any reason, the tube conducts very heavily and may be damaged. This condition can be prevented by using "combination bias," which uses both grid-leak bias and cathode bias. This combination provides the advantages needed with an added safety precaution in case the signal is removed.

15. **Triode Tube Operation**. Since a small voltage change on the grid causes a large change in plate current, the triode tube can be used as an amplifier. If a small a.c. voltage is applied between the cathode and the grid, it will cause a change in grid bias and thus vary plate current. This small a.c. voltage between cathode and grid is called a signal.

16. The large variations in plate current through the plate load resistor (R_L) develops an a.c. voltage component across the resistor which is many times larger than the signal voltage. This process is called amplification and is illustrated in figure 96.

17. The one tube and its associated circuits (the input and output circuits) is called one stage of amplification or a one-stage amplifier. A single-stage amplifier might not produce enough amplification or gain to do a particular job. To increase the overall gain, the output of one stage may be coupled to the control grid of another stage and the output amplified again. Look at figure 97 for a two-stage amplifier. There are various types of couplings. But generally the idea is to block the d.c. plate voltage of the preceding stage to keep it off the grid of the following stage because it would upset the bias of the following stage. A capacitor is used to couple one stage to another because a capacitor blocks d.c. or will not let it pass.

18. **Tetrode Amplifiers**. While a triode is a good amplifier at low frequencies, it has a fault when used in circuits having a high frequency. This fault results from the capacitance effect between the electrodes of the tube and is known as interelectrode capacitance. The capacitance which causes the most trouble is between the plate and the control grid. This capacitance couples the output circuit to the input circuit of the amplifier stage, which causes instability and unsatisfactory operation.

19. To correct this fault, another tube was built that has a grid similar to the control grid placed between the plate and the control grid as seen in figure 98. This new grid is connected to a positive potential somewhat lower than the plate potential. It is also connected to the cathode through a capacitor. The second grid serves as a screen between the plate and the control grid and is called a screen grid. The tube is called a tetrode.

20. **Beam Power Tubes**. Electron tubes which handle large amounts of current are known as beam power amplifiers. Let us compare a voltage

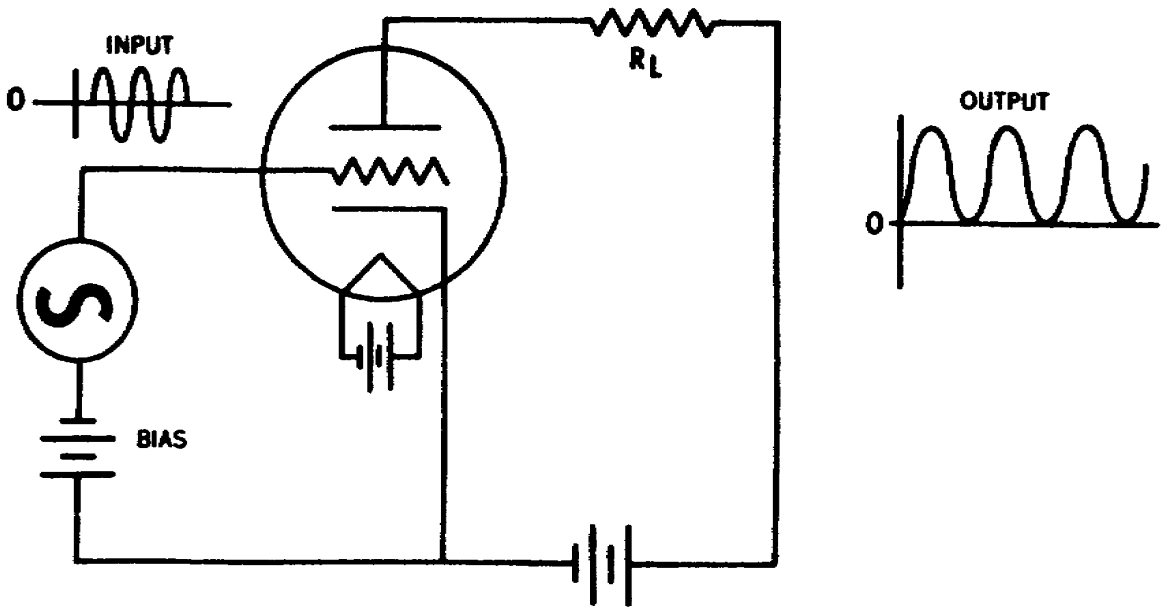


Figure 96. Triode tube operation.

amplifier with a power amplifier. A voltage amplifier may draw 10 milliamperes of plate current while a power amplifier can draw 250 milliamperes of plate current. The beam power amplifier is more rugged, with larger elements, and must dissipate heat faster due to the greater current.

21. In figure 99 a specially constructed tetrode which has a filament or cathode, control grid, screen grid, and plate is called a beam power tetrode. To eliminate secondary emission effect, the screen grid wires lie in the shadow of the control grid thus forming the space current into narrow beams. The resulting beams provide the effect of suppressor grid action, and thus permits the characteristic curves to be similar to those of a pentode.

22. Because of the amount of electrons in the negatively charged beam, any secondary electrons emitted by the plate are returned to the plate. By internally connecting the beam-forming plates to the cathode, the concentration of the electrons are

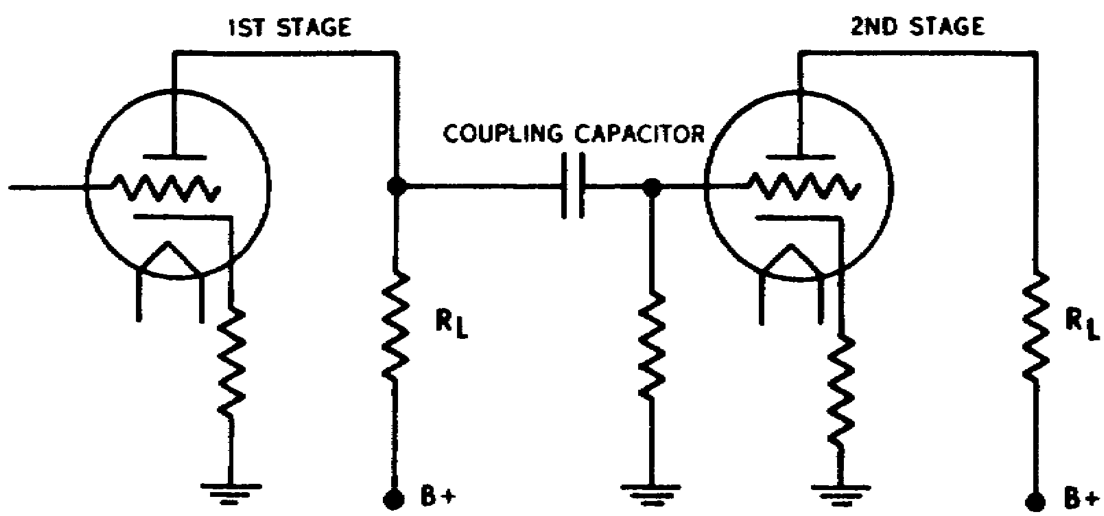


Figure 9. Two-stage amplifier.

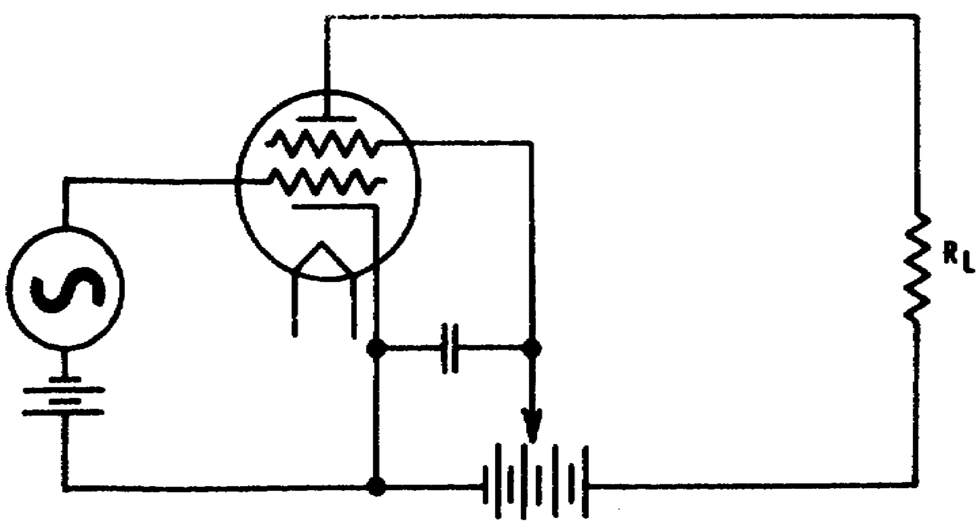


Figure 98. Tetrode amplifier circuit.

even higher, causing the beam to act as a suppressor grid in the pentode.

23. **Pentode Amplifiers**. The tetrode tube is a better amplifier than the triode tube, but it also has a fault. A cold plate does not normally emit electrons. However, high-velocity electrons, produced by the positive potential on the screen grid, cause other electrons to be knocked from the plate. The liberation of these electrons is called secondary emission. The secondary electrons will be attracted to the positive screen grid and will reduce the plate current. To overcome this, a vacuum tube was designed that contains still another grid. This grid, shown in figure 100, is called a suppressor grid and is placed between the plate and the screen grid. A negative potential is applied to the suppressor grid, and the negative potential forces the secondary electrons back to the plate and prevents secondary electrons from reaching the screen grid. These five-element tubes, or pentodes, are the highest development of amplifier tubes.

24. **Classes of Amplifiers**. Amplifiers are divided into the following classes, based on tube operation or bias voltage:

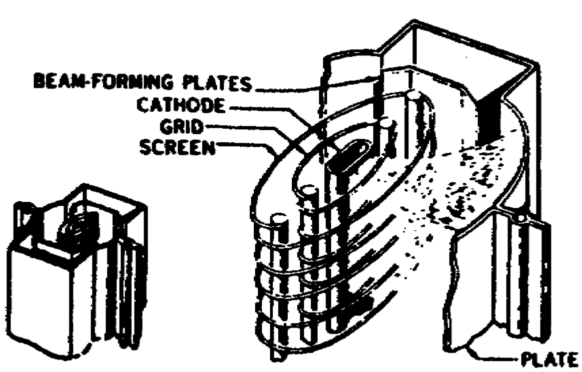


Figure 99. Construction of a beam-power tube.

- A class A amplifier has plate current or conducts for 360° of the input signal.
- A class B amplifier conducts for 180° of the input signal.
- A class AB amplifier is a combination of both class A and B.
- A class C amplifier has plate current flowing for approximately 120° of the input signal.

25. Vacuum tubes have several disadvantages -size, warming up period, etc. Transistors are rapidly replacing vacuum tubes in electronic controls. To understand transistors, you must have a good knowledge of semiconductors.

31. Semiconductors

1. The transistor was discovered in 1948 by the Bell Laboratories. The name comes from two words, "transfer" and "resistance." The transistor is gradually replacing the vacuum tube and is playing a big part in the design of all types of electronic equipment. The main advantages

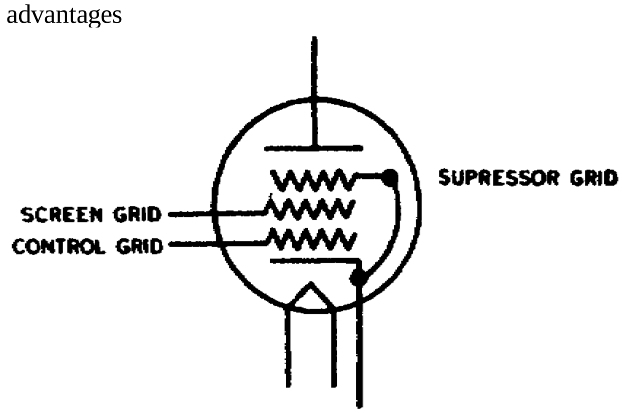


Figure 100. Pentrode amplifier tube.

ELEMENT	SYMBOL	ATOMIC NUMBER
GERMANIUM	Ge	32
SILICON	Si	14
ANTIMONY	Sb	51
ARSENIC	AS	33
INDIUM	IN	49
GALLIUM	GA	31
BORON	B	5

Figure 101. Elements associated with transistors.

of the transistor over the vacuum tube are that it smaller, lighter, and more rugged, and operates at lower voltages than the vacuum tube.

2. **Atomic Structure**. Essential to the understanding of semiconductor operation is the study of atomic characteristics and the basic structure of the atom. The atom contains a nucleus composed of protons and neutrons. Protons are positively charged particles, while neutrons are neutral particles.

3. The other component of the atom is the electron, which is a negatively charged particle. The electrons are arranged in orbits around the nucleus. The orbits, or rings, are numbered starting with the ring nearest the nucleus (which is No. 1) and progressing outward.

4. The maximum number of electrons permitted in each ring is as follows: Ring No. 1, 2 electrons; ring No. 2, 8 electrons; ring No. 3, 18 electrons; ring No. 4, 32 electrons. The atomic structure of germanium and silicon have 14 and 32 electrons respectively. The 3d ring in silicon and the 4th ring in germanium are incomplete, having only 4 electrons. These incomplete outer rings are important to the operation of semiconductor devices. A good conductor has less than 4 electrons in its outer ring. A good insulator has more than 4 electrons in its outer ring. A good semiconductor has 4 electrons in its outer

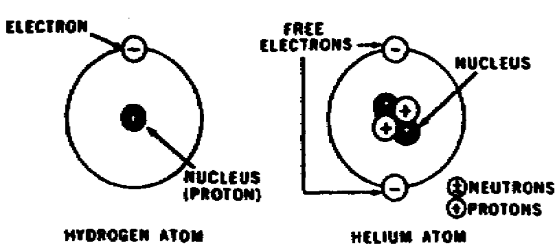


Figure 102. Structure of atoms.

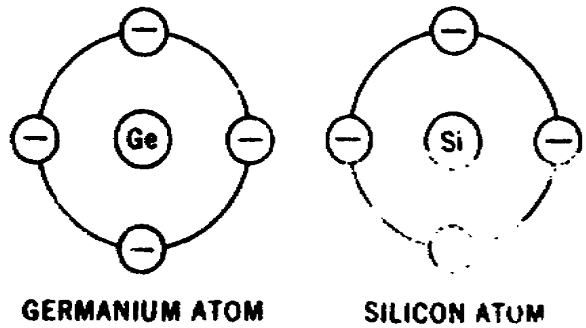


Figure 103. Atoms of semiconductors.

ring. Another name for the outer ring or orbit is the valence ring. The helium atom and the hydrogen atom are both good conductors of electricity–the hydrogen atom being the better.

5. **Atomic Number**. Atoms of different elements are found to have a different number of protons and neutrons in their nucleus. The atomic numbers of some of the elements are listed in figure 101. Figure 102 shows the structure of a hydrogen atom and a helium atom, two examples of good conductors. Figure 103 shows the structure of a germanium atom and a silicon atom, which are examples of a semiconductor.

6. An atom that has only four electrons in its outer orbit or ring will combine with other atoms whose outer orbits are incomplete. If a number of germanium atoms are joined together into crystalline form, the process is called covalent bonding of germanium atoms. Figure 104 shows germanium atoms in covalent bonding. Figure 105 illustrates an atom of germanium and an atom of antimony. For simplification, only the nucleus and the outer rings are shown for each atom. The outer or valence ring for the germanium atom contains four electrons, while

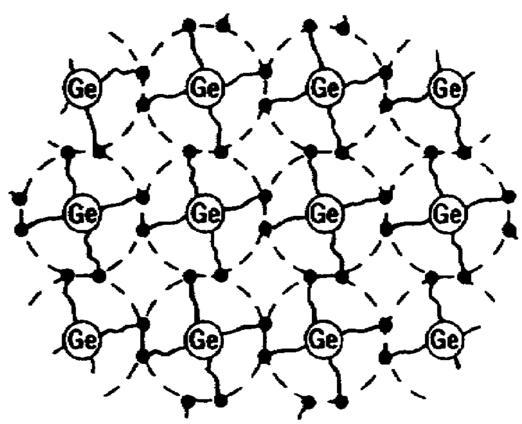


Figure 104. Crystalline germanium.

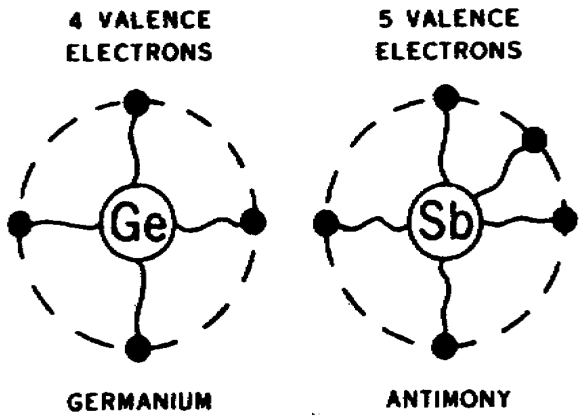


Figure 105. Typical atoms.

the valence ring for the antimony atom contains five atoms.

7. If a small amount of antimony is added to crystalline germanium, the antimony atoms will distribute themselves throughout the structure of the germanium crystal.

8. Figure 106 shows that an antimony atom has gone into covalent bonding with germanium. The antimony atom in the material donates a free electron and these free electrons will support current flow through the material. The antimony is called a donor in that it donates free electrons. The germanium crystal now becomes an N-type (negative type) germanium.

9. P-type (positive type) germanium can be prepared by combining germanium and indium atoms. Figure 107 shows germanium and indium in covalent bonding. For every indium atom in the material, there will be a shortage of one electron that is needed to complete covalent bonding between the two elements. This shortage of an electron can be defined as a hole. This type of material will readily accept an electron to complete

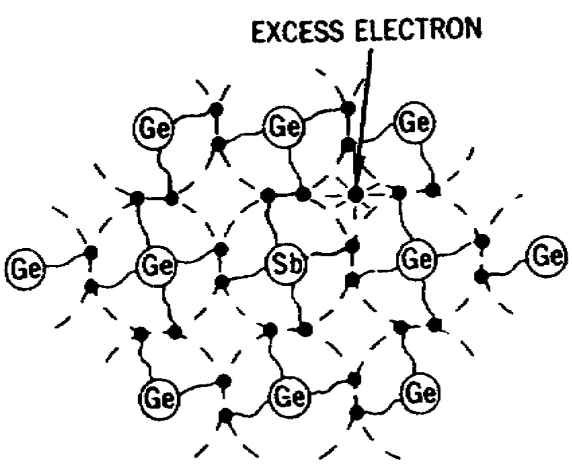


Figure 106. N-type germanium.

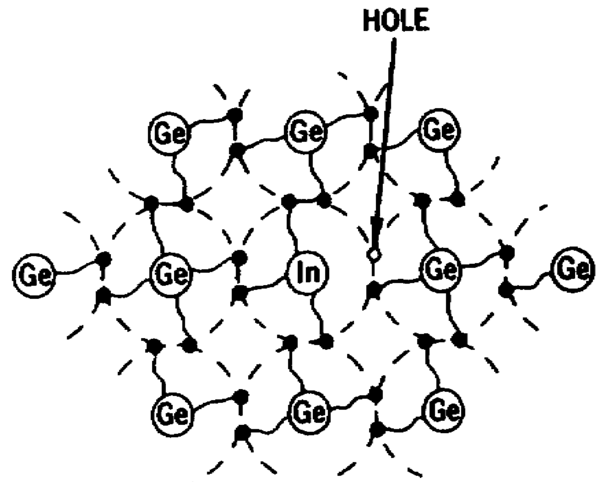


Figure 107. P-type germanium.

its covalent bonding and is therefore called acceptor type material.

10. The hole can be looked upon as a positive type of current carrier, as compared to the electron which is a negative type current carrier. The hole can be moved from atom to atom the same as the electron can be moved from atom to atom. The hole moves in one direction and the electron moves in the opposite direction.

11. **P-N Junctions**. When N-type and P-type germanium are combined in a single crystal, an unusual but very important phenomenon occurs at the surface where contact is made between the two types of germanium. The contact surface is referred to as a P-N junction, shown in figure 108.

12. There will be a tendency for the electrons to gather at the junction in the N-type material and likewise an attraction for the holes gather at the junction of the P-type material. These current carriers will not completely neutralize themselves because movement of electrons and holes cause negative and positive ions to be produced, which means an electric field is set up in each type material that will tend to obstruct the movement of current carriers through the junction. This obstruction builds up a barrier that is referred to as a high resistance or potential hill. This electric field may be referred to as a potential hill battery since the two materials have acquired a polarity which opposes the normal movement of the current carries.

13. **Reverse Bias**. Figure 109 shows an external voltage applied to an N-P junction. The positive electrode of the battery is connected to the N-type material and the negative electrode is connected to the P-type material. Since the N-type material has an excess of electrons, the positive voltage being applied to this material will

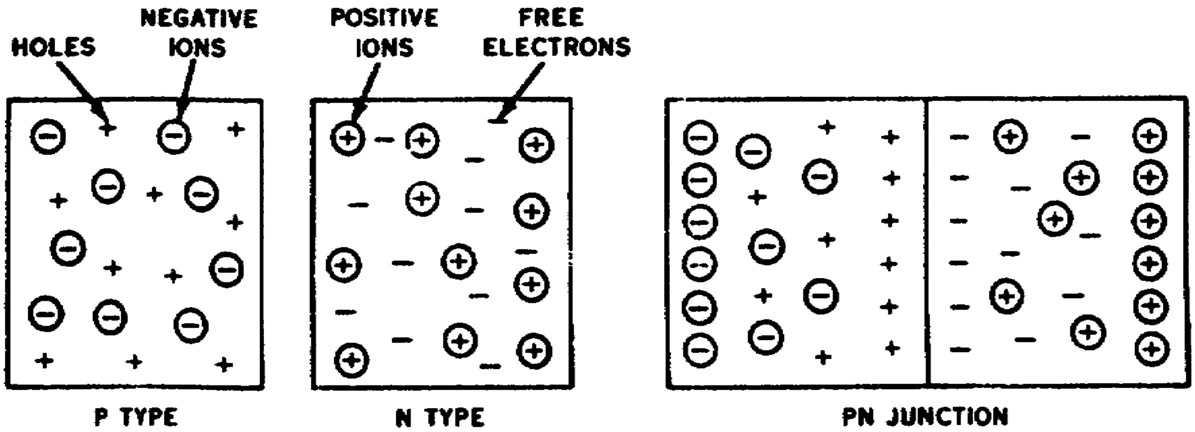


Figure 108. P-N junction.

attract these electrons toward that end of the germanium crystal. The negative voltage being applied to the P-type material, which has an excess of positive current-carrying holes, will attract these holes toward the other end of the crystal and away from the junction. The ammeter in figure 109 indicates no current flow. There is no possibility of recombination at the junction because the potential hill has been built up to a higher value by the application of an external voltage. This is called reversed bias condition or a high-resistance circuit.

14. **Forward Bias**. The battery can be connected with the opposite polarity and cause a different condition. In figure 110 the battery has been reversed, and now the negative electrode of the battery is connected to the N-type material. This negative voltage will repel the electrons in the N-type material toward the junction. The positive electrode is connected to the P-type material which will repel the positive holes toward the junction. With this connection, recombination takes place at the junction, resulting in current toward the N-P junction. This method of connecting the battery is known as forward bias since it encourages current flow.

15. **Diode Action**. Combining P- and N-type germanium into a single crystal is the basis of both diode and transistor action. The P-N junction can be used as a rectifier because of its ability pass current in one direction and practically no current in the other. Applying an a.c. voltage to this junction results in a d.c. output similar to that produced by a vacuum tube diode. Figure 111 shows a semiconductor diode rectifying an alternating voltage. When this P-N junction is biased in the forward direction, current will flow across the load resistor, R_L. When the junction is biased in the reverse direction, no current will flow across the load resistor, R_L. Forward and reverse biasing is caused by the a.c. input.

16. **Point-Contact Diode**. Another type diode is the point-contact diode, shown in figure 112.

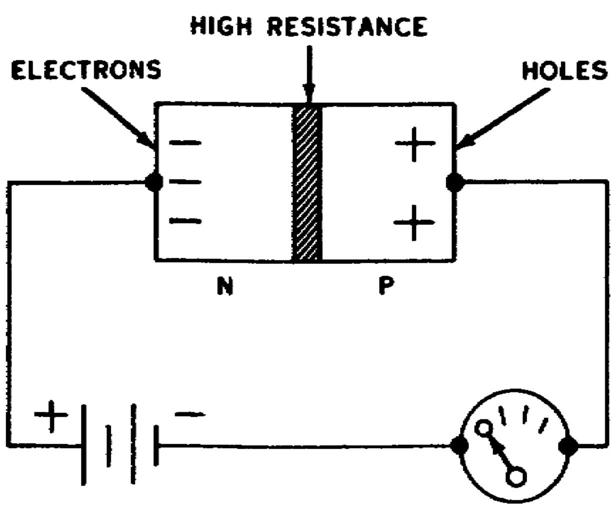


Figure 109. N-P junction with reverse bias.

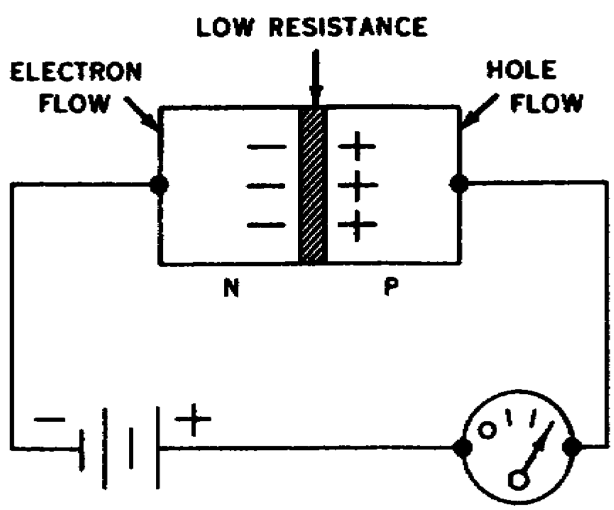


Figure 110. P-N junction with forward bias.

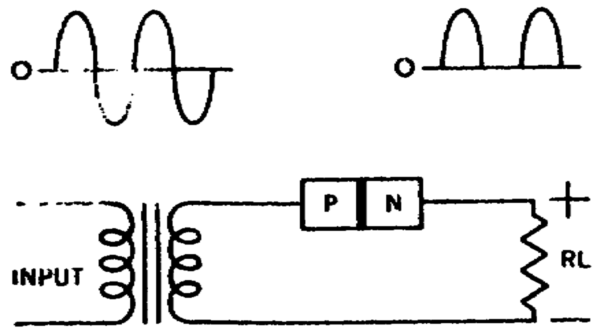


Figure 111. Half-wave rectification.

This diode operates similarly to the P-N junction type. It consists of a semiconductor (N-type germanium), a metal base, and a metallic point contact (cat whisker). A fine beryllium-copper or phosphor-bronze wire is pressed against the N-type germanium crystal. During the construction of the diode a relatively high current is passed through the metallic point contact into the N-type crystal. This high current causes a small P-type area to be formed around the point contact. Thus, a P-type and an N-type germanium are formed in the same crystal. The operation of this diode is similar to the P-N junction diode.

17. **Transistor Triodes**. A review of the operation of P-N germanium junctions reveals that a P-N junction biased in the forward direction is equivalent to the low-resistance element (high current for a given voltage). The P-N junction biased in the reverse direction is equivalent to a high-resistance element (low current for a given voltage). For a given current, the power developed in a high-resistance element is greater than that developed in a low-resistance element. (Power is equal to the current squared multiplied by the resistance value, or simply: $P = I^2R$.) If a crystal containing two P-N junctions were prepared, a signal could be introduced into one P-N junction biased the forward direction (low resistance) and extracted from the other P-N junction biased in the reverse direction (high resistance). This biasing produces a power gain of the signal when developed in the external circuit. Such a device would transfer the signal current from a low-resistance circuit to a high-resistance circuit.

18. **P-N-P and N-P-N Junction Transistors**. The P-N-P transistor is constructed by placing a narrow strip of N-type germanium between two relatively long strips of P-type germanium. And, as the letters indicate, the N-P-N transistor consists of a narrow strip of P-type germanium between two relatively long strips of N-type germanium.

19. To form two P-N junctions, three sections of germanium are required. Figure 113 shows the three sections separated. When the three sections are combined a P-N-P transistor is formed, and each section, like each element in a vacuum tube, has a specific name: emitter, base, and collector. The base is located between the emitter and collector, as the grid in a triode vacuum tube is located between the plate and cathode.

20. Note that when the three sections are combined, two space charge regions (barriers) occur at the junction even though there is no application of external voltages, or fields. This phenomenon is the same as that which occurs when two sections are combined so as to form a P-N junction diode.

21. Transistor action requires that one junction be biased in the *forward direction* and the second junction be biased in the *reverse direction*. Figure 114 shows the first junction biased in the forward direction. The second junction is not biased. Note that the space charge region (barrier) at the first junction is considerably reduced while the space charge region at the second junction is unchanged. The condition is identical to that of a P-N junction diode with forward bias.

22. Figure 114 shows the second junction biased in the reverse direction. The first junction is not biased. Note that the space charge region (barrier) at the second junction increases. Except for minority carriers (not shown), no current flows across the junction. This phenomenon is the same as that which occurs when two sections are combined to form a P-N junction diode with reverse bias.

23. Figure 115 shows what happens when junctions are biased simultaneously. Because of the simultaneous biasing, a large number of holes from the emitter do not combine with the electrons entering the base from the emitter-base battery. Many of the holes diffuse through the base and penetrate the base-collector space charge

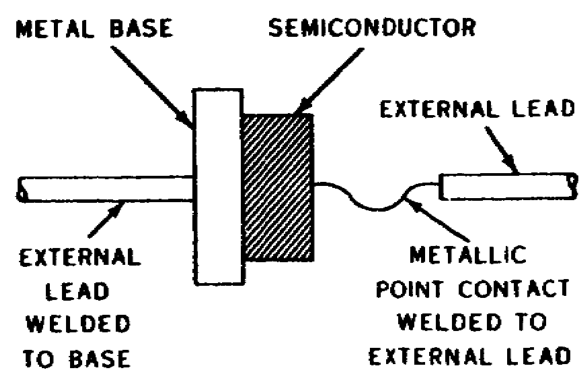


Figure 112. Physical construction of a point-contact diode.

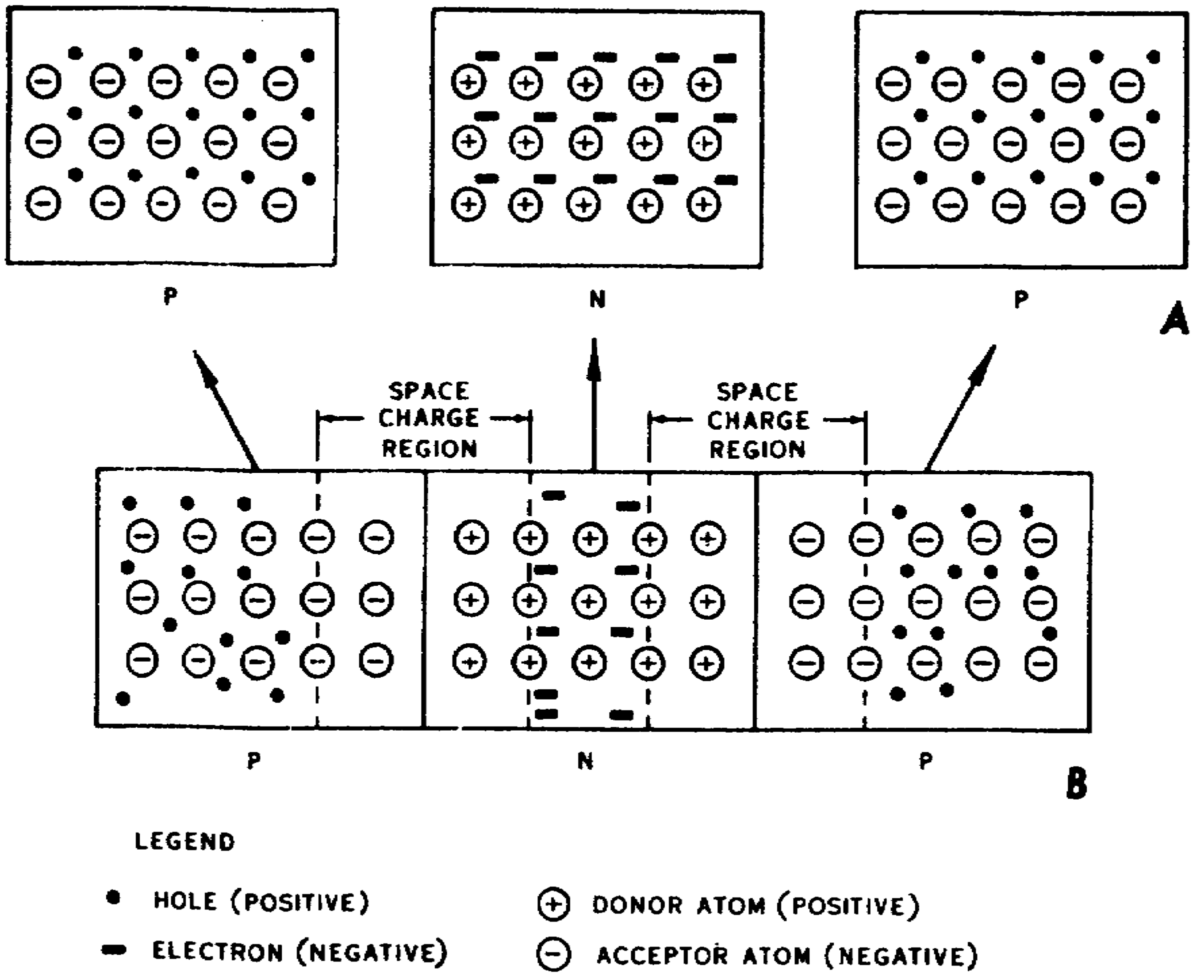


Figure 113. Two sections of P-type germanium and one section of N-type germanium.

region. In the collector region the holes combine with electrons that enter the collector from the negative terminal of the base-collector battery. If holes that enter the base from the emitter-base junction avoid combination with electrons entering the base from the battery, the holes are attracted to the collector by the acceptor atoms (negative) in the collector and the negative potential of the base collector battery.

24. To obtain maximum power gain in a transistor, most of the holes from the emitter must diffuse through the base region into the collector region. This condition obtained in practice by making the base region very narrow compared the emitter and the collector regions. In practical transistors, approximately 95 percent of the current from the emitter reaches the collector.

25. By using forward bias on the emitter-to-base junction there is a relatively low resistance, whereas by using reverse bias on the collector-to-base junction there is a relatively high resistance. A typical value for the emitter-to-base resistance is around 500 ohms, and around 500,000 ohms for the collector-to-base resistance. By Ohms law, voltage is equal to current times resistance; thus, numerically stated:

$$\text{Voltage gain} = \text{current gain} \times \text{resistance gain}$$
$$= 0.95 \times \frac{500{,}000}{500}$$
$$= 950$$

26. Although the current gain (95 percent) in this particular transistor circuit is actually a loss, the ratio of resistance from emitter to collector more than makes up for this loss. Also, this same resistance ratio provides a power gain which makes the transistor adaptable to many electron circuits.

27. **N-P-N Junction Transistors**. The theory of operation of the N-P-N is similar to that of the P-N-P transistor. However, inspection and comparison of figures 115 and 116 will reveal two important differences:

- The emitter-to-collector carrier in the P-N-P transistor is the hole. The emitter-to-collector carrier in the N-P-N transistor is the electron.

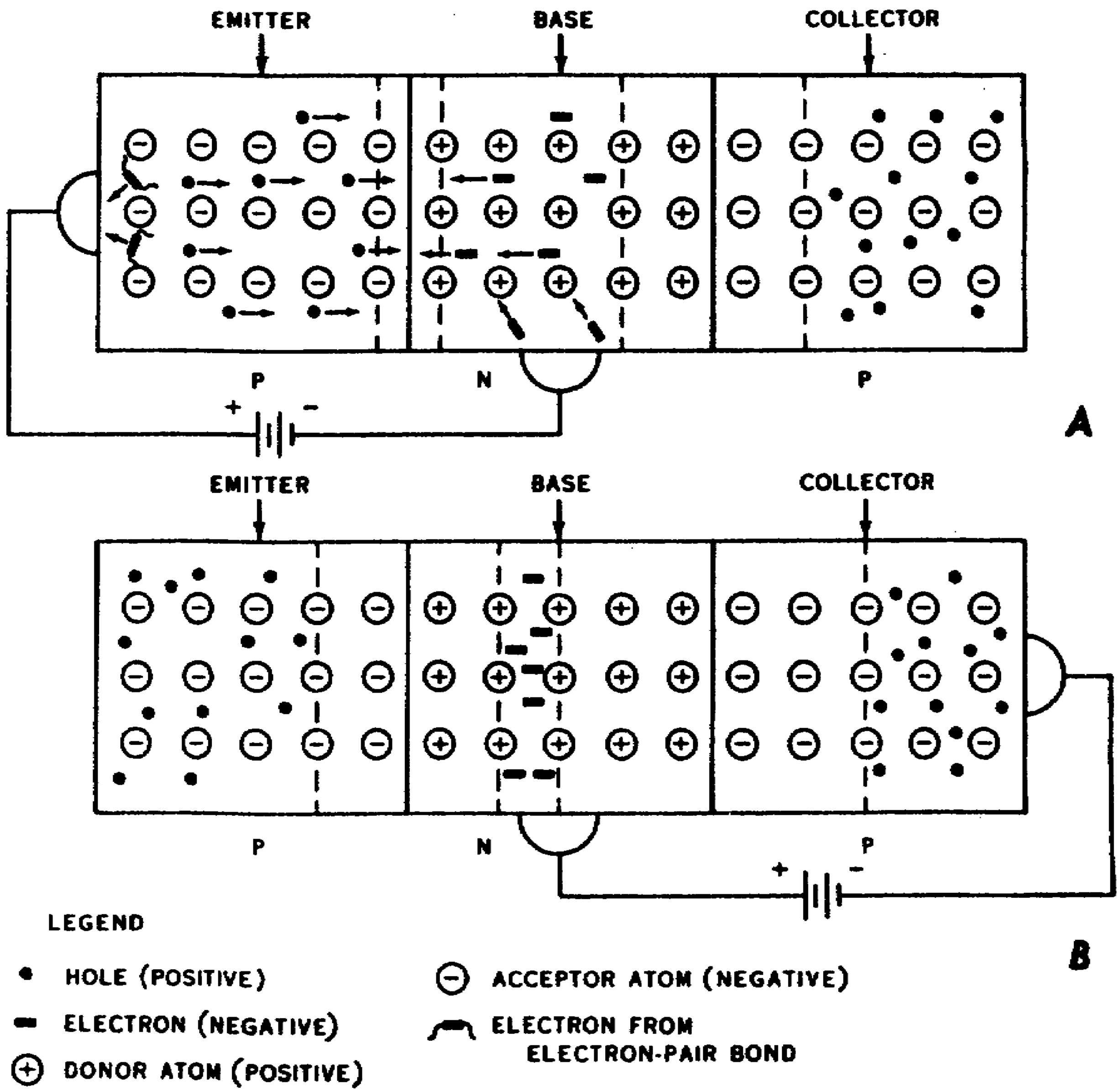


Figure 114. Forward bias between emitter and base (A) and reverse bias between base and collector (B)

- The bias voltage polarities are reversed. This condition is necessitated by the different positional relationships of the two types of germanium as used in the two types of transistors.

28. **Transistors and Electron Tubes**. Some of the differences and similarities between electron tubes and transistors are discussed in the following paragraphs.

29. The main current flow in an electron tube is from cathode to plate (shown in fig. 117). In a junction transistor, the main current flow is from emitter to collector. The electron current in the electron tube passes through a grid. In the transistor, the electron current passes through the base. The cathode, grid, and plate of the electron tube are comparable to the emitter, base, and collector, respectively, of the transistor. Plate current is determined mainly by grid to cathode voltage, and collector current is determined mainly by emitter-base voltage. The electron tube requires heater current to boil electrons from the cathode. The transistor has no heater.

30. For electron current flow in an electron tube, the plate is always positive with respect to the cathode. For current flow in a transistor, the collector may be positive or negative with respect to the emitter depending on whether the electrons or holes, respectively, are the emit-ter-to-collector carriers. For most electron tube

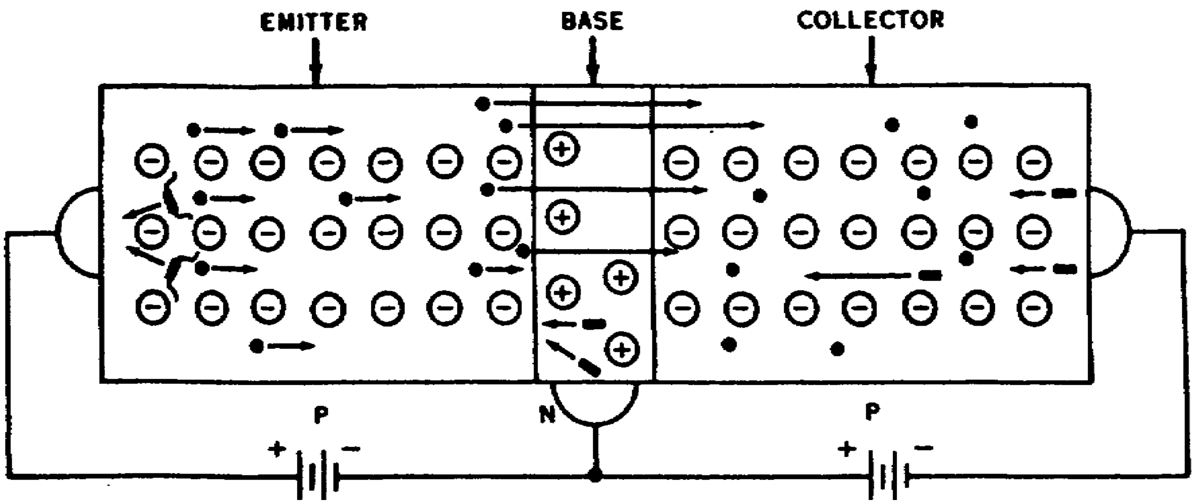


Figure 115. Simultaneous application of forward bias between emitter and base and reverse bias between base and collector of P-N-P transistor.

applications, grid cathode current does not flow. For most transistor applications, current flows between emitter and base. Thus, in these cases, the input impedance of an electron tube is much higher than its output impedance and similarly the input impedance of a transistor is much lower than its output impedance.

31. **Transistor Triode Symbols**. Figure 118 shows the symbols used for transistor triodes. In the P-N-P transistor, the emitter-to-collector current carrier in the crystal is the hole. For holes to flow internally from emitter to collector, the collector must be negative with respect to the emitter. In the external circuit, electrons flow from emitter (opposite to direction of the emitter arrow) to collector.

32. In the N-P-N transistor, the emitter-to-collector current carrier in the crystal is the electron. For electrons to flow internally from emitter to collector, the collector must be positive with respect the emitter. In the external circuit, the electrons flow from the collector to the emitter (opposite to the direction of the emitter arrow).

33. **Point-Contact Transistor**. The point-contact transistor is similar to the point-contact diode except for a second metallic conductor (cat whisker). These cat whiskers are mounted relatively close together on the surface of a germanium crystal (either P- or N-type). A small area of P- or N-type is formed around these contact points. These two contacts are the emitter and collector. The base will be the N- or P-type of which the crystal was formed. The operation of the point-contact transistor is similar to the operation of the junction type. Now that you

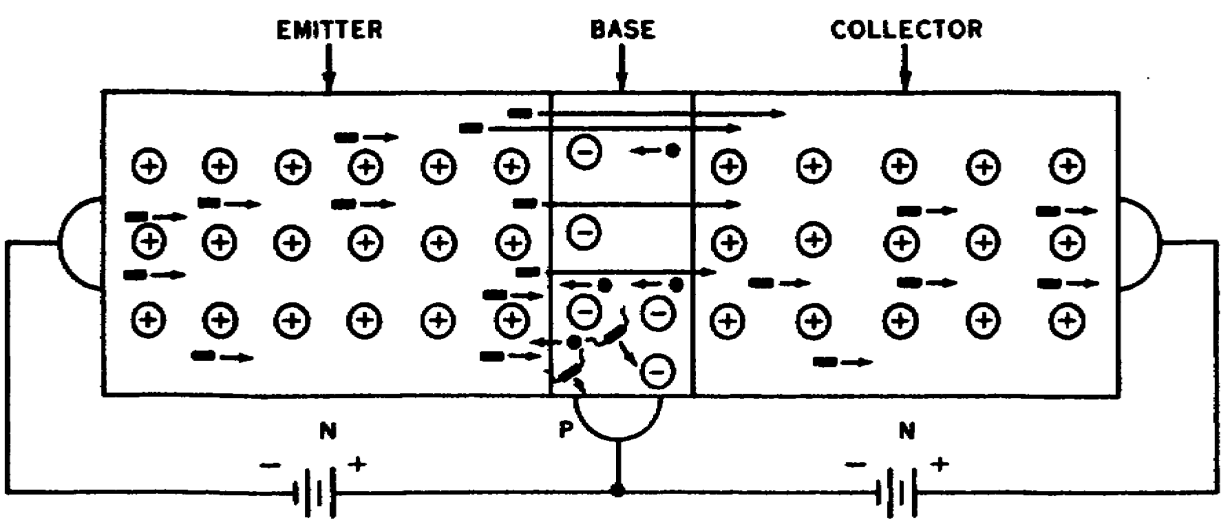


Figure 116. Simultaneous application of forward bias between emitter and base and reverse bias between base and collector of N-P-N transistor.

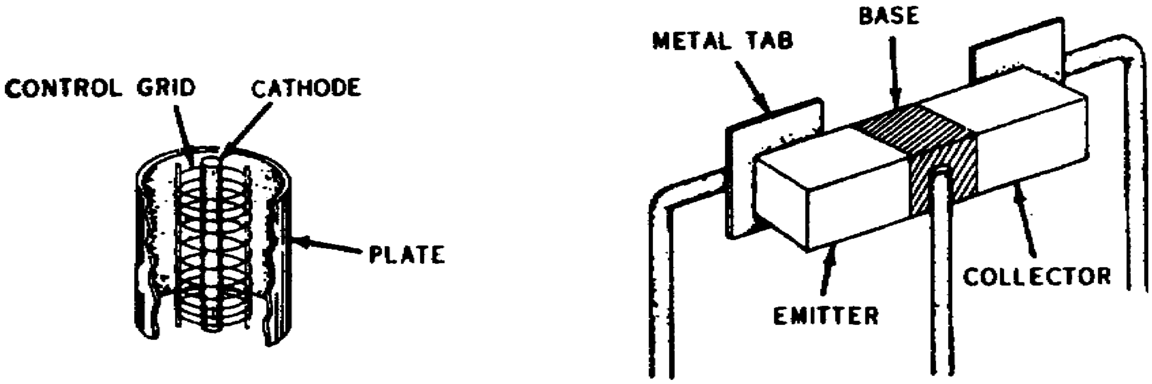


Figure 117. Structure of a triode vacuum tube and a junction transistor.

have studied transistors you must know how they are connected into the circuit.

32. Transistor Circuits

1. The circuit types in which transistors may be used are almost unlimited. However, regardless of the circuit variations, the transistor will be connected by one of three basic methods. These are: common base, common emitter, and common collector. These connections correspond to the grounded grid, grounded cathode, and grounded plate respectively.

2. **Common Base Circuit**. Figure 119 shows a common base circuit using a triode transistor. A thin layer of P-type material is sandwiched between two pellets of N-type material. The layer of P-type material is the base when the two pellets of N-type material are the collector and the emitter. The emitter is connected to the base through a small battery (B_1). This battery is connected with its negative electrode to the N-type emitter and its positive electrode to the P-type base. Thus, the emitter-base junction has forward bias on it. Recombination of the electrons and holes causes base current (Ib) to flow.

3. Battery B_2 is connected to produce reverse bias on the collector-base junction. However, current will flow in the collector-base circuit. Let's see why this current will flow. In this emitter, electrons move toward the emitter-base junction due to the forward bias on that junction. Many of the electrons pass through the emitter-base junction into the base material. At this point the electrons are under the influence of the strong field produced by B_2. Since the base material is very thin, the electrons are accelerated into the collector. This results in collector current (I_c), as shown in figure 119. About 95 percent of the electrons passing through the emitter-base junction enter the collector circuit. Thus, the base current (I_b), which is a result of recombination of electrons and holes, is only 5 percent of the emitter current.

4. **Common Emitter Circuit**. The circuit that will be encountered most often is the common emitter circuit shown in figure 120. Notice that the base is returned to the emitter and the collector is also returned the emitter. The base-emitter circuit is biased by a small battery whose negative electrode is connected to the N-type base and

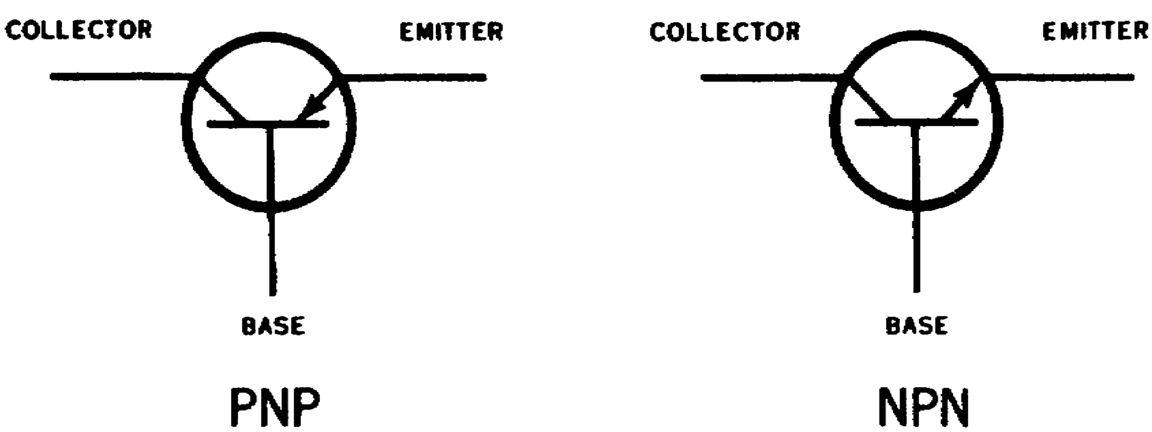


Figure 118. Transistor symbols.

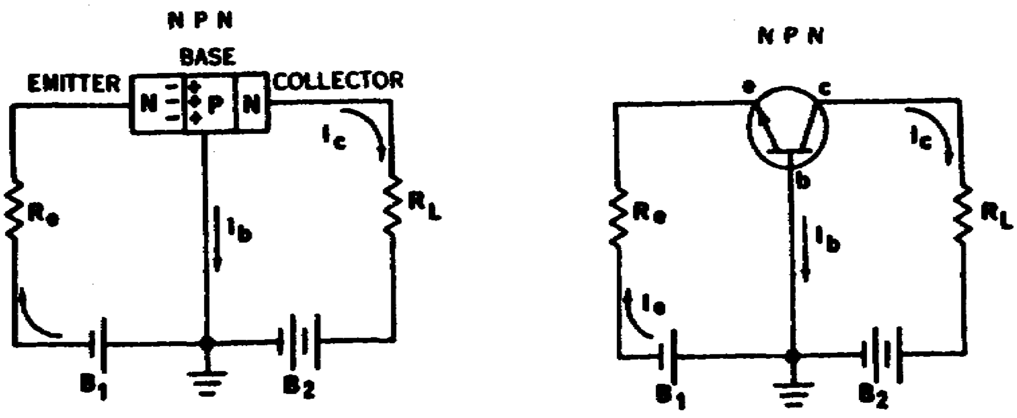


Figure 119. Common base circuit.

The positive electrode to the P-type emitter. This forward bias results in a base-emitter current of 1 milliampere. In the collector circuit the battery is placed so as to put reverse bias on the collector-base junction. The collector current (I_c) is 20 milliamperes. Since the input is across the base emitter and the output is across the collector emitter, there is a current gain of 20. The positive voltage on the emitter repels its positive holes toward the base region. Because of their high velocity, and because of the strong negative field of the collector, the holes will pass right on through the base material and enter the collector. Only 5 percent or less of those carriers leaving the emitter will enter through the circuit. The other 95 percent or more will enter the collector and constitute collector current (I_c).

5. **Common Collector Circuit**. The common collector circuit in figure 121 operates in much the same manner as a cathode follower vacuum tube circuit. It has a high impedance and a low output impedance. It has a small power gain but no voltage gain in the circuit. The circuit is well suited for input and interstage coupling arrangements.

6. **Transistor Amplifiers**. Let's put a signal voltage into the circuit of figure 122 and trace the electron flow. A coupling capacitor (C_1) is used to couple the signal into the emitter-base circuit. R_g provides the right amount of forward bias. When the signal voltage rises in a positive direction, the emitter will be made less negative with respect to the base. This difference will result in a reduction of the forward bias on the emitter-base circuit and, therefore, a reduction in current flow through the emitter. Since the emitter current is reduced, the collector current will likewise be reduced at the same proportion. As the signal voltage starts increasing in a negative direction, the emitter will now become more negative with respect to the base, resulting in increased forward bias. Increased forward bias

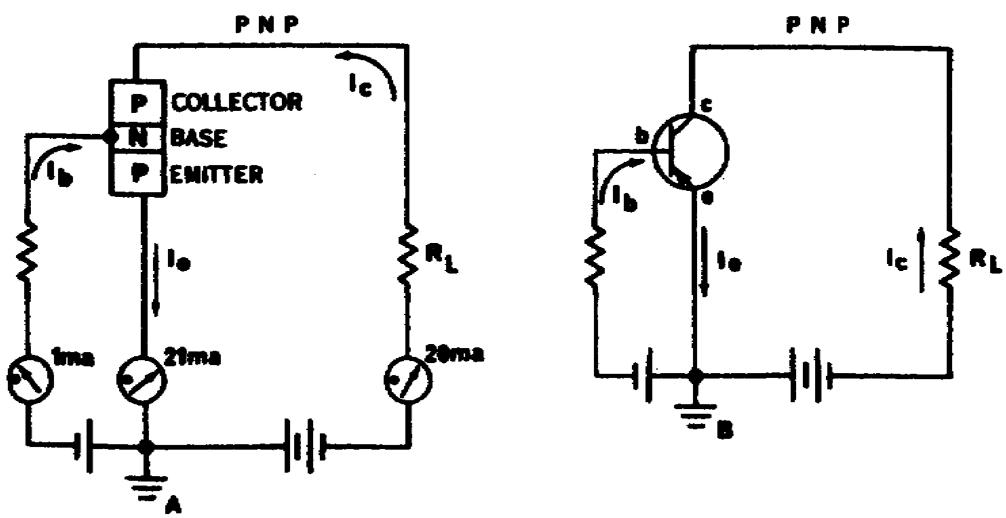


Figure 120. Common emitter circuit.

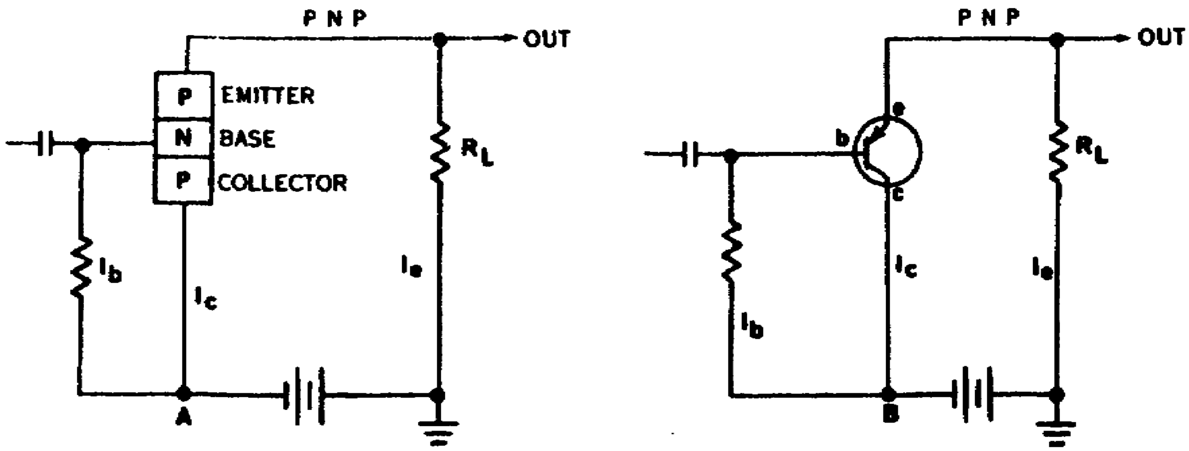


Figure 121. Common collector circuit.

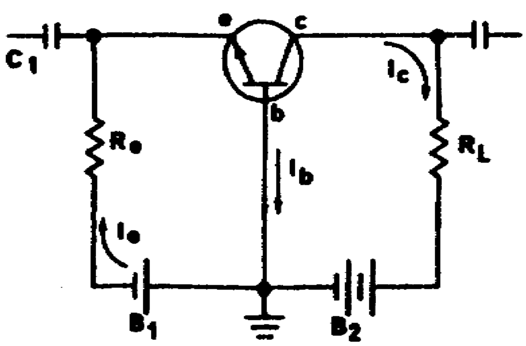


Figure 122. Common base amplifier.

will result in increased current flow in the emitter and collector circuits.

7. The signal being applied to the emitter-base circuit has now been reproduced in the collector circuit. The signal has been greatly amplified because the current flowing in the collector circuit is through a high impedance network. It is also possible to use a P-N-P type transistor, as shown in figure 123.

8. The electrical resistance of a semiconductor junction may vary considerably with its temperature. For this reason, the performance of a circuit will vary with the temperature unless the circuit is compensated for temperature variations. Compensating for temperature minimizes the effects of temperature on operating bias currents and will stabilize the d.c. operating conditions of the transistor. Now let us talk about the circuit that feeds the signal to the amplifier circuit-the bridge circuit.

33. Bridge Circuits

1. The brain of most electronic controls is a modified Wheatstone bridge. To understand the bridge circuit will review the operation of a variable resistor (potentiometer) first. One of the principal uses of the potentiometer is to take a voltage from one circuit to use in another. Figure 124 shows a potentiometer connected across a power source. The full 24 volts of the source is dropped between the two ends of the resistor; this means that 12 volts are being

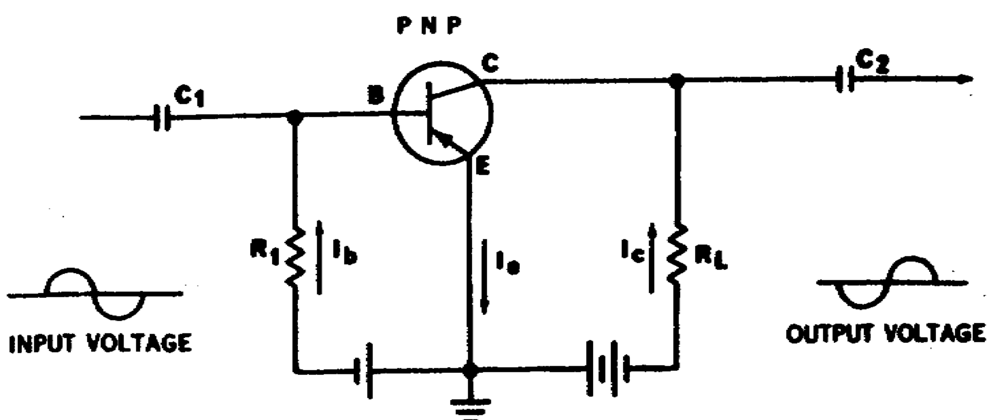


Figure 123. Common emitter amplifier.

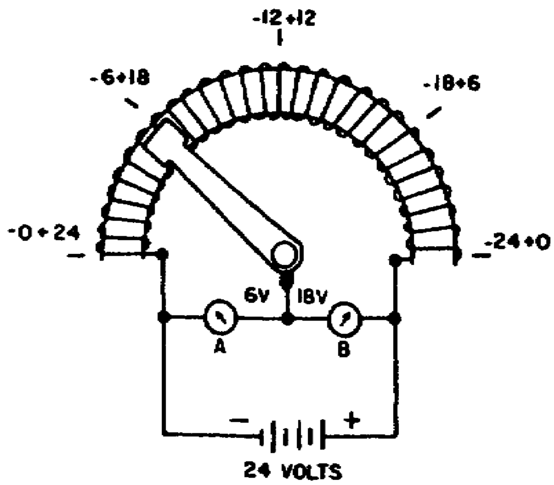


Figure 124. Potentiometer.

dropped across each half, or 6 volts across each quarter (1/4). If a voltmeter is connected from one end, and to the movable wiper, it will read the voltage drop between that end and the wiper. Note that meter A is reading the voltage drop across ¼ of the resistance, or 6 volts. Meter B is reading the voltage drop across the remaining ¾ of the resistance, or 18 volts. As the wiper is moved clockwise, the voltage shown on meter A will increase and B will decrease. Later you will hear the word "pot." This is short for potentiometer.

2. Figure 125 shows two resistances connected in parallel with their wipers connected to a voltmeter. Since the two resistances are connected in parallel, the voltage applied by the battery is equally distributed along each of the two "pots." Such a combination of "pots" is called a bridge. Notice that each wiper is at a positive potential with respect to point C of 6 volts, and consequently the voltmeter indication is zero volts. Since no current flows between the wipers, the bridge is said to be balanced. If wiper A is moved to the center of the top "pot," detail A, it would take off 12 volts; however, wiper B is taking off 6 volts and the meter would read 6 volts, the difference between 6 and 12. Electrons would flow from B (negative) through the meter to A (positive in respect to B). The meter would be deflected to the left 6 volts, so we can say the bridge is unbalanced to the left. Moving wiper B toward the positive potential and A toward negative will cause the bridge to unbalance to the right because current would flow from A to B, deflecting the meter to the right, which is demonstrated in detail B of figure 125.

3. Look at figure 126, a Wheatstone bridge. The basic operation is the same as the common bridge shown in figure 125, but it uses only one variable resistor.

4. The variable resistor has a higher resistance value than the three fixed resistors. When the variable resistor is centered, it has the same value as the fixed resistors; the bridge is in balance, for no voltage is indicated by the meter. Each resistor drops 12 volts. Detail A of figure 126 shows R_4 unbalanced to the left. Because of its higher resistance, it now drops 18 of the applied volts, and the remaining 6 volts are dropped by R_1. The difference between 6 and 12 or 12

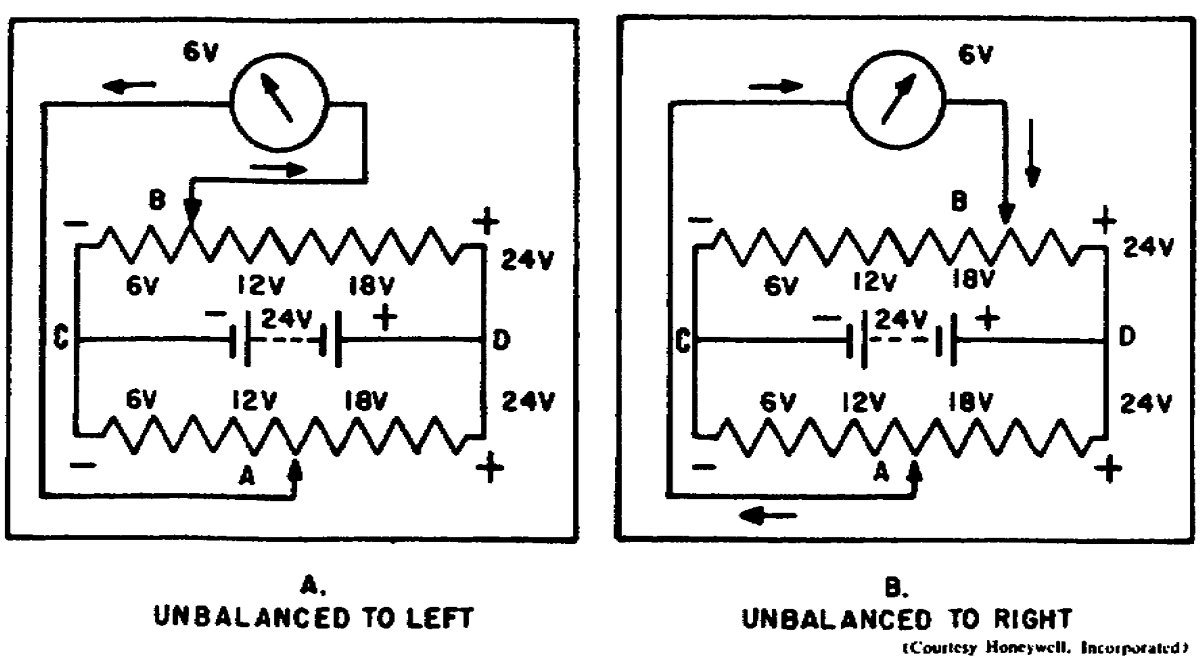


Figure 125. Simple bridge.

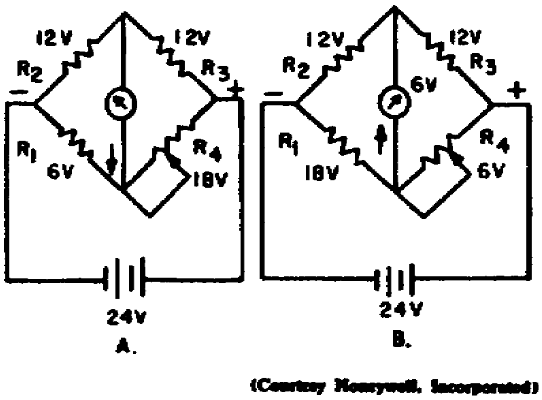


Figure 126. Wheatstone bridge.

and 18 is across the meter (6 volts). Since current flows from negative to positive, the flow through the meter is toward the op of the page. Detail B of figure 126 shows R_4 unbalanced to the right. This drops its value, causing most of the applied voltage to be dropped across R_1 (18 volts). The difference between 12 and 18 (6 volts) is across the meter, but in this case flowing toward the *bottom* of the page (- to +).

5. The Wheatstone bridge can be used on a.c. or d.c., but if a.c. is used, it requires a phase detector, discussed later in this chapter. The a.c. Wheatstone bridge is used with most electronic controls. Note that in figure 127 the d.c. power source has been replaced with a transformer and the voltmeter has been replaced with an amplifier. The amplifier simply "builds up" the small signal from the bridge to operate a relay.

6. T_1 (thermostat) now takes the place of R_3. The sensing element is a piece of resistance wire that changes in value as the temperature changes. An increase in temperature will cause a proportional increase in resistance. As you will note in figure 127, at set point of 74° F., the bridge is in balance. The voltage at points C and D is the same (7.5 volts), and the amplifier will keep the final control element in its present position until we have a temperature change. Now let's assume the control point changes.

7. When the temperature at T_1 is lower than set point, its resistance is *less* than 1000 ohms. This lower resistance causes more than 7.5 volts to be dropped by R_2, which means that point C has a lower voltage than point D. The amplifier will then take the necessary action to correct the control point.

8. When the temperature at T_1 is higher than set point, its resistance is *more* than 1000 ohms, causing less than 7.5 volts to be dropped across R_2. Point C has a higher voltage than point D. The amplifier will once again take the necessary corrective action.

9. The resistance of T_1 changes 2.2 ohms for each degree temperature change. This will cause only 0.0085-volt change between points C and D. For this reason, to check the bridge circuit, one will have to use an electronic meter usually called a V.T.V.M. for vacuum tube voltmeter.

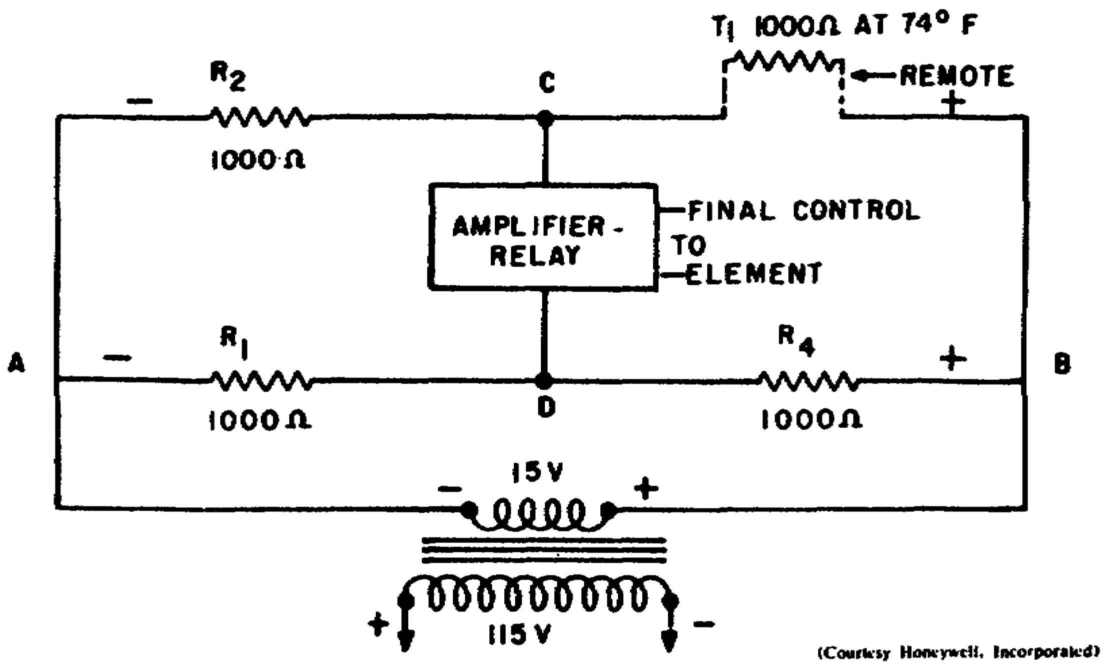


Figure 127. A.c. Wheatstone bridge.

The vacuum tube voltmeter will usually have an ohms scale as well as ac. and d.c. voltage scales.

10. The V.T.V.M. must be plugged into the lower line for operation. Usually, there is no provision for current measurements. Its advantage, however, is an extremely high input resistance of 11 million ohms (11 meg) or more, as a d.c. voltmeter, resulting in negligible loading effect. Also resistance ranges up to R X 1000 allow measurements as high as 1000 megohms. The ohms scale reads from *left* to *right* like the volts scale and is linear without crowding at either end. The adjustments are as follows:

(1) First, with the meter warmed up for several minutes on the d.c. volts position of the selector switch, set the zero adjust to line up the pointer on zero at the left edge of the scale.

(2) With the leads apart and the selector on ohms, the ohms adjust is set to line the pointer with maximum resistance (∞) at the right of the scale.

(3) Set the selector switch to the desired position and use. The ohms adjust should be set for each individual range.

11. CAUTION: When checking voltage on unfamiliar circuits, always start with the highest voltage scale for your safety as well as protection of the meter.

12. Another circuit that you could use in electronic controls is the discriminator circuit. It is used in conjunction with a bridge circuit.

34. Discriminator Circuits

1. The purpose of the discriminator circuit is to determine the direction in which the bridge is unbalanced and take the necessary action to correct the condition. When the control point moves off set point, the bridge becomes unbalanced and sends a small signal to the control grid of the first-stage amplifier, as shown in figure 128.

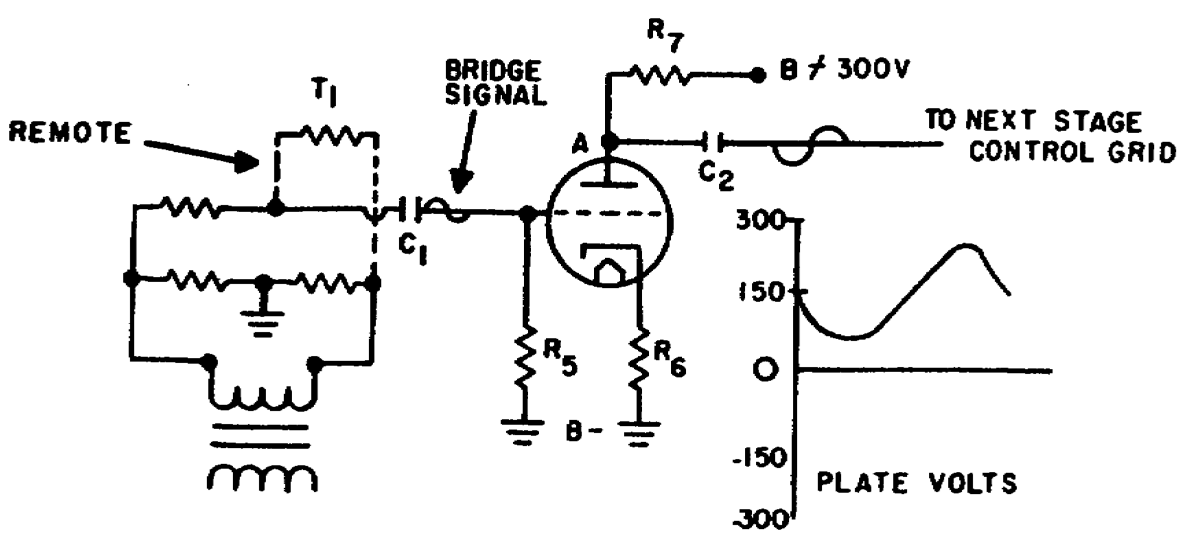
2. The small a.c. signal imposed on the control grid of this triode causes it to conduct more when the signal is positive and less when it is negative. The sine wave in figure 128 shows the plate voltage at point A. Note that when the grid is more positive, the tube conducts more and most of the 300 v.d.c. is dropped across load resistor R_7. When the grid is negative, most of the voltage is dropped across the tube. The sine wave has been inverted and is riding a fixed d.c. value of 150 volts.

3. The blocking capacitor C_2 passes the amplified a.c. component to the second stage but blocks the high voltage d.c. R_6 is the bias resistor for the control grid, and R_5 is the bias bleeder to prevent self-bias.

4. Amplifier stages 2, 3, etc., as seen in figure 129, repeat the process until the signal is strong enough to drive a power tube or discriminator. At this point the signal voltage has been amplified to a sufficient level to drive a power tube.

5. The power amplifier require a higher voltage driving signal but controls a much larger current. This current is then used to energize a relay and operates the final control element. In the discriminator circuit shown in figure 130, when the signal goes negative, cutoff bias is reached on the control grid. Also, the tube will conduct only when the plate is positive. Plate current will therefore be similar to the output of a half-wave rectifier.

6. Since plate current flows in pulse, capacitor C_5 is connected across the coil of the motor relay. The capacitor will charge while the plate



(Courtesy Honeywell, Incorporated)

Figure 128. Bridge and amplifier circuit.

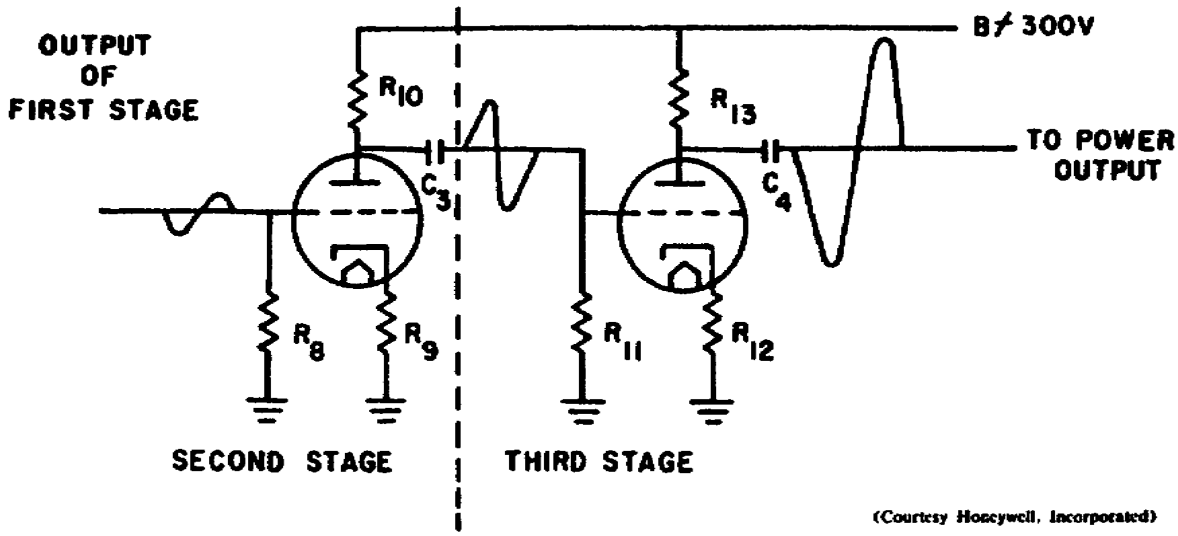


Figure 129. Second- and third-stage amplification.

is conducting and discharge through the coil, holding it energized during the off cycle. This type control is two position, and the final control will either be in the fully open or fully closed position.

7. The bridge supply voltage must come from the same phase as the discriminator supply, shown in figure 131. Supplying voltage from the same phase insures a bridge signal that is either in phase or 180° out of phase with the discriminator supply.

8. The control grid of the discriminator is biased at cutoff; therefore, it will conduct only when the plate and the amplified bridge signal are both positive. With the temperature below set point, as in figure 131, point C will have the same polarity as point B (the resistance of T_1 decreased); and will cause bridge signal to

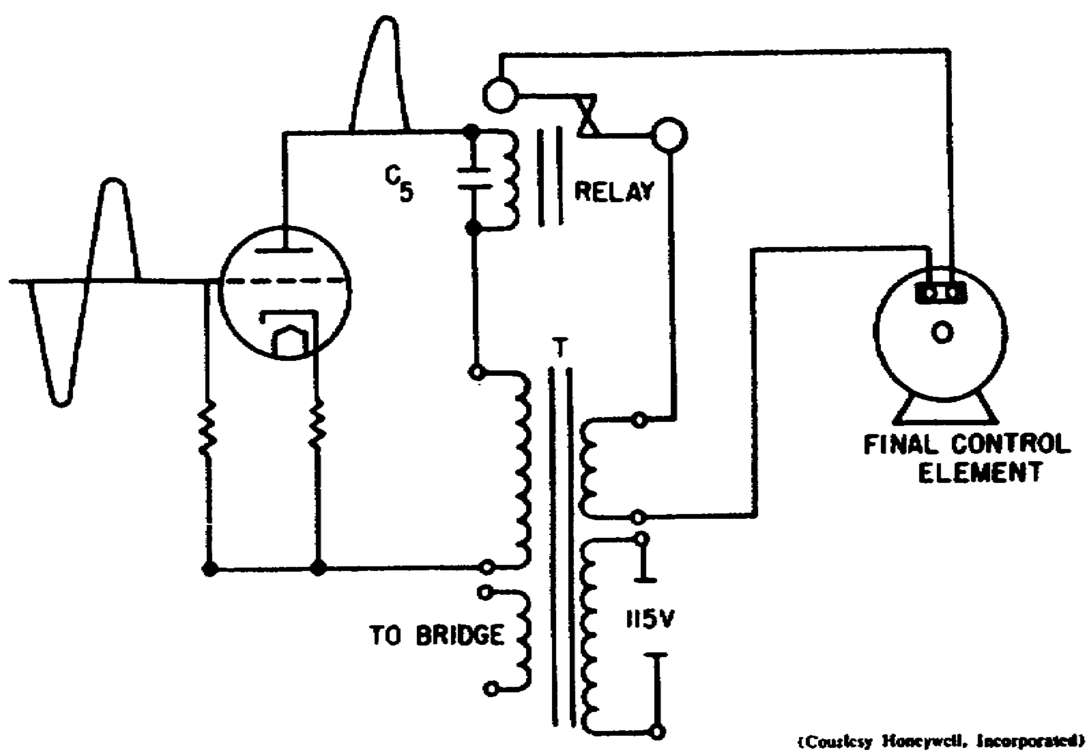
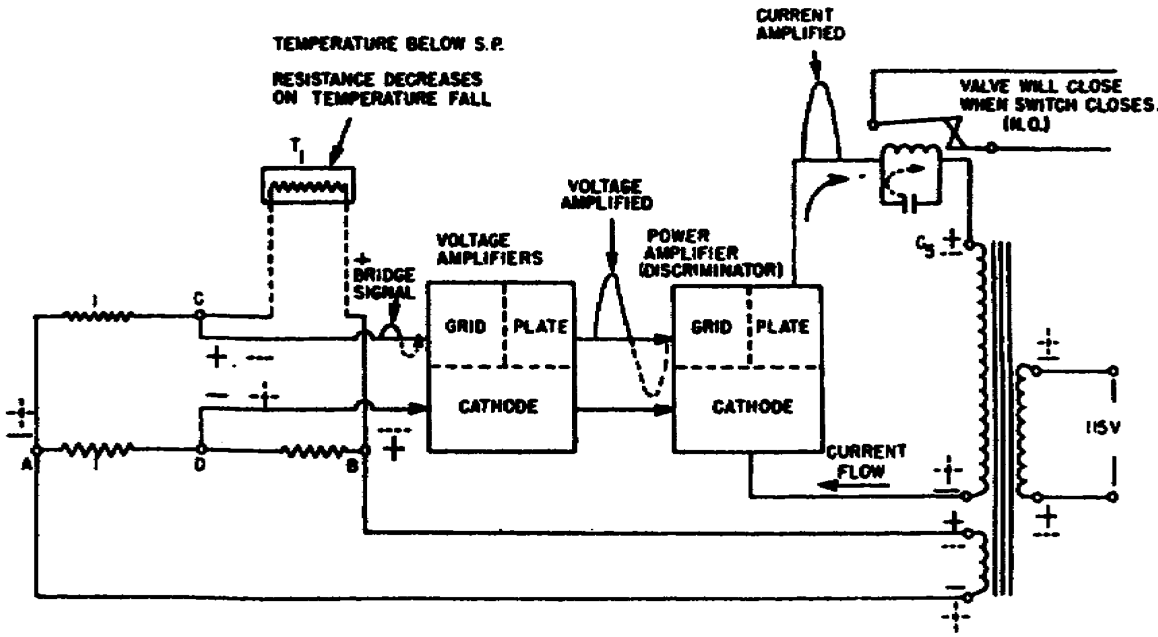


Figure 130. Discriminator circuit.



(Courtesy Honeywell, Incorporated)

Figure 131. Two-position control.

be more positive at the same time the discriminator plate is positive (solid symbols, +). Current flows through the relay and also charges capacitor C_5. During the next half-cycle (dotted symbols, +) the signal is negative and the discriminator plate is negative. No plate current can flow. Capacitor C_5 discharges through the relay which holds it closed until the next alteration.

9. The valve controlling chill water or brine will remain closed until the temperature increases. If the temperature goes above the set point, the grid of the discriminator will be negative when the plate is positive and vice versa. No plate current can flow and the valve opens.

10. For modulating control, illustrated in figure 132, a modulating motor is used with a balancing potentiometer. The balancing potentiometer is wired in series with the thermostat resistor. Its purpose is to bring the bridge back into balance (no voltage between points C and D) when a deviation has been corrected. Assuming a rise in temperature at T_1 and the polarity shown by the solid symbols, point C will be negative. Neither of the discriminator tubes will conduct because the control grids of both are negative beyond cutoff bias. During the next alternation (dotted symbols), when the signal is positive, discriminator number 2 will conduct because its plate is also positive. Capacitor C_6 will charge and relay number 2 will energize, causing the motor to run counterclockwise; this moves the wiper of the balancing potentiometer to the right, adding resistance to R_1, and removing resistance from T_1 until no signal is applied to the amplifier. Cutoff bias is reached on the control grids of the discriminators, capacitor C_6 discharges, relay 2 energizes, and the motor stops at its new position.

11. A decrease in temperature at T_1, causes a 180° phase shift from the bridge. This phase shift places the grid of discriminator tube 1 positive at the same time as the plate. Relay 1 energizes and the motor runs clockwise until the bridge is once again balanced.

12. For control of relative humidity, the thermostat is replaced by a gold leaf humidistat. The principle of operation is the same; however, you must remember that moisture sensed by the gold leaf causes the resistance to change.

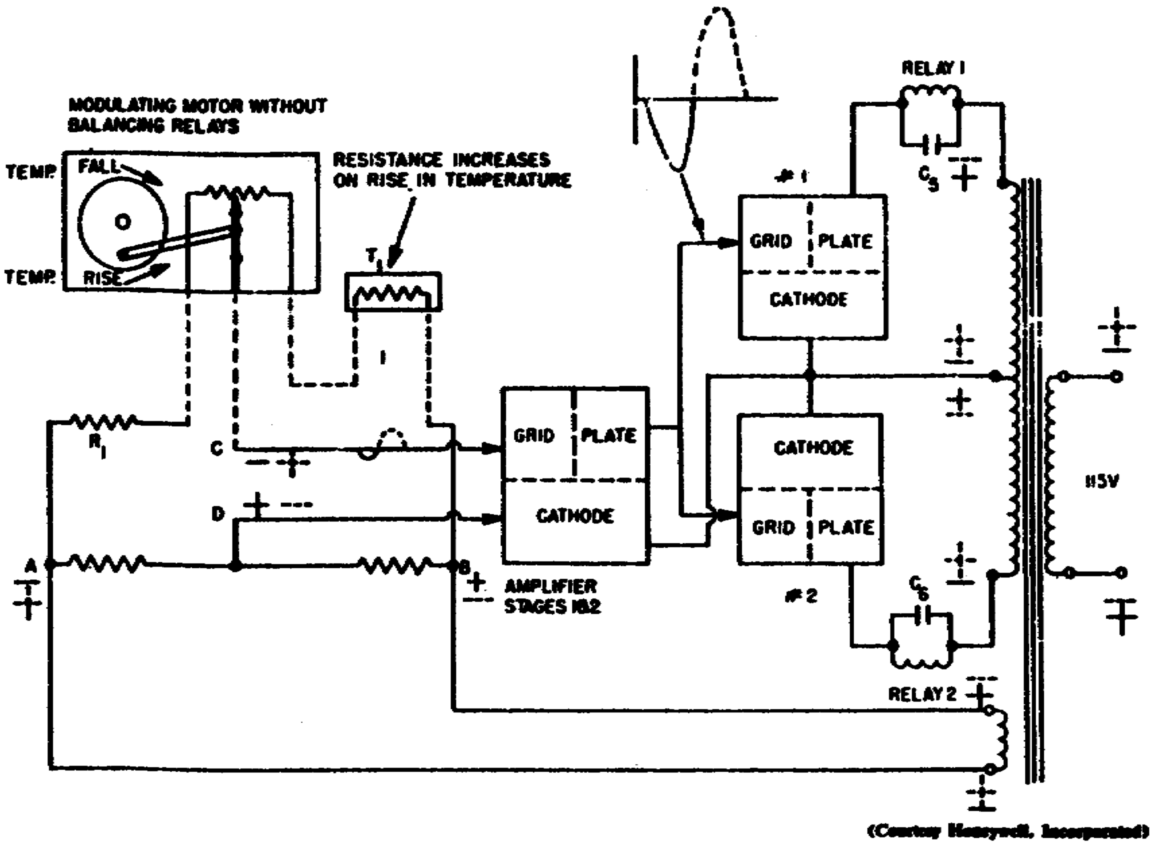


Figure 132. Modulating control.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers.

1. Explain thermionic emission. (Sec. 29, Par. 3)

2. How does a directly heated cathode differ from an indirectly heated cathode? (Sec. 29, Par. 4)

3. Name the elements of a diode vacuum tube. (Sec. 29, Par. 7)

4. The electrons flow from the ________________ to the __________________in a vacuum tube. (Sec. 29, Par . 7)

5. Why does the diode rectify a.c.? (Sec. 29, Par. 8)

6. What factors determine the amount of current flowing through a diode tube? (Sec. 29, Par. 9)

7. The diode will conduct during the ___________ half-cycle of the alternating current. (Sec. 29, Par. 11)

8. How can you filter half-wave rectification with a capacitor? (Sec. 29, Par. 13)

9. What is a duo-diode vacuum tube? (Sec. 2, Par. 16)

10. What is the purpose of the control grid in a vacuum tube? (Sec. 30, Par. 2)

11. Where, inside the tube, is the control grid physically located? (Sec. 30, Par. 2)

12. The usual polarity of the grid with respect to the cathode is _________________. (Sec. 30, Par. 4)

13. What will happen to the current through a triode if you make the control grid more negative? (Sec. 30, Par. 5)

14. Define grid bias. Cutoff bias. (Sec. 30, Pars. 5 and 7)

15. Name the types of grid bias used on vacuum tubes. (Sec. 30, Pars. 8, 9, and 12)

16. What is one disadvantage of contact potential bias? (Sec. 30, Par. 14)

17. Why can a triode be used as an amplifier? (Sec. 30, Par. 15)

18. What is the potential of the screen grid with respect to the cathode in a tetrode vacuum tube? (Sec. 30, Par. 19)

19. How does a power amplifier differ from a triode amplifier? (Sec. 30, Par. 20)

20. What potential is applied to the suppressor grid of a pentode tube? (Sec 30, Par. 23)

21. What is a valence ring? (Sec. 31, Par. 4)

22. A valence ring containing two electrons indicates a good _________________. (Sec. 31, Par. 4)

23. How is N-type germanium made? (Sec. 31, Par. 8)

24. How does N-type germanium material differ from P-type germanium material? (Sec. 31, Pars. 8 and 9)

25. To achieve reverse bias, the positive electrode of the battery is connected to the ________________ material and the negative to the _________________ material. (Sec. 31, Par. 13)

26. Which type of bias encourages current flow? (Sec. 31, Par. 14)

27. How much power is developed in a circuit having 100 ohms resistance and an amperage draw of 5 amps? (Sec. 31, Par. 17)

28. Where is the base of a P-N-P transistor located? (Sec. 31, Par. 19)

29. How is maximum power gain obtained in a transistor? (Sec. 31, Par. 24)

30. What components of a vacuum tube are comparable to the emitter, base, and collector of a transistor? (Sec. 31, Par. 29)

31. Name the three basic transistor circuits. (Sec. 32, Par. 1)

32. Which transistor circuit has a high impedance input and a low impedance output? (Sec. 32, Par. 5)

33. What is the purpose of a coupling capacitor between stages? (Sec. 32, Par. 6)

34. You are checking the voltage drop across a potentiometer. The applied voltage is 12 volts and three-fourths of the resistance is in the circuit. What is the voltage drop across the potentiometer? (Sec. 33, Par. 1)

35. When is a simple two-resistor bridge balanced? (Sec. 33, Par. 2)

36. How is the Wheatstone bridge applied to electronic control? (Sec. 33, Par. 5)

37. What will occur when the temperature at the thermostat, connected in a Wheatstone bridge, increases? (Sec. 33, Par. 8)

38. What type of meter is used to check out electronic controls? Why? (Sec. 33, Par. 9)

39. What is the first step you must take when using a V.T.V.M.? (Sec. 33, Par. 10)

40. What is the purpose of a discriminator circuit? (Sec. 34, Par. 1)

41. Explain the function of the blocking capacitor. (Sec. 34, Par. 3)

42. What has occurred when the signal in the discriminator circuit goes negative? (Sec. 34, Par. 5)

43. Why should the bridge supply voltage come from the same phase as the discriminator supply? (Sec. 34, Par. 7)

44. When will the discriminator circuit conduct? (Sec. 34, Par. 8)

45. Why is a balancing potentiometer read with a modulating motor? (Sec. 34, Par. 10)

Electronic Control Systems

ELECTRONIC control is here to stay. It has been approximately 16 years since the control industry first showed how microvoltages, electronically amplified, could be used in controlling air-conditioning and equipment cooling systems. Despite an erroneous but perfectly human awe in the presence of a revolutionary form of power, engineers, designers, and building owners began to apply this new type of control to their systems. The ordinary serviceman shunned electronic control because the thought that it was a piece of hardware too technical to repair. By 1955, over 5000 electronic control systems were in use, and it had become evident that their adjustment and maintenance were not more difficult but actually simpler than those of the more traditional control systems--pneumatic and electric.

2. In this chapter you will study system components, applications, and the maintenance performed on electronic control systems.

35. Components

1. The components discussed in this section are the humidity sensing element, thermostats, and damper motor. The control panel will be discussed later in this chapter. It houses the bridge and amplifier circuits that we covered in Chapter 6.

2. **Humidity Sensing Element**. The sensing element should be located within the duct at a place where the air is thoroughly mixed and representative of average conditions. You must be careful not to locate the sensing element too close to sprays, washers, and heating or cooling coils. The location should be within 50 feet of the control panel. All wiring and mounting should be accomplished as specified by the manufacturer.

3. **Thermostats**. The thermostats you will study in this chapter are space, outdoor, and insertion. In addition, we will also cover thermostat maintenance.

4. *Space thermostat.* The thermostat should be mounted where it will be exposed only to typical or average space temperature. You should avoid installing it on an outside wall or on a wall surface with hot or cold water pipes or air ducts behind it.

5. In general, try to keep the thermostat out of the way of traffic, but in a representative portion of the space being measured. The most desirable location is on an inside wall, 3 to 5 feet from the outside wall and about 54 inches above the floor.

6. *Outdoor thermostat.* The sensing element is a coil of fine wire wound on a plastic bobbin and coated for protection against dirt and moisture. The thermostat should be mounted out of the sun (on the north side of the building or in some other shaded location), above the snowline, and where it won't be tampered with.

7. *Insertion thermostat.* When using this thermostat as a discharge air controller, you should mount it far enough downstream from the coil to insure thorough mixing of the air before its temperature is measured. When you use it as a return air controller, the thermostat is mounted where it will sense the average temperature of the return air from the conditioned space. If you mount it near a grille, it should be kept out of the airflow from open doors and windows.

8. To mount the thermostat, use the back of the box as a template. Mark the four holes to be drilled in the duct--the center hole and the three mounting holes. The center hole is used to insert the element.

9. *Thermostat maintenance.* To check the re-sistance of the sensing element, you must disconnect one of the leads at the panel. Place an ohmmeter across the leads. Remember, allow for the temperature of the element and accuracy of the meter.

10. A reading considerably less than the total resistance specified indicates a short, either in the element or in the leads to the element. If a short is indicated, take a resistance reading across the thermostat terminals. If the thermostat is shorted it must be replaced. If the meter reads more than the total resistance, there is an open

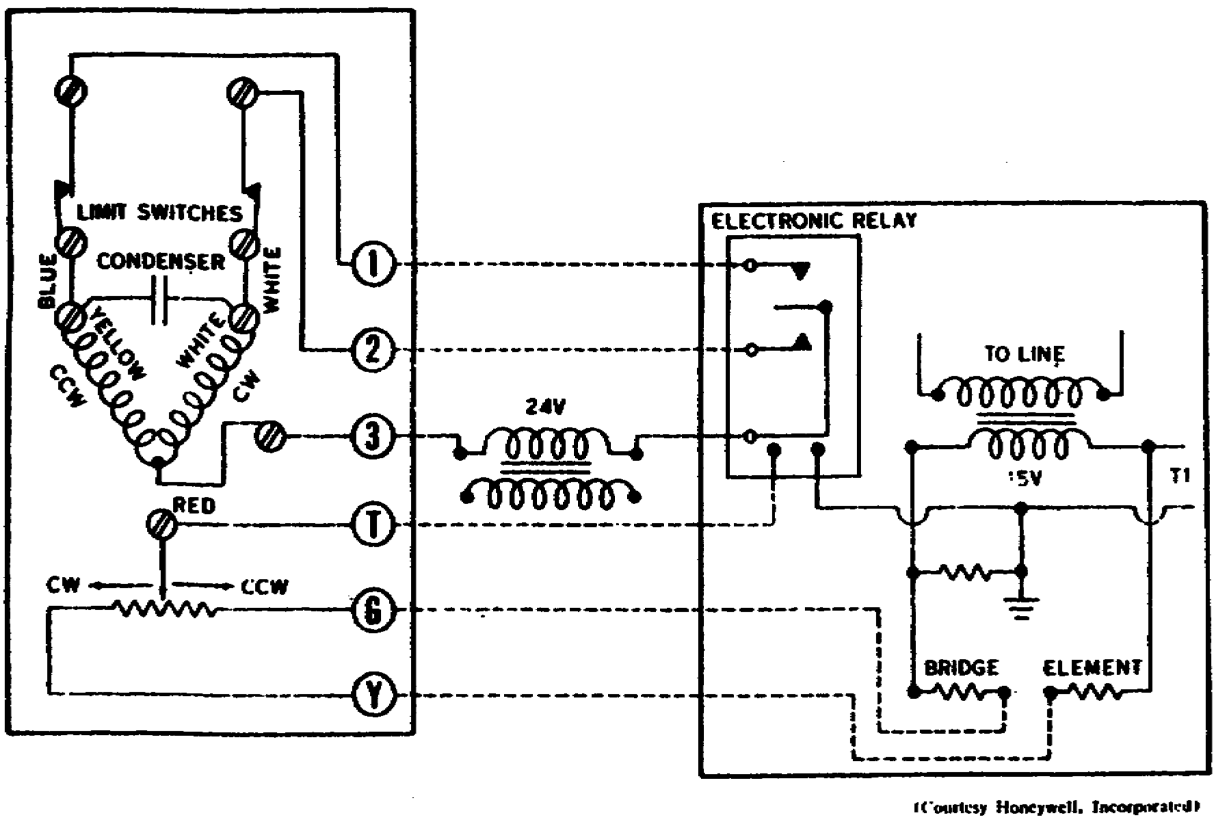


Figure 133. Damper motor schematic.

circuit. Again, a reading across the thermostat terminals will locate the trouble.

11. Excessive dirt accumulated on the element will reduce the sensitivity of the thermostat. Clean the element with a soft brush or cloth. Be careful not to damage the resistance element.

12. **Damper Motor**. The motor may be installed in any location except where excessive moisture, acid fumes, or other deteriorating vapors might attack the metal. The motor shaft should always be mounted horizontally.

13. The motor comes equipped with one crank arm. By loosening the screw and nut which clamp the crank arm to the motor shaft, the crank arm can be removed and repositioned in any one of the four 90° positions on the motor shaft. The adjustment screw on the face of the crank arm provides angular setting of the crank arm in steps of 22½° throughout any one of the four 90° angles. You can see by changing the position of the arm on the square crankshaft and through the means of the adjustment screw on the hub, the crank arm may be set in steps of 22½° for any position within a full circle. The crank arm may be placed on either end of the motor shat.

14. For instructions in the assembly of linkages you must refer to the instruction sheets packed in the carton with each linkage.

15. **Motor Servicing**. The only repairs that can be accomplished in the field are cleaning the potentiometer or limit switch contacts, repairing internal connecting wires, and replacing the internal wires.

16. If the motor will not run, check the transformer output first. Look for the transformer in figure 133. If it checks out good, use the transformer to check the motor. Disconnect the motor terminals (usually numbered 1, 2 and 3) and connect the transformer output leads to terminals 2 and 3. The motor should run clockwise, if it is not already at that end of its stroke. Similarly, connecting the transformer across terminals 1 and 3 should drive the motor counterclockwise.

17. If the motor responds to power from the transformer, the fault probably lies in the relay, wiring, or potentiometer. To check the potentiometer, disconnect terminals T, G, and Y from the outside leads. The resistance of the potentiometer windings can now be checked with an ohmmeter. The resistance across Y and G should be about 150 ohms. The resistance across T and either Y or G should change gradually from near 0 ohms about 135 ohms as the motor is driven through its stroke.

18. If the motor does not respond to direct power from the transformer, you must remove the motor cover and check for broken wires, defective limit switch, or a faulty condenser (capacitor).

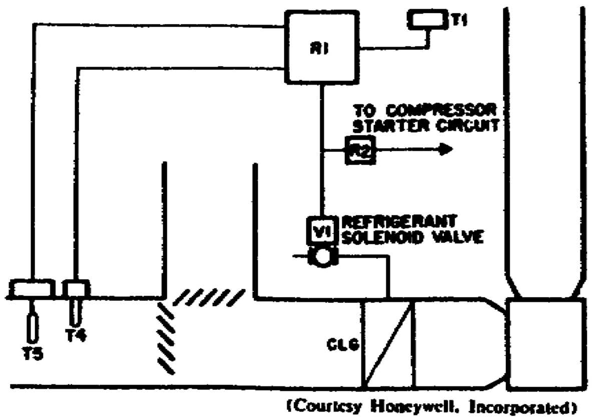


Figure 134. Refrigerant solenoid valve control system.

36. Application

1. The electronic control system has definite characteristics-flexibility, sensitivity, simplicity, speed, and accuracy-that show to best advantage in an air-conditioning system where signals from several controllers must be coordinated to actuate a series of control motors or valves. Each controller is a component of a modified Wheatstone bridge circuit. A change in the controlled variable will cause a change in the voltage across the bridge. This change in voltage is detected by an electronic relay which starts corrective controlled device action. The magnitude of the voltage change and the resulting device movement are a result of the amount of controlled variable change.

2. Authority "pots" in the control panel adjust the change in variable required at a controller to give a certain voltage change. For example, an outdoor thermostat might be adjusted to require a 10° temperature change to give the same voltage change as a 1° change at the space thermostat. For the remainder of this discussion, let us consider temperature as the controlled variable.

3. Voltages resulting from a rise in temperature differ in phase from voltages resulting from a drop in temperature and therefore can be distinguished. Voltages resulting from temperature changes at several thermostats are added in the bridge if they are of the same phase or subtracted if they differ in phase. The total voltage determines the position of the final controlled device. Each controller directly actuates the final controlled device.

4. All adjustments for setting up or changing a control sequence can be made from the control panel. The panel may be mounted in any readily accessible location. Selection of controls is simplified since one electronic control, with its broad range, replaces several conventional controls where each has a smaller range.

5. The following systems are typical examples of how electronics is applied to the control of air-conditioning and equipment cooling systems. The control sequence is given for each application.

6. **Refrigerant Solenoid Valve Control**. The electron control panel R1 in figure 134 will control space temperature by coordinating signals from the space thermostat T_1 and the outdoor thermostat T_4 to operate the refrigerant solenoid valve V_1. T_4 will raise the space temperature as the outdoor temperature rises to a predetermined schedule. T_5 will remove T_4 from the system when the outdoor temperature falls below the setting of T_5 to prevent subcooling of the space at low outdoor temperature.

7. You will find that a nonstarting relay, R_2, is wired into the compressor starting circuit. This relay will prevent the compressor from operating unless the solenoid valve is operating.

8. T_1 is a space thermostat which may have an integral set point adjustment and a locking cover. T_4 and T_5 are insertion thermostats.

9. **Summer-Water Compensation for a Two-Position Heating or Cooling System**. Controller T5 shown in figure 135 will select either the summer or winter compensation schedule. This selection depends upon the outdoor temperature.

10. On the winter compensation schedule, electronic relay panel R1 will control the space temperature by coordinating signals from space thermostat T_1 and outdoor thermostat T_3. The relay will operate either the heating or cooling equipment, depending upon the space temperature requirement. You can adjust the effect of T_3 to overcome system offset or to elevate the space temperature as the outdoor temperature falls.

11. During the summer compensation schedule, the electronic panel will control temperature by coordinating the signals from T_1 and the outdoor thermostat T_4 to operate the appropriate equipment, depending upon space temperature requirements. T_4 will elevate the space temperature

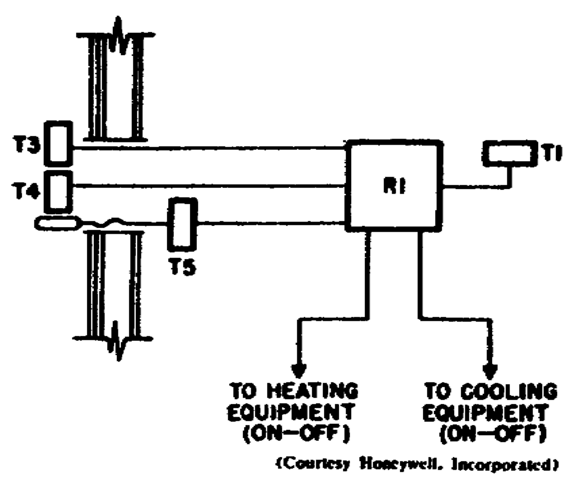


Figure 135. Two-position heating and cooling system.

as the outdoor temperature rises according to a predetermined schedule.

12. The last major topic that you will cover in this volume is maintenance of electronic controls.

37. Maintenance

1. In this section we shall discuss the adjustments, calibration, and calibration checks you will perform. After you have adjusted and calibrated the system, you will learn how it operates. This system differs from the systems previously discussed in that the electronic control panel controls a pneumatic relay. The section will be concluded with a troubleshooting chart. With the information given in this section, you should have very little trouble acquiring the skill to perform most types of maintenance performed on electronic control systems.

2. **Adjustments**. You will find that the throttling range adjustment determines the temperature change at the T_1 thermostat. This adjustment will change the branch line air pressure from 3 to 13 p.s.i.g. An adjustable throttling range is commonly provided with a range from 1° to 50° F.

3. You should set the throttling range to as low a value as possible without causing instability or hunting of the branch line pressure. If the controlled variable varies continually and regularly reverses its direction, too low a setting of the throttling range is indicated. You must increase the throttling range until hunting stops.

4. Stable operation does not mean that the branch line pressure fails to change often; actually the control system is extremely sensitive, and small temperature changes are being detected continuously. It is important for you to learn to distinguish between "jumpiness" and "hunting." Jumpiness is caused by sensitivity of the relay, while hunting is a definite periodic alternating action. You must not interpret small gauge pressure fluctuations as hunting. A condition of this type can be caused by resonance in the valve unit chambers.

5. The authority dials are graduated in percentages. These dials determine the respective authorities of discharge or outdoor thermostats with respect to the space thermostat. The space thermostat is commonly referred to as T1. The remaining thermostats, outdoor, duct, etc., are numbered T_2, T_3, and T_4. With an authority of 25 percent, the outdoor thermostat is one-quarter as effective as the space thermostat. When you set the authority dials at zero percent, you are eliminating all thermostats except T_1 from the system. An authority setting of 5 percent means that a 20° change in outdoor temperature will have only as much effect as a 1° change at the space thermostat.

6. You may find that the control panel has a control point adjuster. This adjuster makes it possible to raise or lower the control point after the system is in operation. The control point adjuster is set at the time the system is calibrated. The control point adjuster dial contains as many as 60 divisions, each of which normally represents a 1° change at the space thermostat.

7. The factory calibration and the valve unit adjustment can be checked or corrected only when the throttling range knob is out. The factory calibration on most systems is properly adjusted when it is possible to obtain a branch line pressure within 1 pound of 8 p.s.i.g. with an amplifier output voltage of 1 ± ¼ volt d.c. If the calibration is not correct, you must turn the factory calibration potentiometer until 1 volt is read from a voltmeter connected at the (+) terminal of the relay and (-) terminal of the bridge panel. A voltmeter of no less than 20,000 ohms per volt resistance must be used. The next step is to turn the valve unit adjusting screw until the branch line pressure is between 7 and 9 p.s.i.g. Clockwise rotation of the valve unit adjustment screw decreases branch line pressure. The factory calibration is now correctly set.

8. **Calibration**. Before you calibrate an electronic control system you must determine the throttling range and the compensator authorities. Start your calibration with the adjustment knobs in the following positions:

(1) Control point adjuster: FULL COOL
(2) Throttling range: OUT
(3) Authority dials: 0

9. After the knobs are set, you must check the factory calibration. The branch line pressure should be 8 p.s.i.g. (±1 p.s.i.g). The actual branch line pressure obtained will be referred to as control reference pressure (CRP).

10. Next, you must measure the temperature at T_1. This temperature will be referred to as the control reference temperature (CRT). After you have obtained the two references, turn the throttling range to the desired setting. At the same time, turn the control point adjuster until the CRP is obtained (7-9 p.s.i.g.).

11. The authority dials are now set. This adjustment will change the branch pressure, so you must reset the control point adjuster to maintain a CRP of 7-9 p.s.i.g. The position of the control point adjuster represents the control reference temperature measured at T_1. Increase or decease the temperature setting as desired. Remember, each scale division is equal to approximately 1° F.

12. If a space thermostat is not used, the

calibration procedure will be the same, provided the discharge controller is connected to T_1 (T_2 is not used) and T_3 authority is turned to the desired setting f the discharge controller is connected to the T_3 position and T_3 authority is tuned to the desired setting, the procedure is the same except that 70 F. is used as the CRT. The correction for the desired set point is made with the control point adjuster dial divisions representing approximately ½° F each.

13. **Calibration Check**. The calibration of any system should be checked after the system has been put in operation. First, we will check a winter system.

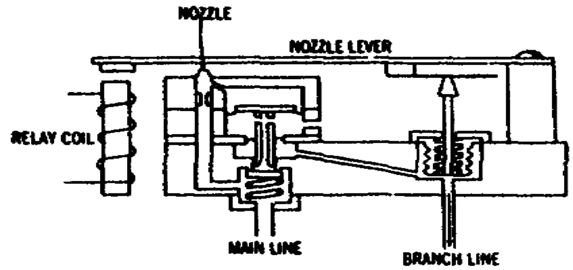
14. At the no-load condition, the control point (measured space temperature) should be equal to the set point. On compensated systems, the control point should be approximately equal to the set point, whereas on an uncompensated system, the control point will be slightly lower than the set point. On systems compensated to provide successively higher temperatures as the outdoor temperature falls, the control point can be expected to be higher than the set point.

15. For any summer system, at the no-load condition, the control point should equal the set point. If the outdoor temperature is above the no-load temperature on an uncompensated system, you may consider it normal because the control point will be slightly higher than the set point. However, on systems compensated to provide successively higher temperatures as the outdoor temperature rises, the control point can be expected to be higher than the set point.

16. To make a correction for a calibration error, simply rotate the control point adjuster the number of dial divisions equal to the calibration error.

17. **Operation**. The one electronic control discussed here is similar to those in other panels; that is, it contains a modified Wheatstone bridge circuit which provides the input voltage for the electronic amplifier. The amplified output voltage is then used to control a sensitive, high-capacity, piloted force-balance pneumatic valve unit.

18. A change in temperature at T_1 will initiate control action by a signal from the bridge circuit.



(Courtesy Honeywell, Incorporated)

Figure 136. Pneumatic valve unit.

This signal change provides a voltage to be fed to the amplifier which operates the pneumatic valve unit. The system will then provide heating or cooling as required until the initial signal is balanced by a change in resistance at T_1 and T_2 (depending upon the system's schedule). An outdoor thermostat, T_3, is used to measure changes in outdoor temperature so that control action can be initiated immediately before outdoor weather changes can be detected at T_1. This in effect compensates for system off. The authority of T_3 may be selected so that in addition to compensating for offset, T_3, will provide setup. For example, it will raise the system control point as outdoor temperature drops.

19. The output of the electronic amplifier controls the current through the magnetic coil. Look at figure 136 for the magnetic coil. As the voltage changes, the nozzle lever modulates over the nozzle. When the lever moves toward the nozzle, the branch line pressure will increase. The new branch line pressure, through the feedback bellows, opposes further movement of the nozzle lever. The forces which a upon the lever a now in balance. When the voltage decreases, the lever will move away from the nozzle. This movement will cause the branch line pressure to decrease until the forces are again in balance.

20. **Troubleshooting**. Troubleshooting a suspected defective device can be speeded up by relating apparent defects to possible causes. The troubleshooting guide, table 21, is broken up into portions related to the setup and calibration procedure given earlier.

TABLE 21

TROUBLESHOOTING ELECTRONIC SYSTEMS

Normal	*Abnormal*	*Probable Cause*
a. On first turning on power. All tubes light up and become warm.	1. One or two tubes remain cold.	1. Bad tubes. 2. Faulty bridge or amplifier circuits. 3. Faulty connections between the amplifier and bridge. 4. Faulty power terminal connections. 5. Power supply

TABLE 21-Continued

Normal	Abnormal	Probable Cause
		of improper voltage and/or frequency.
	2. Tubes light up and burn out. Transformer heats and smokes.	1. Power supply of improper voltage and/or frequency. 2. Bad tubes. 3. Open or short in valve unit relay coils.
B. Checking factory calibration. 1. Factory calibration can be adjusted to supply 1 ± ¼ volt. (See adjustment section.)	1. Unable to obtain proper voltage at the valve unit terminals by means of the factory calibration adjustment, or by oscillating pneumatic valve unit input voltage.	1. Weak tubes. 2. Faulty bridge or amplifier circuits. 3. Open or short in valve unit relay coils.
1. With throttling range out, branch line should be within 1 lb. of 8 p.s.i.g. when the factory calibration potentiometer is adjusted to give 1 ± ¼-volt amplifier output.	2. Branch line pressure is not within 1 lb. of 8 p.s.i.g. and branch line pressure pulsates	1. Improper valve unit lever adjustments. 2. Branch line air leaks. 3. Foreign matter in valve unit or filters. 4. Defective valve unit.
C. Checking the amplifier and bridge. Adjusting the control point adjuster varies the output voltage.	Adjustment of control point adjuster has little or no effect on output voltage.	1. Faulty bridge circuit. 2. Faulty amplifier. 3. Faulty plug-in connection between the amplifier and bridge circuit. 4. Open wiring or shorted sensing element. a. Short bridge or element; zero volt d.c. output. b. Open bridge or element; output voltage considerably in excess of 30 volts d.c. 5. Weak tubes.

Review Exercises

The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers.

1. What precaution should you observe when installing a humidity sensing element? (Sec. 35, Par. 2)

2. Describe the outdoor thermostat sensing element. (Sec. 35, Par. 5)

3. How do you check the resistance of a thermostat sensing element? (Sec. 35, Par. 9)

4. What factor will reduce the sensitivity of a thermostat? (Sec. 25, Par. 11)

5. Explain the procedure you would use to reposition the crank arm on a damper motor. (Sec. 35, Par. 13)

6. Name the repairs that can be made to the damper motor in the field. (Sec. 35, Par. 15)

7. How can you check the transformer output? (Sec. 35, Par. 16)

8. What troubles may exist if the damper motor does not respond to direct transformer power? (Sec. 35, Par. 18)

9. Which component in the control panel adjusts the change in variable required at a controller to give a certain voltage change? (Sec. 36, Par. 2)

10. What factor determines the position of the final control element? (Sec. 36, Par 3)

11. Where are the adjustments made for setting up or changing a control sequence? (Sec. 36, Par. 4)

12. Explain the function of the nonrestarting relay. Where is it connected? (Sec. 36, Par. 7)

13. How does the summer compensation schedule differ from the winter compensation schedule? (Sec. 36, Pars. 10 and 11)

14. What has occurred when the controlled variable varies continually and reverses its direction regularly? (Sec. 37, Par. 3)

15. With an authority setting of 10 percent, how much effect will t2 have when a 10° temperature change is felt? (Sec. 37, Par. 5)

16. How can you reset the control point after the system is in operation? (Sec. 37, Par. 6)

17. A trouble call indicates that an electronic control system is not functioning properly. The following symptoms are present:
(1) The amplifier output voltage is 1 volt.
(2) The branch line pressure is 5 p.s.i.g. What is the most probable trouble? (Sec. 37, Par. 7)

18. What is the control reference temperature? Control reference pressure? (Sec. 37, Pars. 9 and 10)

19. When checking the calibration of a compensated system on winter schedule, what is the relationship of the control point to the set point? (Sec. 37, Par. 14)

20. How does a bridge signal affect the pneumatic relay? (Sec. 37, Pars. 18 and 19)

21. What will happen if a faulty connection exists between the amplifier and bridge? (Sec. 37, table 21)

22. The tubes in the control panel light up and burn out repeatedly. Which components would you check? (Sec. 37, table 21)

1. The three things to consider before installing a preheat coil are necessity for preheat, entering air temperature, and size of coils needed. (Sec. 1, Par. 2)
2. The most probable malfunction when the stream valve is closed and the temperature is 33° F. is that the controller is out of calibration. (Sec. 1, Par. 4)
3. The two functions which the D/X coil serves are cooling and dehumidification. (Sec. 1, Par. 7)
4. When a compressor using simple on-off control short cycles, the differential adjustment on the thermostat is set too close. (Sec. 1, Par. 9)
5. On a two-speed compressor installation, the humidistat cycles the compressor from low to high speed when the space humidity exceeds the set point. (Sec. 1, Par. 11)
6. The nonrestarting relay prevents short cycling during the off cycle and allows the compressor to pump down before it cycles "off." (Sec. 1, Par. 12)
7. When the solenoid valves are not operating, you should check the operation of the fan because the fan starter circuit has to be energized before the control circuit to the valve can be completed. (Sec. 1, Par. 14)
8. The type of compressor used when two-position control of a D/X coil and modulating control of a face and bypass damper are used is a capacity controlled compressor. (Sec. 1, Par. 15)
9. An inoperative reheat coil. (Sec. 1, Par. 18)
10. The humidistat positions the face and bypass dampers to provide a mixture of conditioned and recirculated air to limit large swings in relative humidity. (Sec. 1, Par. 20)
11. The space humidistat has prime control of the D/X coil during light loads when a space thermostat and humidistat are used to control coil operation. (Sec. 1, Par. 26)
12. The only conclusion you can make is that the unit is a "medium temperature unit." Sec. 2. Par. 3)
13. If you installed a medium temperature unit for a 40° F. suction temperature application, the motor would overload and stop during peak load. (Sec. 2, Par. 3)
14. The low-pressure control will cycle the unit when the crankcase pressure exceeds the cut-in pressure setting of the control even though the thermostat has shut off the liquid line solenoid valve. (Sec. 2, Par. 4 and fig. 19)
15. The automatic pump-down feature may be omitted when the refrigerant-oil ratio is 2:1 or less or when the evaporator temperature is above 40° F. (Sec. 2, Par. 5)
16. Th four factors you must consider before installing a D/X system are space requirements, equipment ventilation, vibration, and electrical requirements. (Sec. 3, Par. 1)
17. To prevent refrigerant condensing in the compressor crankcase, warm the equipment area so the temperature will be higher than the refrigerated space. (Sec. 3, Par. 2)
18. The compressor does not require a special foundation because most of the vibration is absorbed by the compressor mounting springs. (Sec. 3, Par. 3)
19. The minimum and maximum voltage that can be supplied to a 220-volt unit is 198 volts to 242 volts. (Sec. 3, Par. 5)
20. A 2-percent phase unbalance is allowable between any two phases of a three-phase installation. (Sec. 3. Par. 5)
21. During gauge installation, the shutoff valve is back-seated to prevent the escape of refrigerant. (Sec. 3, Par. 9)
22. The liquid line sight glass is located between the dehydrator and expansion valve. (Sec. 3, Par. 12)
23. Series. (Sec. 3, Par. 14)
24. Parallel. (Sec. 3, Par. 14)
25. Dry nitrogen and carbon dioxide are used to pressurize the system for leak testing. (Sec. 3. Par. 15)
26. Moisture in the system will cause sludge in the crankcase. (Sec. 3, Par. 16)
27. The ambient temperature (60° F.) allows the moisture to boil in the system more readily. This reduces the amount of time required for dehydration. (Sec. 3, Par. 17)
28. A vacuum indicator reading of 45° F. corresponds to a pressure of 0.3 inch Hg absolute. (Sec. 3, Par. 18, fig. 17)
29. Shutoff valves are installed in the vacuum pump suction line to prevent loss of oil from the vacuum pump and contamination of the vacuum indictor. (Sec. 3, Par. 20)
30. Free. (Sec. 3, Par. 22)
31. The valves are backseated before installing the gauge manifold to isolate the gauge ports from the compressor ports to prevent the entrance of air or the loss of refrigerant. (Sec. 3, Par. 25)
32. The four items that you must check before starting a new compressor are the oil level, main water supply valve, liquid line valve, and power disconnect switch. (Sec. 3, Par. 26)
33. Frontseating the suction valve closes the suction line to the compressor port, which causes the pressure to drop and cut off the condensing unit on the low-pressure control. (Sec. 3, Par. 34)
34. Placing a refrigerant cylinder in ice will cause the temperature and pressure of the refrigerant within the cylinder to fall below that which is still in the system. (Sec. 4, Par. 3)

35. A partial pressure is allowed to remain in the system to prevent moist air from entering the system when it is opened (Sec. 4, Par. 4)
36. To prevent moisture condensation, you must allow sufficient time for the component that is to be removed to warm to room temperature. (Sec. 4, Par. 6)
37. Basket; disc. (Sec. 4, Par. 9)
38. Noncondensable gases collect in the condenser, above the refrigerant. (Sec. 4, Par. 10)
39. Noncondensable gases are present in the condenser when the amperage draw is excessive, the condenser water temperature is normal, and the discharge temperature is above normal. (Sec. 4, Par. 10)
40. A discharge pressure drop of 10 p.s.i.g. per minute with the discharge shutoff valve frontseated would indicate a leaky compressor discharge valve. (Sec. 4, Par. 15)
41. Valve plates ere removed from cylinder decks with jacking screws. (Sec. 4, Par. 18)
42. The emergency procedure you can use to recondition a worn valve is to lap the valve with a mixture of fine scouring powder and refrigerant oil on a piece of glass in a figure 8 motion. (Sec 4, Par. 21)
43. The oil feed guide is installed with the large diameter inward. Sec. 4, Par. 27)
44. A hook is used to remove the rotor to prevent bending of the eccentric straps or connecting rods. (Sec. 4, Par. 29)
45. A small space is left to provide further tightening in case of a leak. (Sec. 4, Par. 34)
46. 1.5 foot-pounds. (Sec. 4, Par. 35)
47. Check the start capacitor for a short when the air conditioner keeps blowing fuses when it tries to start and the starting amperage draw is above normal. (Sec. 4, Par. 36)
48. A humming sound from the compressor motor indicates an open circuited capacitor. (Sec. 4 Par. 36)
49. Closed. (Sec. 4, Par. 38)
50. Counter EMF produced by the windings causes the contacts of the starting relay to open. (Sec. 4, Par. 38)
51. Relay failure with contacts closed can cause damage to the motor windings. (Sec. 4, Par. 41)
52. Heater (and) control. (Sec. 4, Par. 43)
53. Oil pump discharge pressure; crankcase pressure. (Sec. 4, Par. 44)
54. Disagree. The oil safety switch will close when the pressure differential drops. (Sec. 4, Par. 45)
55. A burned-out holding coil or broken contacts will cause an inoperative motor starter. (Sec. 4, table 1)
56. A restricted dehydrator is indicated when the dehydrator is frosted and the suction pressure is below normal. (Sec. 4, table 2)
57. The expansion valve is trying to maintain a constant superheat. To accomplish this with a loose bulb, the valve is full open, which causes liquid refrigerant to flood back to the compressor. (Sec. 4, table 5)
58. A low refrigerant charge (flash gas in the liquid line). (Sec. 4, table 6)
59. An excessive pressure drop in the evaporator. (Sec. 4, table 6)
60. The most probable causes for an exceptionally hot water-cooled condenser are an overcharge and noncondensable gases in the system. These conditions may be remedied by bleeding the non-condensables or excessive refrigerant from the condenser. (Sec. 4 , table 7)
61. An obstructed expansion valve. (Sec. 4, table 10)
62. When a capacity controlled compressor short cycles you must reset the compressor capacity control range. (Sec. 4, table 10)

CHAPTER 2

1. The component that should be checked when the condenser waterflow has dropped off is the thermostat that controls the capacity control valve. The thermostat is located in the chill water line. (Sec. 5, Par. 2)
2. Tap water; lithium bromide. (Sec. 5, Par. 3)
3. When heat is not supplied to the generator, the salt solution in the absorber will become weak and the cooling action that takes place within the evaporator will stop. This will cause the chill water temperature to rise. (Sec. 5, Par. 5)
4. Disagree. It heats the weak solution. (Sec. 5, Par. 5)
5. The component is the capacity control valve. The reduced pressure will cause the thermostat to close the capacity control valve which reduces or stops the flow of water through the condenser. The capacity of the system will decrease without condenser waterflow. (Sec. 5, Pars. 6 and 7)
6. 4. (Sec. 5, Par. 7)
7. A broken concentration limit thermostat feeler bulb will cause the vapor condensate well temperature to rise because the capacity control valve will remain closed. (Sec. 5, Par. 8)
8. The chill water safety thermostat has shut the unit down because the leaving chill water temperature was 12° above the design temperature. To restart the unit, the off-run-start switch must be placed in the START position so that the chill water safety thermostat is bypassed. After the chill water temperature falls below the setting of the chill water safety control, the off-run-start switch placed in the RUN position. (Sec. 5, Pars. 9 and 10)
9. The pumps are equipped with mechanical seals because the system operates in a vacuum. (Sec. 5, Par. 14)
10. Disagree. It only controls the quantity of water in the tank. It does not open a makeup water line. (Sec. 5, Par. 14)
11. The nitrogen charge used during standby must be removed. (Sec. 6, Par. 3)
12. A low water level in the evaporator will cause the evaporator pump to surge. (Sec. 7, Par. 3)
13. A partial load. (Sec. 7, Par. 4)
14. The solution boiling level is set at initial startup of the machine. (Sec. 7, Par. 5)
15. When air is being handled, the second stage of the purge unit will tend to get hot. (Sec. 7, Par. 7)

16. Solution solidification. (Sec. 7, Par. 9)
17. You can connect the nitrogen tank to the alcohol charging valve to pressurize the system. (Sec. 7, Par. 14)
18. Three. (Sec. 7, Par. 15)
19. You can determine whether air has leaked in the machine during shutdown by observing the absorber manometer reading and checking it against the chart. (Sec. 8, Par. 2)
20. Corrode. (Sec. 8, Par. 2)
21. To check a mechanical pump for leaks, you must close the petcocks in the water line to the pump seal chamber and observe the compound pressure gauge. A vacuum indicates a leaky seal. (Sec. 8, Par. 3)
22. Flushing the seal chamber after startup will increase the life of the seal. (Sec. 8, Par. 4)
23. Chill water as leaked back into the machine. (Sec. 8, Par. 5)
24. Octyl alcohol is added to the solution to clean the outside of the tubes in the generator and absorber. (Sec. 8, Par. 7)
25. When actyl alcohol is not drawn into the system readily, the conical strainer is dirty and must be removed and cleaned. This is normally accomplished at the next scheduled shutdown. If this situation persists, the solution spray header must be removed and cleaned. (Sec. 8, Par. 8)
26. When the purge operates but does not purge, the steam jet nozzle is plugged. To correct this, you must close the absorber purge valve and the purge steam supply valve. Then remove the steam jet cap and clean the nozzle with a piece of wire. The steam supply valve can be opened to blow out the loosened dirt. After the nozzle is clean, replace the cap and open the valves. (Sec. 8, Par. 9)
27. Silver nitrate. (Sec. 8, Par. 10)
28. Three drops of indicator solution is added to the solution sample. (Sec. 8, Par. 10)
29. 1. (Sec. 8, Par. 11)
30. When more silver nitrate is needed to turn the sample red, the sample contains more than 1 percent of lithium bromide. The evaporator water must be reclaimed. (Sec. 8, Pars. 10 and 11)
31. The length of time needed to reclaim evaporator water depends upon the amount of salt (lithium bromide) in the evaporator water circuit. (Sec. 8, Par. 12)
32. It takes 2 or 3 days for the dirt to settle out when the solution is placed in drums. (Sec. Par. 14)
33. The conical strainer is cleaned by flushing it with water. (Sec. 8, Par. 16)
34. The purge is cleaned with a wire or nylon brush. (Sec. 8, Par. 20)
35. Disagree. The diaphragm in a vacuum type valve is replaced every 2 years. (Sec. 8, Par. 22)
36. A steady rise in vapor condensate temperature indicates that the absorber and condenser tubes must be cleaned. (Sec. 8, Par. 25)
37. Soft scale may be removed from the condenser tubes with a nylon bristle brush. (Sec. 8, Par. 28)
38. The maximum allowable vacuum loss during a vacuum leak test is one-tenth of an inch of Hg in 24 hours. (Sec. 8, Par. 28)
39. The refrigerant used to perform a halide leak test is R-12. (Sec. 8, Par. 29)
40. Three causes of lithium bromide solidification at startup are condenser water too old, air in machine, improper purging, or failure of strong solution valve. (Sec. 8, table 11)
41. To check for a leaking seal, close the seal tank makeup valve and note the water level in the tank overnight (Sec. 8, table 12)

CHAPTER 3

1. 1200 pounds. (Sec. 9, Par. 1)
2. The economizer reduces the horsepower requirement per ton of refrigeration. (Sec. 9, Par. 2)
3. Disagree. The chilled water flows through the tubes. (Sec. 9, Par. 3)
4. Condenser float chamber. (Sec. 9, Par. 5)
5. The pressure within the economizer chamber is approximately halfway between the condensing and evaporating pressures. (Sec. 9, Par. 5)
6. Line with the shaft. (Sec. 10, Par. 1)
7. The impellers are dipped in hot lead to protect them from corrosion. (Sec. 10, Par. 2)
8. Two. (Sec. 10 Par. 3)
9. Brass labyrinth packing prevents interstage leakage of gas. (Sec. 10, Par. 4)
10. Axial thrust will affect suction end of the compressor. (Sec. 10, Par. 5)
11. Main compressor shaft. (Sec. 10, Par. 7)
12. The pump lubricates the thrust bearing first. (Sec. 10, Par. 8)
13. Oil is returned from the oil pump drive gear by gravity. (Sec. 10, Par. 9)
14. Oil pressure actuates the shaft seal. (Sec. 10, Par. 10)
15. The two holes in the inner floating seal ring allow the passage of oil to the front journal bearing. (Sec. 10, Par. 11)
16. 8. (Sec. 10, Par. 12)
17. The oil pressure gauge located on the control panel are the seal oil reservoir and "back of seal." (Sec. 3, Par. 13)
18. A flow switch in the water supply oil cooler line turns the oil heater on automatically when waterflow stops. (Sec. 10, Par. 14)
19. Disagree. They are held apart during operation. (Sec. 10, Par. 16)
20. A high-grade turbine oil is used in centrifugal compressors. (Sec. 10, Par. 17)
21. Increases. (Sec. 11, Par. 1)
22. Journal speed, tooth speeds, (and) clearances. (Sec. 11, Par. 3)
23. The gear drive cooling water is turned on when the oil temperature reaches 100° F. to 110° F. (Sec. 11, Par. 5)
24. Gear wear. (Sec. 11, Par. 9)

25. The gear to compressor coupling uses a spool piece. (Sec. 12, Par. 1)
26. The hub is heated with oil, steam, or open flame to expand it: (Sec. 12, Par. 2)
27. Feeler gauge. (Sec. 12, Par. 3)
28. The offset alignment of a coupling is checked with a dial indicator. (Sec. 12, Par. 4)
29. The couplings that have collector rings in the end of the cover can be lubricated while running. (Sec. 12, Par. 8)
30. Three; 60; adjustable speed wound. (Sec. 13, Par. 3)
31. Slipring circuit; speed. (Sec. 13, Par. 3)
32. When the start button is held closed, the oil pressure switch is bypassed. (Sec. 13, Par. 4)
33. The secondary function of the condenser is to collect and concentrate noncondensable gases. (Sec. 14, Par. 1)
34. A perforated baffle is used to prevent the discharge gas from directly hitting the condenser tubes. (Sec. 14, Par. 2)
35. When you remove the water box cover you must leave two bolts in the cover until the cover is supported with a rope or chain. (Sec. 14, Par. 3)
36. A blocked compressor suction opening. (Sec. 14, Par. 6)
37. Check the sight glass on the cooler to determine the system refrigerant charge. (Sec. 4, Par. 11)
38. A load increase is indicated when the refrigerant and chill water temperature differential increases (Sec. 14, Par. 13)
39. Surging. (Sec. 15, Par. 1)
40. The liquid injector is used desuperheat the hot gas (Sec. 15, Par. 2)
41. The pressure drop across the orifice created by the flow of gas through the orifice controls the amount of liquid refrigerant flowing to the hot gas bypass. (Sec. 15, Par. 3)
42. Disagree. The high-pressure control resets automatically when the pressure falls to 75 p.s.i.g. (Sec. 16, Par. 3)
43. The weir and trap is located in the center of the evacuation chamber. (Sec. 16, Par. 3)
44. Air is in the system. (Sec. 16, Par. 5)
45. Air in the condenser is released through the purge air relief valve. (Sec. 16, Par. 6)
46. One-half pint of water per day collected by surge unit indicates leaky tubes. (Sec. 16, Par. 8)
47. A pressure drop will exist across the pressure-regulating valve when it is wide open. (Sec. 16, Par. 9)
48. Large amounts of air are normally purged after repairs and before charging. (Sec. 16, Par. 10)
49. Water is drained from the separator unit when it can be seen in the upper sight glass. (Sec. 16, Par. 12)
50. Low oil pressure, high condenser pressure, low refrigerant temperature, (and) low water temperature. (Sec. 17, Par. 1)
51. The low oil pressure control does not require manual resetting. (Sec. 17, Par. 2)
52. The high condenser pressure control has a differ-ential of 7 pounds. (Sec. 17, Par. 3)
53. You can change controllers with the rotary selecting switch on the safety control panel. (Sec. 17, Par. 6)
54. Control the speed of the compressor. (Sec. 18, Pars. 1 and 2)
55. When you add more resistance to the rotor circuit of the drive motor, the compressor speed will decrease. (Sec. 18, Par. 3)
56. Suction damper control is more effective than speed control when it is necessary to maintain a non-surging operation at light loads. (Sec. 18, Par. 4)
57. During startup the drum controller lever is in number 1 position, all resistance in the circuit to the rotor. (Sec. 19, Par. 2)
58. Condensed refrigerant will cause the oil level to rise in the pump chamber during an extended shut-down. (Sec. 9,. Par 6)
59. 1. (Sec. 20, Par. 2)
60. Agree. The 2-inch plug does prevent leakage when the ¾-inch plug is removed. (Sec. 20, Par. 3)
61. To charge refrigerant into the system as a gas, you must let the drum rest on the floor and open the drum charging valve. (Sec. 20, Par. 5)
62. The system may be pressurized with the purge recovery unit. (Sec. 20, Par. 6)
63. High condenser pressure is normally caused by air in the condenser. (Sec. 20, table 19)
64. Light load, air leak, (or) high condenser pressure. (Sec. 20, table 19)
65. When the economizer float valve is stuck, the compressor second stage will frost. (Sec. 20, table 19)
66. Low "back of seal" oil pressure and a high seal oil pressure are caused by a dirty filter or a filter cartridge improperly installed. (Sec. 20, table 19)
67. Misalignment, insufficient lubrication, (or) excessive wear. (Sec. 20, table 19)
68. Agree. A high oil level will cause the gear to overheat. (Sec. 20, table 19)

CHAPTER 4

1. The main scale-forming compound found in con-densing water systems is calcium carbonate. (Sec. 21, Par. 1)
2. 7.1 (to) 14; 200. (Sec. 21, Par. 4)
3. Using the formula

   Cycles of concentration

   $$= \frac{\text{bleedoff hardness (circulating water)}}{\text{makeup hardness}}$$

   $$\text{c of c} = \frac{200}{100}$$

   $$\text{c of c} = 2$$

   (Sec. 21, Par. 6)
4. Four methods of preventing scale are bleedoff, pH adjustment, adding polyphosphates, and using the zeolite softener. (Sec. 21, Par. 7)
5. Using the formula

   Hardness p.p.m. = 20 X (total No. of ml. of std.

soap solution required to obtain a permanent lather)
p.p.m = 20 X 10
p.p.m = 200
(Sec. 21, Par. 9)

6. The lime-soda process changes calcium and magnesium from a soluble to an insoluble state. (Sec. 21, Par. 11)
7. The zeolite process replaces the calcium and magnesium compounds with soluble sodium compounds. (Sec. 21, Par. 11)
8. It is necessary to add lime or clay to the Accelator to add weight which prevents rising floc. (Sec. 21, Par. 15)
9. The factors that would limit the use of the Spiractor are excessive magnesium hardness, high water temperature, and turbidity over 5 p.p.m. (Sec. 21, Par. 17)
10. A salt or brine solution is uniformly distributed on top of the zeolite bed, which passes evenly down through the bed. (Sec. 21, Par. 18)
11. Corrosion is more rapid in a liquid with a low pH value. (Sec. 22, Par. 2)
12. The most common type of corrosion in an acid liquid is uniform corrosion. (Sec. 22, Par. 4)
13. Pitting corrosion is characterized by cavities and gradually develops into pinhole leaks. (Sec. 22, Par. 5)
14. The type of corrosion that corrodes steel in a system that contains an abundance of copper is known as galvanic corrosion. (Sec. 22, Par. 6)
15. Erosion-corrosion is caused by suspended matter or air bubbles; the best control for this type of corrosion is a good filtration system, and air purging valves installed in the highest point of the water system. (Sec. 22, Pars. 7 and 8)
16. The two most common chemical corrosion inhibitors are chromates and polyphosphates. (Sec. 22, Par. 10)
17. 200 (to) 500 p.p.m.; 7.5. (Sec. 22, Par. 11)
18. The most common chromate used is sodium bichromate because it is more economical than others. (Sec. 22, Par. 11)
19. The chromate concentration of treated water is measured by color comparison of the sample to that of a tube chromate water known to contain a certain p.p.m. of chromate. (Sec. 22, Par. 14)
20. High concentration of polyphosphates precipitate out in the form of calcium phosphate. (Sec. 22, Par. 14)
21. First of all, there is no yellow residue produced by polyphosphates, as there is by chromates. Secondly, polyphosphates reduce sludge and rust (tuberculation). (Sec. 22, Par. 15)
22. Bleedoff must be adjusted on condenser water systems using polyphosphates to avoid exceeding the solubility of calcium phosphate. (Sec. 22, Par. 16)
23. The chemical corrosion inhibitors that are in a nylon net bag which is placed in a cooling tower may be in pellet or crystal form. (Sec. 22, Par. 18)
24. Chilled water and brine solution systems require the pot type corrosion inhibitor feeders. (Sec. 22, Par. 18)
25. Algae formations will plug the nozzles in cooling towers, thus causing high condensing temperatures and reducing the system's capacity. (Sec. 23, Par. 1)
26. The amount of chlorine needed to eliminate algae growth is 1.5 p.p.m. (Sec. 23, Par. 2)
27. Disagree. The sample is heated after the orthotolidine is added. (Sec. 23, Par. 3)
28. Chlorination is effective because the bactericidal efficiency of chlorine increases with the increase in the temperature of the water. (Sec. 23, Par. 6)
29. The orthotolidine test measures only the total available chlorine residual, while the orthotolidine-arsenite test measures the relative amounts of free available chlorine, combined available chlorine, and color caused by interfering substances. (Sec. 23, Par. 8)
30. The combined available chlorine residual is 3.25 – 2.5 = .75 p.p.m. (Sec. 23, Par. 9)
31. To perform a chlorine demand test, you must first prepare a test sample by mixing 7.14 grams of calcium hypochlorite with 100 cc. Of water to produce a 5000 p.p.m. chlorine solution. Add 1 milliliter of this sample to the water to be tested. Wait 30 minutes and perform a chlorine residual test. You must then subtract the chlorine residual from the test dosage to obtain the chlorine demand. (Sec. 23, Pars. 13, 14, and 15)
32. To perform the pH determination with a color comparator, you would fill the color comparator tube with the sample to be tested to the prescribed mark on the tube. The you would add 0.5 ml. mark on the tube. Then you would add 0.5 ml. of cresol red-thymol blue solution to the sample. After mixing the solution thoroughly in the sample, you would place the sample tube in the comparator and match the sample color with the cresol red-thymol blue disc. (Sec. 23, Pars. 17, 18, and 19)
33. Alkaline, because a pink color indicates a pH above 8.3. (Sec. 23, Par. 22)
34. Sulfuric, sodium sulfate, and phosphoric acids are added to adjust the pH. They are added to the water through a solution feeder. (Sec. 23, Par 24)
35. Calcium hypochlorite contains more chlorine by weight; 65 to 70 percent available chlorine by weight. (Sec. 23, Pars. 26 and 27)
36. To add 100 gallons of chlorine solution per day, you would select the Wilson type DES hypochlorinator because its capacity is 120 gallons per day. (Sec. 23, Par. 32)
37. 4.

$$\text{Dosage} = \frac{20}{8.34 \times 500{,}000}$$

$$\frac{20}{4{,}170{,}000} = \text{1 part per 258,500 parts of water}$$

$$\frac{1}{258{,}500} = \text{approximately 4 p.p.m.}$$

(Sec. 23, Par. 34)

38. You would have to add 43 pounds of HTH to that water which requires 30 pounds of chlorine.

$$\text{Pounds of chlorine required} = \frac{30 \times 100}{70}$$

70 = percentage of available chlorine present in HTH by weight.

$$\frac{3000}{70} = \frac{300}{7} = 42\tfrac{6}{7} = 43 \text{ lbs.}$$

39. Thirty gallons of chlorine is added per day to treat

2 million gallons of water when the dosage is 1.5 p.p.m. and dosing solution is 10 percent.

40. The precautions that must be followed while per-forming the turbidimeter test are as follows: The glass tube must be placed in a vertical position with the centerlines matched. The top of the candle support should be 3 inches below the bottom of the tube. The candle must be made of beeswax and spermaceti, gauged to burn within 114 and 126 grains per hour. The flame must be a constant size and the same distance below the tube. The tube should be inclosed in a case when observations are made. Soot, moisture and impurities must not be accumulated on the bottom of the glass tube. (Sec. 24, Pars. 4, 5, and 6)
41. The number of gallons that a vertical type pressure filter, 4 feet in diameter, can treat in 1 hour is:

    Area = π^2
    Area = 3.146 X (1/2d)
    Area = 3.146 X (2 X 2)
    Area = 3.146 X 4
    Area = 12.564 or 12.6
    12.6 X 3 = 37.8
    37.8 X 60 =2268 gallons.

    (Sec. 24, Par. 11)
42. The precaution for taking water samples that is common to both types of analysis is that the equipment (bottle, stopper, etc.) must be sterilized. (Sec. 25, Pars. 3 and 4)
43. To sterilize a bottle that is to be used for chlorine rating 0.2 to 0.5 grams of sodium thiosulfate is added to the sample in the bottle. Then it is sterilized at a temperature below 392° to prevent decomposition of the thiosulfate (Sec. 25, Par. 4, *a*)
44. You should hold the bottle least 3 inches below the surface of water in a tank when you take a sample. (Sec. 25, Par. 4, *c*)
45. A solution of lysol, mercuric chloride, or of bicarbonate of soda is used to rinse your hands after making water tests. (Sec. 25, Par. 7)

CHAPTER 5

1. The amount of cement that you would mix with 12 pounds of sand and 24 pounds of crushed rock is 4 pounds. (Sec. 26, Par. 1)
2. A 1-inch space is left between the foundation and baseplate to allow enough room for grouting after the baseplate is level. (Sec. 26, Par. 1)
3. A ¾-inch baseplate bolt requires a sleeve made from 1.875-inch pipe. (Sec. 26, Par. 1)
4. To level the baseplate, you would place two wedges below the center of the pump and two a below the center of the motor. (Sec. 26, Par. 3)
5. The angular alignment of a “spider” is checked at four points on the circumference of the outer ends of the coupling hubs at 90° intervals. (Sec. 26, Par. 4)
6. Angular alignment is accomplished by loosening the motor holddown bolts and shifting or shimming the motor. (Sec. 26, Par. 5)
7. To grout the unit, you must build a wooden dam around the foundation and wet the top of the foundation. Then fill the space with grout. (Sec. 26, Par. 7)
8. One part of Portland cement to three parts of sharp sand is used to make grout. (Sec. 26, Par. 7)
9. You should allow 48 hours for the grout to harden. (Sec. 26, Par. 7)
10. To establish initial alignment of the pumping unit, you must tighten the foundation and holddown bolts. Check the gap, angular adjustment, and parallel alignment. Recheck alignment after each adjustment. (Sec. 26, Par. 9)
11. The unit may become misaligned because of foundation settling, seasoning, or springing; pipe strains; shifting of the building structure; or springing of the baseplate. (Sec. 26, Par. 9)
12. Strainer. (Sec. 26, Par. 10)
13. The pump will lose a and capacity if smaller discharge pipe is installed. (Sec. 26, Par. 11)
14. To prime the pump, fill it with the fluid to be pumped through the priming opening in the pump. (Sec. 27, Par. 1)
15. After the pump is primed and before it is started, make sure that all the pump connections are airtight and rotate the pump shaft by hand to be sure that it moves freely. (Sec. 27, Par. 1)
16. Loose pump connections, low liquid level in the pump, loose suction line joints, improper direction of rotation, motor not up to nameplate speed, and dirty suction strainer will cause the failure of a newly installed pump. (Sec. 27, Par. 3)
17. The lantern ring. (Sec. 28, Par. 2)
18. You must pipe clean water to the stuffing box when the water being pumped is dirty, gritty, or acidic. (Sec. 28, Par. 3)
19. Loose packing will leak excessively and tight packing will burn and score the shaft. (Sec. 28, Par. 4)
20. When five-ring packing is used, stagger the packing joints approximately 72°. (Sec. 28, Par. 5)
21. Back off the gland bolts. (Sec. 28, Par. 10)
22. The bellows should not be disturbed unless it is to be replaced. (Sec. 28, Par. 11)
23. The four types of bearings found in centrifugal pumps are grease-lubricated roller and ball bearings, oil-lubricated ball bearings, and oil-lubricated sleeve bearings. (Sec. 28, Par. 17)
24. Overlubrication causes overheated bearings. (Sec. 28, Par. 17)
25. Mineral greases with a soda soap base are recommended for grease lubricated bearings. (Sec. 28, Par. 19)
26. Vegetable and animal greases are not used to lubricate pump bearings because they may form acid and cause deterioration. (Sec. 28, Par. 19)
27. 180° F. (Sec. 28, Par. 20)
28. 150° F. (Sec. 28, Par. 22)
29. The four drilled recesses facilitate the removal and

installation of the coupling bushing. (Sec. 28, Par. 24)

30. Disagree. The recessed holes should face away from the pump. (Sec. 28, Par. 26)

Chapter 6

1. Thermionic emission is a method of emitting electrons from the cathode with heat. (Sec. 29, Par. 3)
2. In a directly heated cathode, the material that heats also emits electrons, whereas the indirectly heated cathode has separate heating and emitter elements. (Sec. 29, Par. 4)
3. The elements of a diode vacuum tube are the cathode and plate. (Sec 29, Par. 7)
4. Cathode; plate. (Sec. 29, Par. 7)
5. The diode rectifies a.c. because current will pass through the tube in one direction. (Sec. 29, Par. 8)
6. The factors that determine the amount of current flowing through a diode tube are the temperature of the cathode and the potential difference between the cathode and plate. (Sec. 29, Par. 9
7. Positive. (Sec. 29, Par. 11)
8. The capacitors will filter half-wave rectification by charging during the positive half-cycle and discharging through the load resistance during the negative half-cycle. (Sec. 29, Par. 13)
9. A duo-diode is a tube containing two diode tubes. It may have one cathode and two plates. (Sec. 29, Par. 16)
10. The purpose of the control grid is to provide more sensitive control of the plate current. (Sec. 30, Par. 2)
11. The control grid is physically located between the cathode and plate. (Sec. 30, Par. 2
12. Negative. (Sec. 30, Par. 4)
13. When the grid is made more negative, the current through the tube will decrease. (Sec. 30, Par. 5)
14. Grid bias is the potential difference of the d.c. voltage on the grid with respect to the cathode. Cutoff bias is the point at which the negative grid voltage stops all current flow in the tube. (Sec. 30, Pars. 5 and 7)
15. The types of grid bias used on vacuum tubes are fixed, cathode, and contact potential. (Sec. 30, Pars. 8, 9, and 12)
16. A disadvantage of contact potential bias is that bias is developed only when a signal is applied to the grid. (Sec. 30, Par. 14)
17. The triode can be used as an amplifier because a small a.c. voltage applied between the cathode and grid will cause a change in at grid bias and vary the current passing through the tube. (Sec. 30, Par. 15)
18. The potential of the screen grid is positive with respect to the cathode. (Sec. 30, Par. 19)
19. The power amplifier handles larger values of current than triode amplifiers. (Sec. 30, Par. 20)
20. A negative potential is applied to the suppressor grid of a pentode tube. (Sec. 30, Par. 23)
21. The valence ring is the outer ring or orbit of an atom. (Sec. 31, Par. 4)
22. Conductor. (Sec. 31, Par. 4)
23. N-type germanium is made when an antimony atom has gone into covalent bonding with germanium. The antimony in the material donates a free electron. (Sec. 31, Par. 8)
24. N-type material has free electrons which support electron flow, whereas P-type material has a shortage of electrons. This shortage causes current to flow from the N-type material to the P-type material. (Sec. 31, Pars. 8 and 9)
25. N-type; P-type. (Sec. 31, Par. 13)
26. Forward bias encourages current flow. (Sec. 31, Par. 14)
27. 2500 watts is developed in a circuit having 100 ohms resistance and an amperage draw of 5 amps ($P = I^2R$). (Sec 31, Par. 17)
28. The base is located between the emitter and collector. (Sect. 31, Par. 19)
29. Maximum power gain is obtained by making the base region very narrow compared to the emitter and collector regions. (Sec. 31, Par. 24)
30. The emitter is comparable to the cathode, the base to the grid, and the collector to the plate. (Sec. 31, Par. 29)
31. The three basic transistor circuits are the common base, common emitter, and common collector. (Sec. 32, Par. 1)
32. The common collector circuit has a high impedance input and a low impedance output. (Sec. 32, Par. 5)
33. The coupling capacitor is used to couple the signal into the emitter-base circuit of the transistor. (Sec. 32, Par. 6)
34. The voltage drop is 9 volts (3/4 X 12 = 9). (Sec. 33, Par. 1)
35. A simple two-resistor bridge is balanced when no current flows between the wipers. (Sec. 33, Par. 2)
36. The Wheatstone bridge sends a signal to the amplifier, which builds up the bridge signal to operate a relay. (Sec. 33, Par. 5)
37. The higher temperature will unbalance the bridge by increasing the resistance in one circuit. The signal from the bridge will be amplified and operate a relay. (Sec. 33, Par. 8)
38. A vacuum tube voltmeter is used because it has a high input resistance. (Sec. 33, Par. 9)
39. The first step to take when using a V.T.V.M. is to turn the meter on and allow it to warm up. (Sec. 33, Par. 10)
40. The purpose of the discriminator circuit is to determine in which direction the bridge is unbalanced and take the necessary action to correct the condition. (Sec. 34, Par. 1)
41. The function of the blocking capacitor is to pass a.c. to the second stage and block the high-voltage d.c. (Sec. 34, Par. 3)
42. When the signal in the discriminator circuit goes negative, the cutoff bias is reached on the control grid. (Sec. 34, Par. 5)
43. The bridge supply voltage should come from the same phase as the discriminator supply to insure a bridge signal that is either in phase of 180° out of

phase with the discriminator supply. (Sec. 34, Par. 7)

44. The discriminator circuit will conduct when the plate and the amplified bridge signal are both positive. (Sec. 34, Par. 8)
45. A balancing potentiometer is used with a modulating motor to bring the bridge back into balance when a deviation has been corrected. (Sec. 34, Par. 10)

Chapter 7

1. The precaution you should observe when installing a humidity sensing element is to locate it not too close to sprayers, washers, and heating or cooling coils, but within 50 feet of the control panel. (Sec. 35, Par. 2)
2. The outdoor thermostat sensing element is a coil of fine wire wound on a plastic bobbin and coated for protection against dirt and moisture. (Sec. 35, Par. 5)
3. To check the resistance of the sensing element, disconnect the leads and connect an ohmmeter across them. (Sec. 35, Par. 9)
4. Dirt on the sensing element will reduce the sensitivity of a thermostat. (Sec. 35, Par. 11)
5. To reposition the crank arm on the damper motor shaft, loosen the screw and nut that hold the arm on the shaft. This will allow you to reposition the shaft in four different positions, 90° apart. The adjustment screw on the face of the crank arm provides angular setting of the crank arm in steps of 22 1/2° throughout any one of the four positions on the shaft. (Sec. 35, Par. 13)
6. The damper motor repairs that may be made in the field are cleaning the potentiometer or limit switch contacts, repairing internal connecting wires, and replacing the internal wires. (Sec. 35, Par. 15)
7. You can check the transformer output by connecting a voltmeter across its terminals. (Sec. 35, Par. 16)
8. If the damper motor does not respond to direct transformer power, the most probable faults are broken wires, defective limit switch, or faulty condenser. (Sec. 35, Par. 18)
9. The authority "pots" adjust the change in variable required to give a certain voltage change. (Sec. 36, Par. 2)
10. The total voltage across the bridge determines the position of the final control element. (Sec. 36, Par. 3)
11. The adjustments for setting up or changing a control sequence are made at the control panel. (Sec. 36, Par. 4)
12. The nonrestarting relay is connected in the compressor starting circuit. It will prevent the compressor from operating unless the solenoid valve is operating. (Sec. 36, Par. 7)
13. The summer compensation schedule differs from the winter compensation schedule in that outdoor thermostat T_3 will be replaced by T_1. (Sec. 36, Pars. 10 and 11)
14. When the controlled variable varies continually and reverses its direction regularly, the throttling range is set too low. (Sec. 37, Par. 3)
15. With a 10 percent authority and 10° temperature change T_3 will have the same effect as a 1° change in temperature at T_1. (Sec. 37, Par. 5)
16. The control point can be reset after the system is in operation by positioning the control point adjuster in the control panel. (Sec. 37, Par. 6)
17. When the amplifier output voltage is 1 volt and the branch line pressure is 5 p.s.i.g., the most probable trouble is that the valve unit is out of adjustment. (Sec. 37, Par. 7)
18. The control reference temperature is temperature measured at T1. The control reference pressure is the actual branch line pressure. (Sec. 37, Pars. 9 and 10)
19. The control point of a compensated system on winter schedule should be equal to the set point. (Sec. 37, Par. 14)
20. The bridge signal is amplified and fed to a magnetic coil in the pneumatic valve. The amount of current flowing through the coil positions nozzle lever over the nozzle. The position of this lever controls the amount of branch line pressure sent to the controlled device. (Sec. 37, Pars. 18 and 19)
21. A faulty connection between the amplifier and bridge will cause one or more of the tubes to remain cold. (Sec. 37, table 21)
22. The transformer output and the valve unit relay must be checked when the tubes light up and burn out repeatedly. (Sec. 37, table 21)

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