d. A plate valve formed as a ring with some part of the valve structure clamped. A full plate is sometimes used with two or more sets of slots arranged in circles. By clamping the center of the plate a force is provided for closing the valve. Most problems in ring valve design are connected with the shape of the valve during operation. Unless the shape is known the stresses cannot be calculated. Every effort is therefore being made to shape backstops or valve supports so that they will limit the stresses. As an example, it can be seen that a simple ring with four spokes to a clamped hub will have a combination of bending and twisting during normal opening. If there are uneven gas forces in addition, stresses can go far beyond the values calculated for normal operation. Various methods have been used to produce better defined movement of the valve. Wave-shaped backstops matched with the spoke-ring transition points will limit the stress concentration where the spokes join the ring. A full clamping across a diameter will produce a motion similar to a cantilever reed and curved back stops are usually provided for this type. Other constructions provide a large number of support fingers, almost like gear teeth, so that the deflection is nearly the shape of a flat cone.

Many ring valves are provided with relief arrangement to avoid damage during liquid slugging. The relief is usually obtained by using a heavy spring to hold the valve assembly in place.

Capacity Control

A perfect capacity control system would have the following operating characteristics:

1. Continuous adjustment to load.
2. Same efficiency for full or partial load.
3. Full load efficiency should not be affected by the mechanism.
4. Capacity control should not affect compressor reliability.

Not all of these benefits can be had in the same machine.

Capacity control may be obtained by: controlling suction pressure by throttling, controlling discharge pressure, returning discharge gas to suction, adding re-expansion volume, changing the stroke, opening a cylinder discharge port to suction while closing the port to discharge manifold, reducing compressor speed, and closing off cylinder inlet.

The most commonly used are the opening of the suction valves by some external force, hot gas bypassing discharge to suction within compressor and hot gas bypassing external to the compressor.

Valve Plates

Valve plates are usually made of cast iron or steel.

Where floating ring valves are used, the valve seats are usually hardened to resist the severe impact. Designs employing reed valves fixed at one end, or ring valves held at the center do not usually require hardened valve seats.

Crankcase Heaters

Migration of the refrigerant back to the oil in the compressor crankcase always exists. To minimize the migration during shutdown, crankcase heaters should be employed. Crankcase heaters should keep the crankcase temperature at least 20 F above the rest of the system but well below the breakdown temperature of the oil.

Cylinder Cooling

Cylinder cooling is accomplished by means of air, water and refrigerant. This can be done by finning the crankcase and/or cylinder heads for air cooling or by providing flow passages in the heads for refrigerant or water cooling. Cylinder cooling means are always employed on ammonia compressors and on some Refrigerant 22 installations to maintain the discharge temperature below 300 F to prevent oil breakdown. Temperatures in excess of 300 F can cause refrigerant breakdown and should be avoided. Temperatures as measured should be 300 F at the discharge valve guide or 275 F on the discharge line immediately following the service valve.

Oil Cooling

Oil cooling is always employed on ammonia compressors and where warranted on Refrigerant 22 applications. Oil coolers are normally of the water to oil type. Refrigerant to oil or air to oil coolers are also used. The maximum operating oil temperature that will insure adequate seal cooling in open compressors is 160 F and bearing cooling in hermetic compressors is approximately 180 F.

APPLICATION

Motor Protection

The purpose of the protection system is to keep the motor from overheating or drawing excessive operating currents. As a second function, it will alert the operator to abnormalities which then can be corrected before further damage occurs.

The system should comply with the *National Electric Code*, which will not allow the motor to draw current in excess of 140 percent of full load current. This maximum current occurs at a torque point well beyond the normal full load torques and is selected to allow safe continuous operation up to that point.

During normal operations, motor temperatures will be relatively low even at the maximum current point of the system. However, in selecting a protection scheme recognition of conditions where high temperatures exist in spite of low currents must be made. Conditions which create this state are: (1) loss of motor coolant (refrigerant charge loss), (2) low suction pressure and high superheat at the compressor, and (3) blockage of the device feeding refrigerant to the evaporator.

Whereas the *National Electric Code* defines maximum current, no clear indication of allowable maximum motor temperature is made. Hence, the selection is dependent on the design of the compressor, the motor insulation system, refrigerant, oil and required range of operation.

Another criterion for selection is that of response, i.e., the time that elapses from the sensing of the unsafe condition to the actual operation of the device. If the time is extremely short, difficulties in starting may occur. If too long, a burnout on locked rotor would happen. Thus there is an optimum range of trip response for a given current. At a stalled condition a 2 second minimum and a 10 second maximum are considered adequate for conventional protectors.

One somewhat special application is the use of the protective device as a normal operating control. Refrigerator and room air-conditioning motors, for instance, will not generally start against full load and are taken off the line by the protector, then immediately restarted automatically until pressures have equalized to a level allowing a proper start. This scheme has a low initial cost, but has the disadvantage of not distinguishing between normal operation and trouble.

The specific types of motor protection now in common use are:

1. *Current Sensitive Overloads:* These remove the compressor from the line when a given current is reached. Depending on the type, all are more or less sensitive to the surrounding ambient temperature and it must be considered when the selection is made. In hermetic compressors where suction gas refrigerant is employed as a motor coolant, the ratio of starting current to full load amps is relatively small and the heating rise rate at the stalled condition high. The trip current, therefore, must be relatively high and the response rate short to adequately anticipate the stalled motor temperatures. This device then would have a response rate close to the 2 second minimum mentioned above.
2. *Temperature Sensing Switch:* Presently these are available in hermetically sealed cases and can be *buried* in the motor windings. These devices are used strictly to keep the motor below a predetermined maximum temperature during running operation. Generally they do not respond to a rapid temperature rise quickly enough to offer locked rotor protection.

3. *Temperature and Current Combination Devices:* These are available in hermetically or non-hermetically sealed packages. Essentially temperature sensing, the source of the temperature can be either motor current as carried by the device or a heat generating condition such as loss of refrigerant charge. The non-hermetic devices must be mounted on the external casing and as such provide marginal overheating protection particularly in the case of the internally spring-mounted compressors. The hermetically sealed devices can be mounted directly on or in the windings. Depending on their rating, they can break line current directly or, by handling a fraction of line current, operate a holding coil.
4. *Temperature, Current, and Rise Rate Combination Devices:* These devices in addition to sensing current and temperature respond to motor rise rates. The trip time during locked rotor will vary inversely as the motor temperature rise rate. They employ mechanical or solid state components. In their present state, these are being applied on large motors in the control circuit.

Liquid Return to Compressor

A compressor is not designed for, nor can it be made to handle, large quantities of liquid without eventual damage to parts. Primarily, the compressor pistons move too rapidly; the velocity of the flow through the suction and discharge valve is purposely designed high. Therefore, if liquid enters the cylinder, it will almost act as a solid mass and cause inconceivably high damaging forces upon all parts.

It is not sufficient to put a trap in the suction line to catch this liquid, unless there are means to get rid of it. Eventually the trap will fill and the liquid will come into the cylinder anyway. It is, of course, best to evaporate the liquid in the evaporator by controlling the liquid feed.

During shutdown, many things continue to happen inside a system. The refrigerant in the condenser and receiver will try to flow toward the source of low pressure and temperature. The flow will come through the expansion device and also try to pass the discharge valves in the compressor. When gas enters the evaporator it condenses due to the temperature prevailing there. This liquid in the evaporator can build up and become a potential hazard when it returns to the compressor during start-up.

This problem can be solved:

1. By controlling refrigerant charge in the system so that the quantity returning to the low side during shut down is small.
2. By using suction accumulators that provide space where a liquid mass can be delayed and broken up. This accumulator may be the compressor itself if it has sufficient volume to hold the entire system charge without slugging.
3. By applying heat to any point where liquid is undesirable.

A crankcase heater is very effective in this respect. Since it is only necessary to make the compressor temperature slightly higher than the temperature of the rest of the system a heater of low wattage can be used. It is finding more and more use with the extensive application of condensing units placed outdoors in split systems with large refrigerant charges. Heating of the crankcase also keeps the lubricating oil nearly undiluted so that the bearings receive, at least for a short period, pure oil at full pressure when the compressor starts.

Remember that the heater is effective only during shutdown and that proper sizing of the system and feeding device, properly sized charge or the use of an accumulator are required to insure normal operation after startup.

For details of design and application to prevent liquid return, see Chapters 76 to 80, 1964 Guide And Data Book.

Heat Exchangers

A heat exchanger in the suction return gas will aid system performance and assure return of dry gas to the compressor.

Good design of the exchanger is essential to avoid excessive pressure loss, trapping of oil and insure efficient transfer of heat. The velocity of the gas through the exchangers must be great enough to insure oil return at all operating conditions.

For details of design and application, see Chapters 76 to 80 of the 1964 Guide And Data Book.

Automatic Oil Separators

Oil separators are used to insure oil return to the compressor crankcase and in some cases to prevent oil from entering the evaporator. They are recommended for use in systems where the oil is not miscible with the refrigerant (Ammonia, and Refrigerant 13 in particular).

With the halocarbons, the low oil circulation rate of the modern compressor and proper design of the systems has eliminated the use of oil separators in all except a few cases.

Parallel Operation

Parallel operation of compressors presents many difficulties in connection with oil return from the evaporator and oil level in the crankcases. The development in recent years has been towards multiple, completely independent refrigerant circuits which have the same benefits as parallel operation (low starting current, high efficiency at partial loads) and none of its disadvantages. It gives better control and the added cost of multiple lines can be less than the cost of cross-controls for the parallel system.

With a number of compressors operating in parallel, the returned oil must be properly apportioned between the compressors. Fig. 4 shows the method most widely used. Line *A* connects the top of the crankcase and equalizes the pressures above the oil, while line *B* connects to a point just above the oil level and insures a normal level in each crankcase. When these lines are of sufficient size, little variation in level between units will be noted.

In addition to these connections, the high-pressure sides of the lubrication pump can be cross-connected so that if one pump ceases to function due to failure, oil pressure can be maintained in both compressors.

A central reservoir for collecting return oil and level control means (such as float valves) to feed oil to the various crankcases, may also be used.

For details of design and application, see Chapters 76 to 80 of the 1964 Guide And Data Book.

Protective Devices

Compressors are provided with one or more of the following devices for protection against abnormal conditions and to comply with various codes.

1. Over current protection as required by the *National Electric Code.*
2. High pressure protection as required by *Underwriters' Laboratory* and per *ARI Standards* and *ASA* B9.1, *Safety Code.* This may include:
   a. A high pressure cutout.
   b. A high to low side internal relief valve or rupture member.
   c. A relief valve or rupture member on the compressor with casing similar to those used on other pressure vessels.
3. High temperature control devices to protect against motor overheating and oil breakdown.
   a. Motor over temperature protective devices which were discussed in section on Motor Protection.
   b. To protect against oil and refrigerant breakdown a limit switch is sometimes used to stop the compressor when discharge temperatures exceed safe values. Discharge temperatures may reach unsafe values at high pressure ratios or at partial compressor loads.
   c. Oil temperatures sometimes are controlled on large compressors where separate oil coolers are employed.
   d. Where crankcase heaters are used to maintain a minimum crankcase temperature, a thermostat is sometimes used to limit the maximum oil temperature.
4. Low pressure protection may be provided for:
   a. Suction gas. Many compressors are limited to a minimum suction pressure and a protective switch is provided.