

Why and How we Use Capacity Control

On refrigeration and air conditioning applications where the load may vary over a wide range, due to lighting, occupancy, product loading, ambient weather variations, or other factors, some means of compressor capacity control is desirable for optimum system performance.

Capacity modulation can reduce power and energy consumption, provide better dehumidification, reduce compressor cycling, decrease the starting load, and provide good oil return if properly piped.

The simplest form of capacity control is on-off cycling of the compressor. Under light load conditions, this could lead to short cycling and could reduce the life of the compressor.

On systems where ice formation is not a problem, users will sometimes lower the low pressure cut out setting beyond the design limits in order to prevent short cycling. As a result, the compressor may operate for long periods at extremely low evaporator temperatures. Compressor capacity decreases as suction pressure decreases. Refrigerant velocity is inadequate to return oil to the compressor also resulting in a high compressor superheat, which causes the compressor to overheat. All of these conditions can cause premature compressor failure.

Capacity control allows more continuous operation of the compressor, minimizing electrical problems and improving lubrication.

There are many ways to achieve capacity control. Variable speed compressors, hot gas bypass with or without liquid injection, unloading, Moduload, Digital control for scrolls, and simple on/off compressor operation on multiple compressor setups.

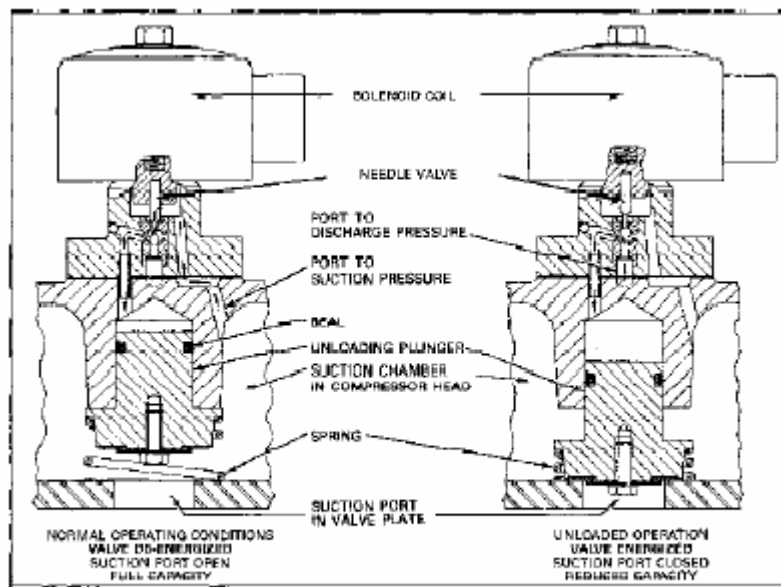
Some applications will use two or more methods for smoother switching and better control such as unloading in conjunction with hot gas bypass.

This article will deal with the most common methods today which are unloading and hot gas bypass.

4, 6, and 8 Cylinder UNLOADING

Blocked suction internal unloading has been successfully used for many years to unload 4 and 6 cylinder reed compressors for air-conditioning applications. More recently, blocked suction unloading has been applied on selected 4, 6, and 8 cylinder Discus compressors for high, medium, and low temperature applications. Compressor capacity modulation can reduce power consumption, provide continuous dehumidification, reduce compressor cycling and decrease the starting electrical load. Blocked suction capacity control also makes efficient compressor operation possible when the compressor is unloaded.

Internal Capacity Control Valve Construction



SCHEMATIC OPERATION OF INTERNAL UNLOADER VALVE

Figure 1

A schematic illustration of the internal valve operation is shown in **Figure 1**.

In the normal (full capacity) operating position with the solenoid valve de-energized, the needle valve is seated on the lower port, and the unloading plunger chamber is exposed to suction pressure through the suction port. Since the face of the plunger is open to the suction chamber, the gas pressures across the plunger are equalized, and the plunger is held in the open position by the spring.

When the solenoid valve is energized, the needle valve is seated on the upper port, and the unloading plunger chamber is exposed to discharge pressure through the discharge pressure port. The differential between discharge and suction pressure forces the plunger down, sealing the suction port in the valve plate, thus preventing the entrance of suction vapor into the unloaded cylinders.

The seal on the unloading plunger minimizes any leakage in pressure so that a pump down cycle may be used with the valve either energized or de-energized without excessive compressor cycling.

Application

When an unloading valve in a operating system is switched from the loaded to the unloaded position, a new system balance takes place. In air-cooled systems the suction pressure will rise and the condensing pressure will drop. In water-cooled systems the suction pressure will rise, but the condensing pressure will remain substantially the same.

The pressure or temperature control should have as wide a differential as necessary to prevent rapid cycling of the unloading valve. Rapid cycling can lead to wear and premature failure of the solenoid valve and/or internal un-loader components. The un-loader cycle rates should be limited to no more than 10 to 12 per hour to ensure satisfactory un-loader life. A wider differential will be required with the pressure control method than the temperature control method because of the thermal mass (or flywheel effect) of the cooled medium.

Application Requirements

Because of the decreased volume of suction vapor returning to the compressor from the system and available for motor cooling, the operating range of unloaded compressors must be restricted. Reed style compressors should be limited to a minimum evaporating temperature of 25°F when operating unloaded.

Discus compressors can be operated unloaded below 25°F with the addition of head cooling fans and oil coolers.

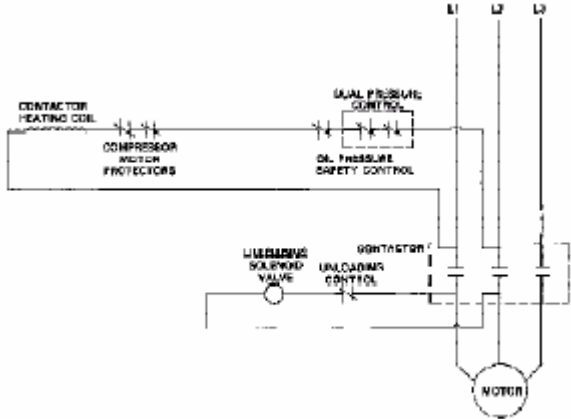
The capacity control valve is in the normal discharge position (loaded) when de-energized, and in the unloaded position when energized. The solenoid valve may be energized either by means of a reverse acting low pressure control or a temperature control thermostat. On six cylinder compressors with two un-loaders, two stage thermostats may be employed, but if sequence control of un-loaders from compressor suction pressure is desired, two separate controls are necessary.

Although the leak back rate when the coil is energized during a compressor off cycle is minimal, to prolong the solenoid coil life it is recommended that the capacity control solenoid valve be de-energized when the compressor is not operating.

In control circuits operating at line voltage, the solenoid valve and control can be connected to the load side of the contactor as in **Figure 6**. The un-loader solenoid valve will then be de-energized and closed when the compressor is not operating.

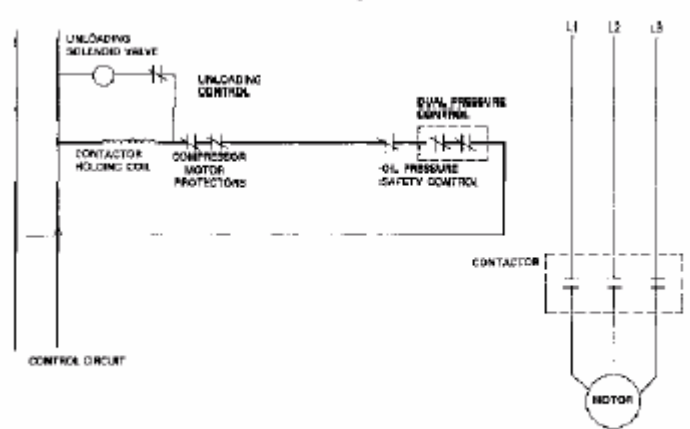
On large installations, the control circuit may have a power source independent of the compressor power supply. In such cases the unloading solenoid valve and control may be connected as shown in Figure 6, or they may be connected in parallel with the compressor

contactor coil as in **Figure 7**.



TYPICAL CONTROL CIRCUIT FOR COMPRESSOR WITH UNLOADING VALVE

Figure 6



TYPICAL CONTROL CIRCUIT FOR COMPRESSOR WITH UNLOADING VALVE AND SEPARATE POWER SOURCE CONTROL CIRCUIT

Figure 7

Piping

One very important factor to be considered in the design of any system equipped with an unloading type compressor is the gas velocity. It must be maintained at a sufficiently high level to insure oil return to the compressor when it is unloaded. When an unloading type compressor is employed on a single evaporator with a single suction line, it may be necessary to employ double risers constructed as shown to insure oil return.

If the unloading type compressor is to be installed on a system employing multiple evaporators with solenoid valves to control the flow of refrigerant to the evaporators, a separate suction line should be run from each evaporator to the machine room and there connected into a common line, which must slope downward toward the compressor. See **Figure 8**. Expansion valves for systems with unloading compressors must be able to control the refrigerant flow while the compressor is unloaded as well as when loaded. They generally cannot maintain stable control below 25-35% of their rated capacity and, therefore must not be oversized for the fully loaded condition.

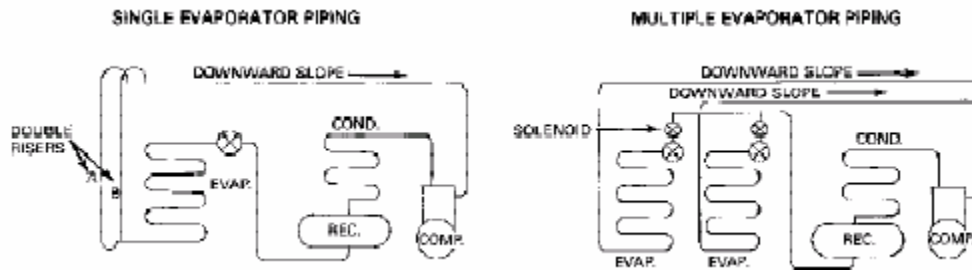


Figure 8

3 Cylinder Unloading

Copeland has developed Modu-load, an efficient method for unloading small Discus compressors.

Modu-load will permit efficient unloading on Copeland compressors with less than 4

cylinders for high, medium, and low temperature applications. Moduload assures smooth, vibration free operation in the unloaded mode by unloading all cylinders equally.

Theory of Operation

Modu-load compressors unload by allowing compressed gas to fill a storage chamber above each cylinder and re-expand back into the cylinder during the suction stroke. As the gas re-expands, both volumetric efficiency and compressor capacity are reduced. The energy consumed during compression is almost completely recovered during re-expansion, resulting in high efficiency in the unloaded mode. Modu-load uses a piston, cylinder, and spring mechanism which are solenoid actuated. All cylinders are unloaded equally, thus providing well-balanced operation at all times.

Since compressed gas is re-expanded to obtain unloading, the percent capacity reduction is a function of operating compression ratio. The higher the compression ratio, the greater the percent capacity reduction during unloading.

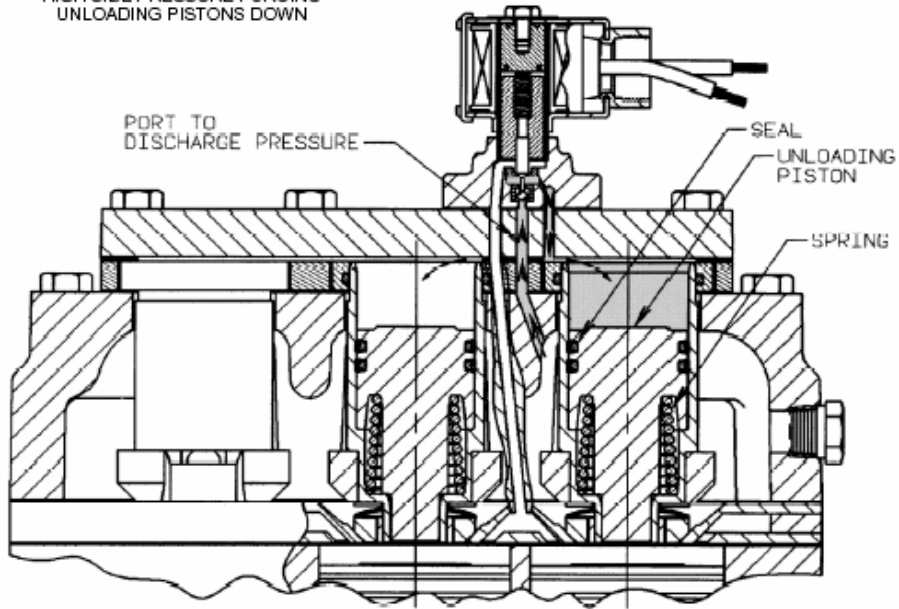
Capacity Control Valve Construction

The unloading assembly is considerably different in design from either the blocked suction unloading used on Copeland 4, 6, and 8 cylinder. The unloading hardware consists of a spring and plunger assembly for each cylinder housed in a chamber mounted on top of the valve plate. See Figure 1.

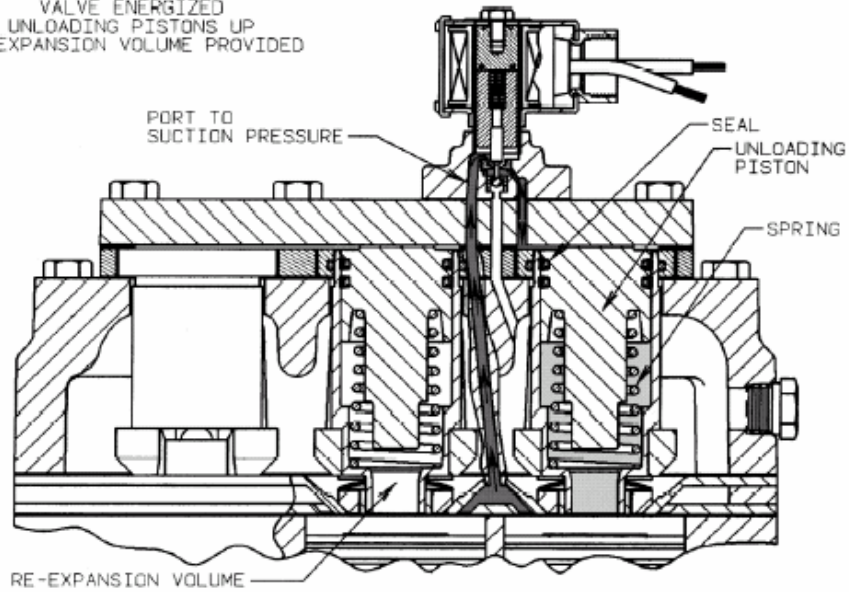
In the fully loaded operating mode (with the solenoid valve de-energized), the solenoid needle valve is seated in the upper port, and the top of the unloading piston is exposed to discharge pressure through the discharge pressure port. The high pressure discharge gas on top of the un-loader piston forces it to remain seated in the Discus valve.

When unloaded operation is required, the solenoid valve is energized. The needle valve seats in the lower port, and the unloading piston chamber (above the unloading piston) is exposed to suction pressure through the suction port. With suction pressure on top of the piston, the spring force underneath the piston is sufficient to move the piston to the top of the chamber. In this position, the un-loader piston opens a passage in the center of the Discus valve through which high-pressure gas enters the expansion chamber during the compression stroke. During the suction stroke, the gas contained in the unloading chamber re-expands through the passage into the cylinder thus reducing capacity.

NORMAL OPERATING CONDITIONS
 VALVE DE-ENERGIZED
 HIGH SIDE PRESSURE FORCING
 UNLOADING PISTONS DOWN



UNLOADED OPERATION
 VALVE ENERGIZED
 UNLOADING PISTONS UP
 RE-EXPANSION VOLUME PROVIDED



■ Suction Gas □ Discharge Gas

Figure 1

Modu-load Performance

When operating unloaded, the percent of full load capacity is a function of operating compression ratio. The higher the ratio, the greater the capacity reduction.

Application

Basically the same as the un-loader operation

• Operating Envelope

Low temperature as well as high and medium temperature applications are approved for Modu-load unloading because of reductions in compressor operating temperatures due to Discus valving and improved internal gas flow.

Depending upon the exact hardware configuration, tolerances, and spring force, stable operation of the Modu-load un-loader requires a minimum of 60 to 70 psi differential between suction and discharge pressure in order for the discharge pressure acting on top of the un-loader piston to overcome the upward forces of the un-loader spring and cylinder pressure.

• Cooling Requirements

Head cooling fans are required when the saturated suction temperature is at or below 0°F for both the loaded and unloaded mode.

• Wiring

The capacity control valve is in the loaded position when de-energized and in the unloaded position when energized. The solenoid valve may be energized either by means of a reverse-acting low pressure control or a temperature-control thermostat.

Although the leak-back rate when the coil is energized during a compressor off cycle is minimal, to prolong the solenoid coil life it is recommended that the capacity control solenoid valve be de-energized when the compressor is not operating.

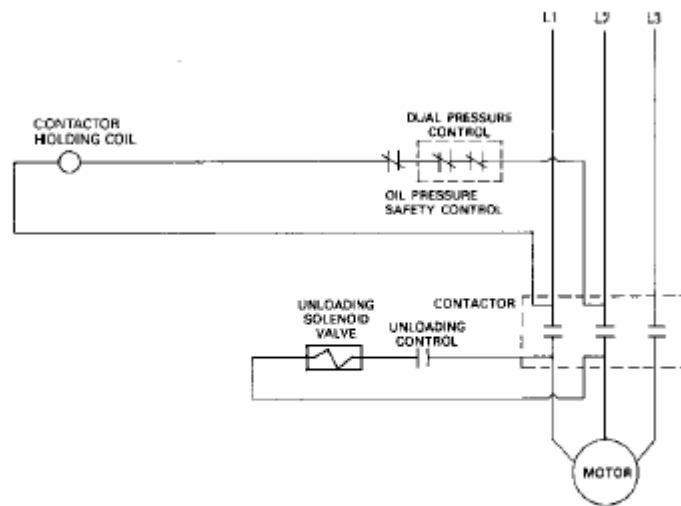
Note: As with any unloading compressor it is recommended the un-loader solenoid be de-energized before pumping down the low side. Operating in the unloaded mode will greatly increase the time period for pump down. In control circuits operating at line voltage, the solenoid valve and control can be connected to the load side of the contactor as in Figure 6.

The un-loader solenoid valve will then be de-energized and closed when the compressor is not operating.

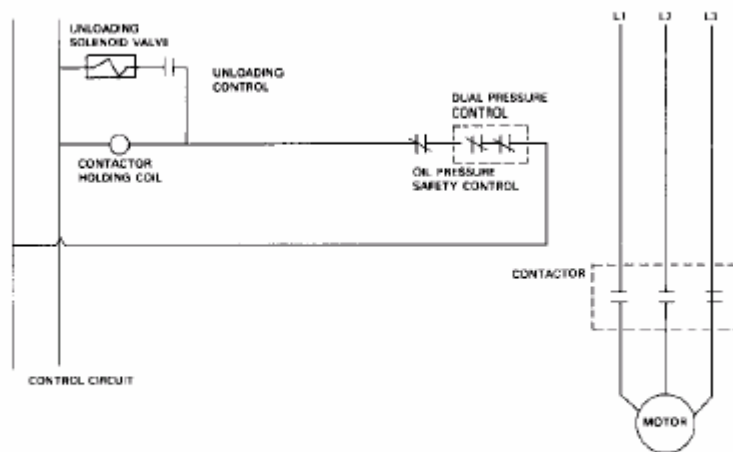
On large installations, the control circuit may have a power source independent of the compressor power supply. In such cases, the unloading solenoid valve and control may be connected as shown in Figure 6 or they may be connected in parallel with the compressor contactor coil as in Figure 7.

• Piping

The same as unloading.



Typical Control Circuit For Compressor With Unloading Valve
Figure 6



Typical Control Circuit for Compressor With Unloading Valve
and Separate Power Source Control Circuit
Figure 7

Compressor Capacity Control with Hot Gas Bypass

Compressor capacity modulation by means of hot gas bypass is recommended where normal compressor cycling or the use of un-loaders may not be satisfactory. Basically this is a system of bypassing the condenser with compressor discharge gas to prevent the compressor suction pressure from failing below a desired setting. All hot gas bypass valves operate on a similar principle.

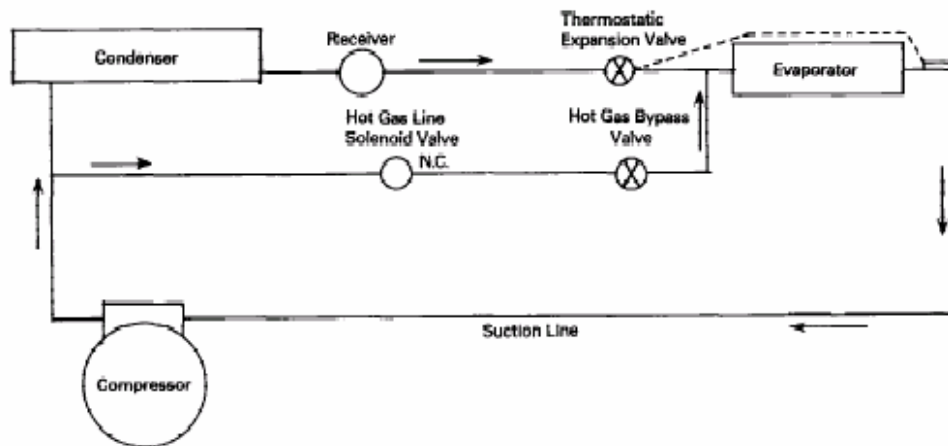
They open in response to a decrease in downstream pressure, and modulate from fully open to fully closed over a given range. Introduction of the hot, high pressure gas into the low pressure side of the system at a metered rate prevents the compressor from lowering the suction pressure further.

The control setting of the valve can be varied over a wide range by means of an adjusting screw. Because of the reduced power consumption at lower suction pressures, the hot gas valve should be adjusted to bypass at the minimum suction pressure within the compressor's operating limits which will result in acceptable system performance.

CONTINUOUS OPERATION

If a refrigeration system is properly designed and installed, field experience indicates that maintenance may be greatly reduced if the compressor operates continuously within the system's design limitations as opposed to frequent cycling. Electrical problems are minimized, compressor lubrication is improved, and liquid refrigerant migration is avoided.

Therefore, on systems with multiple evaporators where the refrigeration load is continuous, but may vary over a wide range, hot gas bypass may not only provide a convenient means of capacity control, it may also result in more satisfactory and more economical operation.



TYPICAL SCHEMATIC CONNECTION - BYPASS INTO EVAPORATOR INLET

Figure 1

BYPASS INTO EVAPORATOR INLET

On single evaporator, close connected systems, it is frequently possible to introduce the hot gas into the evaporator inlet immediately after the expansion valve. Distributors are available with side openings for hot gas inlet. Bypassing at the evaporator inlet has the effect of creating an artificial cooling load. Since the regular system thermostatic expansion valve will meter its feed as required to maintain its superheat setting, the refrigerant gas returns to the compressor at normal operating temperatures, and no motor heating problem is involved. High velocities are maintained in the evaporator, so oil return is aided. Because of these advantages, this type of control is the simplest, least costly and most satisfactory bypass system. This type of bypass is illustrated in Figure 1.

BYPASS INTO SUCTION LINE (with liquid Injection)

Where multiple evaporators are connected to one compressor, or where the condensing unit is very remote from the evaporator it may be necessary to bypass hot gas into the refrigerant suction line. Suction

pressures can be controlled satisfactorily with this method, but a de-superheating expansion valve is required to meter liquid refrigerant into the suction line in order to keep the temperature of the refrigerant gas returning to the compressor within allowable limits. It is necessary to thoroughly mix the bypassed hot gas, the liquid refrigerant, and the return gas from the evaporator so that the mixture entering the compressor is at the correct temperature. A mixing chamber is recommended for this purpose, and a suction line accumulator can serve as an excellent mixing chamber while at the same time protecting the compressor from liquid flood-back. See **Figure 2** for typical installation.

Another commonly used method of mixing is to arrange the piping so that a mixture of discharge gas and liquid refrigerant is introduced into the suction line at some distance from the compressor, in a suction header if possible. **Figure 3** illustrates this mixing method.

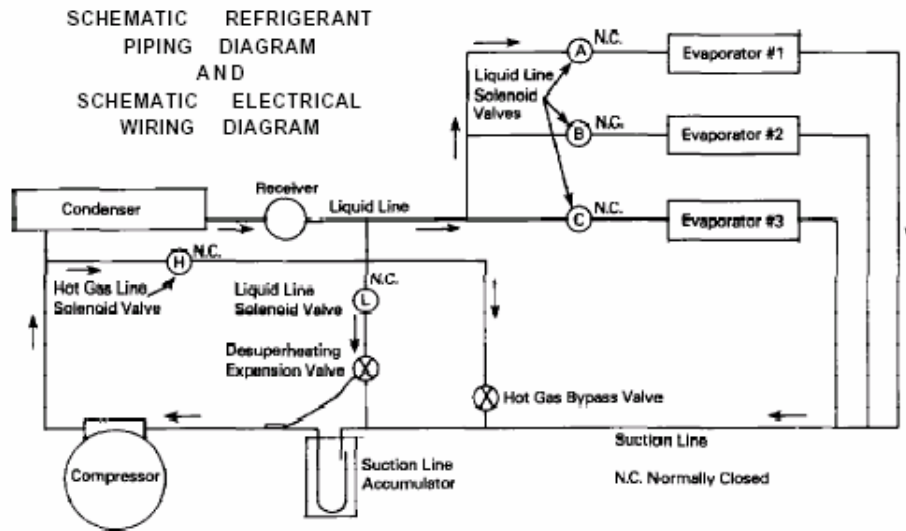
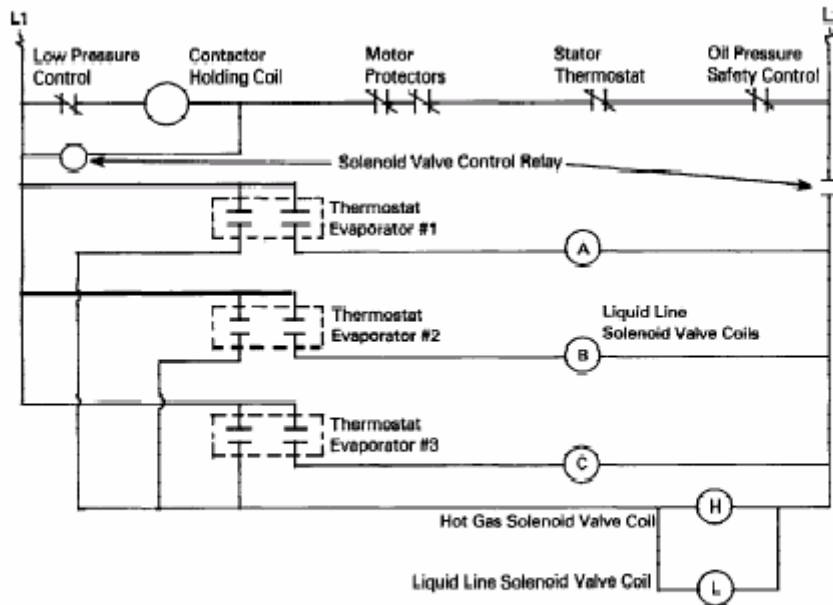


Figure 2A



**TYPICAL HOT GAS BYPASS CONTROL SYSTEM
WITH BYPASS INTO SUCTION LINE**

Figure 2B

SOLENOID VALVES FOR POSITIVE SHUT-OFF AND PUMPDOWN CYCLE

In order to allow the system to pump down, a solenoid valve must be installed ahead of the hot gas bypass valve. Since the hot gas valve opens on a decrease of downstream pressure, it will be open any time the system pressure is reduced below its setting. If the system control is such that this solenoid valve is closed during the normal cooling cycle, it may also prevent possible loss of capacity due to leakage.

A solenoid valve is also recommended ahead of the de-superheating expansion valve to prevent leakage and allow pump down. Both of the solenoid valves should be of the normally closed type, and wired so they are de-energized when the compressor is not operating.

DESUPERHEATING EXPANSION VALVE

If a de-superheating expansion valve is required, it should be of adequate size to reduce the temperature of the discharge gas to the proper level under maximum bypass conditions. The temperature sensing bulb of the expansion valve must be located so that it can sense the temperature of the gas returning to the compressor after the introduction of the hot gas and the de-superheating liquid. Suction gas entering the compressor should be no higher than 65°F under low temperature load conditions, or 90°F under high temperature load conditions. On low temperature applications where hot gas bypass is used to prevent the compressor suction pressure from falling below safe operating levels, valves with unusually high superheat setting may be required. For example, suppose a control was desired to prevent a system using R-404A from operating below -35°F. The temperature of the gas returning to the compressor must be prevented from exceeding 65°F. Therefore, when the de-superheating expansion valve is feeding, it will sense on one side of its diaphragm, the system pressure equivalent to -35°F. or 6.7 psig, and in order to maintain 65°F return gas, it will require a superheat setting of 65°F plus 35°F or 100°F. Expansion valves with special charges are available from expansion valve manufacturers with superheat settings over extremely wide ranges, although these will not normally be available in a local wholesaler's stock.

Contact the expansion valve manufacturer's local representative for assistance in selecting valves with nonstandard superheat settings.

TYPICAL MULTIPLE - EVAPORATOR CONTROL SYSTEM

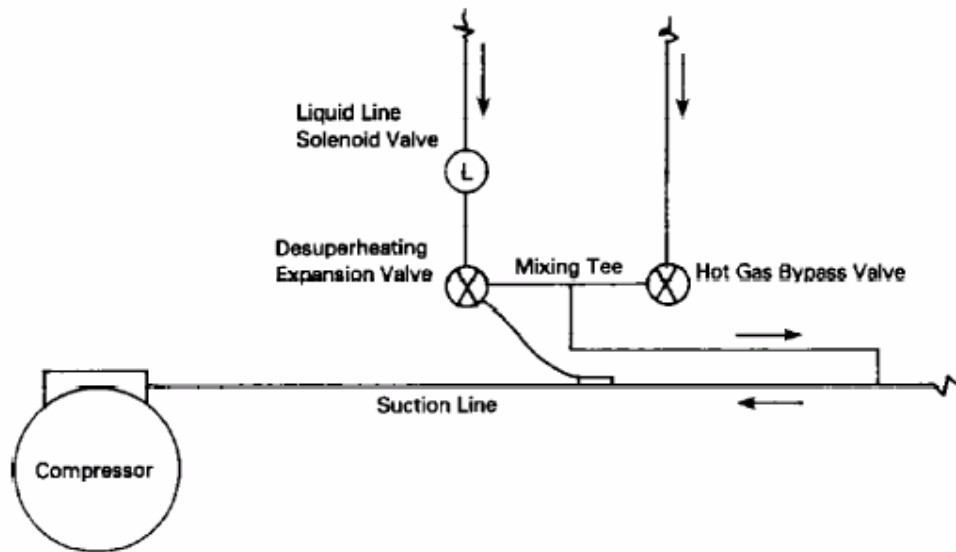
A typical hot gas bypass control system with three evaporators is illustrated in **Figure 2**, together with a schematic electric control system for cycling control of the compressor. The double pole thermostats close on a demand for refrigeration, and as long as any one evaporator is demanding cooling the compressor operates, and the hot gas bypass valve modulates flow as necessary to prevent the suction pressure from falling below a fixed set point.

If all evaporators are satisfied, all of the thermostats are open, and all liquid line solenoid valves and the hot gas solenoid valve are de-energized, and therefore closed. The compressor will then cycle off on low pressure control until thermostat again closes.

In order to protect the compressor against danger from liquid flooding in the event of a trip of a compressor safety device, provision must be made in the wiring circuit to de-energize the hot gas and the de-superheating liquid line solenoid valves if the compressor is inoperative. On a pump down system, this can be accomplished by means of a solenoid valve control relay as shown in **Figure 2**.

If continuous compressor operation is desired, single pole thermostats can be used, and the hot gas and de-superheating liquid line solenoid valves should be connected directly to the load side of the compressor contactor. In the event all three evaporators are satisfied, the compressor will operate on 100% hot gas bypass until cooling is again required.

Compressors equipped with inherent protection can cycle on the inherent protector independently of the contractor. To avoid flooding the compressor with liquid refrigerant in the event the inherent protector should trip, the hot gas solenoid valve and the liquid line solenoid valve should be connected through a current sensing relay as shown in **Figure 4**.



ALTERNATE METHOD OF BYPASS INTO SUCTION LINE

Figure 3

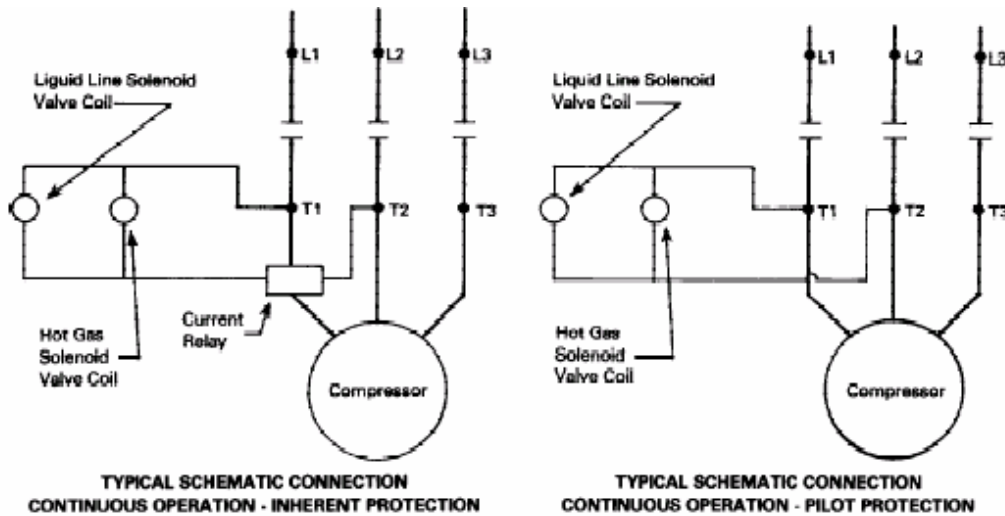


Figure 4

Power Consumption with Hot Gas Bypass

Since the power consumption as well as the capacity of a compressor is reduced with a decrease in compressor suction pressure, the control system should be such that the system is allowed to reach its lowest satisfactory operating suction pressure before hot gas is bypassed.

Where major reductions in capacity are required, operating economy may be best achieved by handling the load with two compressors. One can be cycled for a 50% reduction in both capacity and power, while the capacity of the compressor remaining on the line is modulated by hot gas control. It is not necessarily true that continuous compressor operation with hot gas bypass will result in a higher power bill than cycling operations for a given load. Almost all utilities make a monthly demand charge based on peak loads. Since the peak motor demand occurs when locked rotor current is drawn on start-up, the utility demand charge may reflect motor starting requirements rather than the true running load. With continuous operation, once the motors are on the line, starting peaks may be eliminated, and the reduction in the demand charge may offset the increased running power consumption.

Compressor Operating Limits

Compressors should not be operated outside of the operating limits shown on the published compressor specification sheets, and low pressure controls should not be set below the minimum settings without prior written approval of the Copeland Application Engineering Department. Operating below the allowable minimum suction pressure may result in excessive discharge temperatures which can cause cylinder and valve damage, and may result in lubrication problems. Since high discharge temperatures can occur even though the motor is cool, the motor thermostat will not protect the compressor against these conditions.

Operation of motor-compressors beyond the established recommended operating limits will be considered misuse and abuse, and damage may result.