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AIR TO AIR HEAT PUMP SYSTEM DESIGN

In a world growing increasingly short of natural energy sources, the pressure for more efficient usage of electrical energy makes inevitable a tremendous expansion in the usage of heat pumps. A very real danger exists that because of the energy shortage and the search for alternative means of obtaining heating efficiency, the heat pump may be promoted as a political panacea, without regard for its operating limitations. The history of heat pumps in the United States has not been a happy one, with failure rates in general much higher than air conditioning equipment. Many of the past problems in heat pump application can be traced to motor insulation not suitable for the extreme stresses inherent in heat pump application, or system designs that failed to provide adequate safeguards against the operating hazards involved.

Heat pumps can be designed and built to provide satisfactory performance and acceptable reliability, and many manufacturers are building such heat pumps today. Tremendous improvements have been made in motor insulation in the past decade, but if the air conditioning industry as a whole is to avoid the failure patterns of the past, it is essential that the basic operating problems are recognized, and that adequate steps are taken in system design to protect the compressor from conditions which it cannot survive. It would be a tragedy not only for our industry, but for our nation, if in a blind pursuit of lower first cost, we ignored the lessons of the past, failed to provide the necessary system safeguards, and repeated the industry's experience of a generation ago.

The heat pump, as it name implies, is basically a design concept for moving heat energy from one point to another, extracting heat from the heat source and rejecting heat to the heat sink. The heat source and heat sink are normally air or water, and the heat pump can be applied with various combinations - air-to-air, water-to-air, air-to-water, and water-to-water. The compressor not only acts as the transfer pump, it also increases the temperature level of the refrigerant by compression so that it can be rejected at a higher temperature level. As a result, in addition to comfort heating, interest has been expressed in using heat pumps for domestic hot water heating and swimming pool heaters, and undoubtedly other proposed applications will arise.

There are physical limitations on the temperatures and stresses which a compressor is designed to withstand, and in general conventional compressors are not suitable for continuous operation at extremely high condensing temperatures. In order to maintain safe operating conditions for the compressor, there are very critical limitations on heat pump applications where the user might desire high utilization temperatures, and any such application must be carefully screened from an application standpoint to insure system reliability.

HEAT PUMPS - A UNIQUE DESIGN CHALLENGE

To fully understand the problems involved in heat pump design and application, it is first necessary to face some rather unpleasant facts of engineering life that differ from conventional air conditioning design practice.

In order to operate a compressor in an air source heat pump under low outdoor ambient temperature conditions, the evaporating temperature required to extract from the cold outdoor air is so low that the system in effect becomes a low temperature refrigeration system. A typical welded compressor because of its basic construction has inherent characteristics that are not desirable for low temperature usage. The motor is not in direct physical contact with the welded shell, and the compressor surface is not designed as an efficient heat radiation surface. The net result is that a welded compressor in the size range suitable for heat pump usage if applied with conventional low temperature design criteria will develop temperatures so hot they will literally destroy the compressor.

So the first fact we must face is that in order to successfully apply that welded compressor on a heat pump to operate in low ambient temperatures, we have to deliberately break most of the rules of design practice normally accepted for low temperature refrigeration. We have to deliberately flood the compressor with liquid refrigerant to keep it cool, and in so doing we expose the compressor to potential hazards, both of a lubrication and mechanical nature, that we would rather avoid from a reliability standpoint. It can be done, but it means we must maintain a balance between sufficient flooding to cool the compressor, and excessive flooding which could adversely affect lubrication.

Why then can't we build a compressor that would be better adapted to heat pump usage? The answer is simple, since we already have such a compressor in the accessible hermetic design such as the Copelametic compressor which is a standard of the low temperature refrigeration industry. It does have metal to metal heat transfer from the motor, it does have an excellent heat transfer surface, and it can and is working all day long at conditions no more demanding than a heat pump. From an engineering and physical standpoint it is ideal, but because of its construction it costs approximately twice as much as a welded compressor. So long as it is possible to apply a welded compressor without an excessive failure rate, and industry experience indicates it is, at least in smaller horsepower sizes, first cost alone will usually dictate the choice of a welded compressor on any product sold in a highly price competitive market.

The second fact of life we must face is that a reverse cycle heat pump is a compromise system. The same heat transfer coils are used for both heating and cooling cycles, but the compressor has a steadily declining capacity capability as the outdoor temperature falls on the heating cycle. As a result, there usually is a far greater refrigerant requirement during the cooling cycle than there is in the heating cycle, and as the outdoor ambient temperature drops, and the evaporating temperature drops correspondingly on the heating cycle, a surplus of excess liquid refrigerant develops. This refrigerant acts like a juvenile delinquent, roaming around looking for some place to hang out, and becoming potentially dangerous if not properly handled.

One of the better design solutions to this in the past was a charge compressor, which was really nothing more than a little receiver tank to hold the excess liquid during the heating cycle. Again, cost has pretty well driven this feature from the market place. Where does that excess refrigerant go? It may go to the indoor coil, to the compressor crankcase, or to a suction accumulator, depending on the system design and control characteristics. In any event, the system again is operating on a delicate balance, extremely vulnerable to variations in refrigerant charge.

The third engineering fact of life is that refrigerant R-22, which is almost universally used in heat pumps, is a very poor low temperature refrigerant, and therefore not a good refrigerant for the heating cycle. the relatively low density of R-22 vapor and its specific heat characteristics result in a much greater temperature response to heat than is true of refigerants such as R-12 or R-502.

So why not use another refrigerant - R-502 for example which has much better temperature characteristics? Again, the heat pump is a compromise, and for the cooling cycle, R-22 is ideal, has better efficiency characteristics than R-502 and last but not least, costs less. Possibly of equal importance, you cannot solve all the problems of low temperature operation merely with a change of refrigerant, so the system design is still going to require attention. As in the case of the previous problems, R-22 leaves little tolerance for error.

The fourth fact of life is one we all know, but due to the eternal optimism that seems to blossom in the hearts of air conditioning and refrigeration engineers, is frequently ignored. A compressor is not physically capable of digesting large amounts of liquid refrigerant without encountering stresses that if continued long enough, are almost certain to destroy the compressor. At the beginning and termination of a reverse cycle defrost, large amounts of liquid refrigerant are lying in the coil suddenly exposed to suction pressure, and in response to the sudden change in system pressures, come roaring down the suction line to the compressor.

At the present state of technology, some type of suction accumulator is the most positive means of providing a reasonable degree of protection against flooding refrigerant.

To meet the challenge which the heat pump poses, Copeland has embarked on two major programs. A line of welded compressors especially designed for heat pump applications has been developed with increased bearing surfaces and improved lubrication to provide greater reliability when operated under high compression ratios. As these new heat pump compressors become available in production, standard welded air conditioning compressors will be withdrawn from heat pump applications.

As a second step in the heat pump program, some basic specifications for the application of Copelaweld compressors to heat pump systems have been established. Any replacement under warranty of a compressor failing on a heat pump application is contingent on the system meeting these specifications.

AIR TO AIR HEAT PUMPS

This is the type of system most people associate with the term heat pump, using direct expansion coils to heat or cool the conditioning air as required, while rejecting or absorbing heat from the outdoor ambient air. As the outdoor ambient air temperature declines in the heating mode, the stresses to which the compressor is exposed increase, and the principal goal of air to air heat pump design must be survival under the lowest outdoor ambient conditions to be expected. To insure system reliability, there are a number of critical factors in system design.

1. Compressor selection

The ability of the bearing surfaces and the running gear in the compressor to withstand the stresses of high compression ratios under conditions of high dilution of the crankcase oil with liquid refrigerant can only be achieved by proper compressor design. The choice of a motor insulation that can withstand frequent exposure to liquid refrigerant must also be part of the compressor design criteria.

Since existing air conditioning compressors may not have construction characteristics suitable for the stresses encountered in heat pump usage, only compressors designed for heat pumps applications should be used.

2. Refrigerant Control

On conventional air conditioning and refrigeration systems, it is a basic principle of system design that from 10° to 15° of superheat must be provided in the refrigerant vapor returning to the compressor to avoid lubrication problems. Once we face the fact that the only way the welded compressor in a heat pump can survive at low ambient conditions is by controlled flooding of liquid refrigerant to reduce the compressor operating temperatures, it is obvious that conventional control criteria cannot apply.

The question that then arises is the degree of liquid flooding that can be tolerated in a heat pump compressor without adversely affecting lubrication. Extensive laboratory testing at Copeland has demonstrated, contrary to popular belief, that dilution of the oil in the compressor crankcase by liquid refrigerant under constant operating conditions up to levels of 10% or more can be tolerated for long periods of operation without damaging the bearing surfaces.

The operating characteristics of a capillary tube are such that essentially it is a constant feed device. When applied to a heat pump, this typically results in liquid control the 10° to 15° of superheat at standard rating conditions, (47°F DB, 43°F WB outdoor temperature), the superheat diminishing as the outdoor ambient drops, with liquid flooding occurring as the outdoor ambient approaches 10°F. Thus the capillary tube has ideal characteristics from a compressor cooling standpoint.

In contrast, the thermal expansion valve depends on superheat for its control characteristics. Not only can this create extreme discharge temperatures at low ambients, it can also create oil return problems as the oil becomes more viscous at low temperatures. A third undesirable characteristic of a thermal expansion valve is the storage of excess liquid refrigerant in the indoor coil during the heating cycle, reducing the effective heat transfer surface causing higher condensing temperatures, higher compression ratios, and contributing to liquid flooding at the initiation of defrost.

It would appear that ironically, the good control characteristics of expansion valves may actually rule against their use on heat pumps utilizing welded compressors.

Special expansion valves are available with flooding characteristics at low suction pressures, and these are certainly acceptable from an operating standpoint. However, such valves are normally not commercially available except on a factory order.

3. Suction Accumulator

The most critical heat pump operating hazard is that posed by liquid refrigerant flooding back to the compressor.

Repeated surges of liquid refrigerant into the compressor not only cause physical stress and adversely affect compressor lubrication, they can have detrimental effects on motor insulation. Liquid return to the compressor during and after a defrost cycle are of particular concern, as is excessive floodback during the heating cycle.

Both laboratory testing and field experience indicate that a properly designed suction accumulator can provide excellent protection against both potential hazards.

The accumulator can act as a receiver during the heating cycle when system unbalance or an overcharge from field service result in excessive liquid refrigerant in the system, storing the refrigerant until needed and feeding it back to the compressor at an acceptable rate.

Major movements of refrigerant take place at the initiation and termination of a defrost cycle, and while it is not necessary or even desirable to stop this movement, it is essential that the rate at which the liquid refrigerant is fed back to the compressor be controlled. Again the accumulator can effectively maintain the crankcase temperature at acceptable limits.

Laboratory testing revealed that most commercially available accumulators had excessive liquid return characteristics on heat pump systems, and this was traced to the sizing of the orifice provided for oil return. Typical accumulators manufactured for air conditioning or commercial usage have oil return orifices ranging in size from .0625 to .125 inch diameter.

Extensive testing on modified accumulators with an orifice in the .040 to .050 inch diameter size has proven that this simple modification has tremendously improved accumulator performance while still retaining the capability of adequate oil return at the full range of heat pump operating conditions.

Accumulators intended for heat pump application should be specifically designed for that application with a properly sized orifice.

Accumulator is considered a Copeland specification requirement on all air source heat pumps unless slugging and floodback test under low ambient and defrost conditions are run and satisfactorily passed to prove that operation without an accumulator is acceptable.

Temperature provides a convenient means of checking the dilution of the oil in the crankcase with liquid refrigerant. Life tests indicate that the compressor can survive for long periods at a 10% dilution level without incurring lubrication damage. Holding dilution limits to this level can easily be accomplished with a properly designed suction accumulator, even with a 20% overcharge of liquid refrigerant in the system. In general, so long as the sump temperature is maintained at least 50°F warmer than the saturated temperature equivalent of the suction pressure, the liquid dilution will be within safe limits.

The sump temperature should be taken on the bottom of the compressor opposite the suction inlet. There will be some variation in internal compressor temperature, and the accuracy of the thermocouple reading depends on good insulation, so there could be variations in the thermocouple readings on different areas of compressor shell.

4. High Pressure Control

Studies of failure patterns on heat pumps indicate that one of the major sources of unit malfunction and compressor failures are dirty air filters on the indoor coil. As the filter becomes increasingly plugged, the discharge pressure increases on the heating cycle, increasing the operating compressor ratio. During heavy load periods such as immediately after defrost the head pressure can reach extreme levels.

If the compressor has internal pressure relief valve, the high discharge pressure can cause the pressure relief valve to open. Even with a very dirty filter, there is still some airflow over the indoor coil, and since the load decreases after the defrost termination, it is quite possible that the compressor will continue to operate, and the internal pressure relief valve will not reseat. With a direct internal bypass from the discharge side of the compressor to the suction side, extreme temperatures can result, and early compressor failure is a probability.

Field experience has shown that the addition of a high pressure control to heat pump systems can result in a significant reduction in compressor failures. With the goal of system reliability in mind, a high pressure control is a requirement of Copeland application specifications.

5. Continuous Compressor Operation

On the new heat pump compressors, the improved bearing characteristics allow the compressor to be used without restriction so long as compressor temperatures are maintained within proper limits.

There exists some difference of opinion in the industry as to whether the compressor should be allowed to operate continuously so long as there is a demand for heating, or whether the compressor should be prevented from operating below a given ambient temperature by means of a lockout thermostat.

In the case of compressors whose bearing surfaces were not designed for high compression ratios, obviously operation at low ambient temperatures would not be desirable. It is also true that as the compressor's suction pressure decreases, the capacity decreases, and at some point no more effective heat is obtained from the heat pump cycle than would be realized from the same electrical input strip heaters.

As pointed out previously, systems utilizing expansion valves may create excessive temperatures, and may not be capable of operating at low ambients.

With proper liquid refrigerant control, however, the compressor will be running cold due to liquid flooding. Since exposure to the relatively high degree of liquid refrigerant dilution of the oil for the somewhat limited periods of time that very low temperatures will occur does not appear to be a threat to the bearings, total system reliability may be enhanced by continuous compressor operation. If the compressor were to be cycled off as the temperature dropped, becoming thoroughly chilled during long hours exposed to the cold, the oil in the crankcase would become the consistency of molasses, the electrical controls would be exposed to ice and frost, and the probability exists that the motor might not be able to start the compressor when the temperature rose to the cut-in point.

The available evidence would appear to indicate that there is less hazard to the compressor and greater reliability can be obtained utilizing a heat pump compressor, capillary tube control, and no low ambient lockout.

6. Refrigeration Oil

When Copeland heat pump compressors were first introduced, "white oil" was recommended because of its good low foaming characteristics. Availability problems have forced a reevaluation of its need in heat pumps. Extensive laboratory testing has proven that with today's compressors specifically designed for heat pump duty, equal reliability can be obtained in properly designed heat pump systems with the natural naphthenic oils. Therefore the requirement for white oil in heat pump applications is being dropped, standard refrigeration oils are acceptable, and the availability of "white oil" in Copeland heat pump compressors is being phased out.

7. Crankcase Heater

The largest size crankcase heater that can be safely applied, or the use of the compressor motor for off cycle heat, is a mandatory item on every heat pump. The compressor must operate throughout the winter months, and liquid migration to the crankcase is a constant threat.

Recommended Test Procedure For Air-To-Air Heat Pumps

In addition to the standard capacity and maximum load tests, the following special tests are recommended for qualification of heat pump system design.

Prior to starting the tests, if may be educational and helpful to install a sight glass in the suction accumulator.

Attach a thermocouple to the bottom portion of the compressor housing opposite the suction inlet, below the oil level and well away from the crankcase heater. Insulate well. Add a 20% overcharge of refrigerant to simulate possible overcharging in the field.

A. After stable operation for one hour at an indoor temperature of 70°F and an outdoor temperature of 17°F, record the suction and discharge pressures. Check the thermocouple reading to obtain the estimated oil temperature. If the sump temperature is not at least 50°F warmer than the saturation temperature of the suction pressure, remedial action must be taken. Normally liquid flooding can be controlled with a properly designed suction accumulator.

B. Disconnect the defrost control, and allow the system to operate continuously at the 70/17 condition overnight, or if necessary spray the outdoor coil with water until it has frosted sufficiently to cause the evaporating temperature to fall to -20°F or below. Check the thermocouple reading to obtain the estimated oil temperature. Record the suction pressure. If the sump temperature is not as least 50°F warmer than the saturation temperature of the suction pressure, then remedial action must be taken. Check the discharge temperature to be sure it does not exceed 250° F maximum. If it is in excess of 250° F, then the expansion device must be changed or a discharge line thermostat applied.

Water-To-Air Heat Pumps

If a constant supply of water is available, a water-to-air heat pump can take advantage of all the efficiencies of heat pump operation while avoiding the stresses involved in defrost and low ambient air sources. One successful approach utilizes a central system for multiple apartments or offices, with individual heat pumps in each conditioned space operating from a central water supply system. This permits the system to take advantage of concurrent heating and cooling loads, usually supplemented with a cooling tower for summer heat rejection, and a conventional fuel fired boiler for auxiliary make up heat in winter operation.

It would appear that solar heating could easily be adapted to this type of system as an auxiliary heat source, maintaining the central water supply at a desired temperature during the heating season.

Since the stresses on the compressor with normally available water temperatures are not extreme, the system design is conventional and none of the critical design criteria for air-to-air heat pumps apply. However, compressor operating hours may be very high, and long term reliability is related to the compressors ability to survive extensive cycling.

There has been some consideration of solar assisted water-to-air heat pumps where the water source would be allowed to go to high temperatures, with the thought that the compressor would have greater efficiency at very high suction pressures. Such operation may be feasible, but it results in a requirement for the compressor to operate at conditions beyond its tested limits. It is possible the compressor may operate satisfactorily under very high suction pressure conditions provided the condensing pressure is low, but such factors as motor loading, return gas temperature, and other system design criteria must be evaluated by the Copeland Application Engineering Department to determine the acceptability of the application.

WATER-TO-WATER HEAT PUMPS

Water-to-water heat pumps have many of the same advantages as water-to-air heat pumps so far as the heat source is concerned. The most obvious problem that almost invariably arises is the desired water temperature for heating.

Most existing water heating systems are utilizing water temperatures of 150°F or higher. Refrigerant condensing temperatures in that temperature range are beyond the capabilities of conventional refrigeration compressors with normally used refrigerants. Therefore if the heat pump is being considered as add-on heating source with the thought of utilizing existing heat transfer equipment, a change of refrigerant may be required.

For conventional equipment utilizing R-22, and assuming that reliability and a reasonable life expectancy are desired, the normal operating condensing temperature in the heating cycle should not exceed 135°F, which probably limit the utilization water temperature to 125°F or below.

Another limiting factor with high operating condensing temperatures is the possibility of overloading the compressor motor should the heat source water temperature be too high, and this would have to be taken into consideration if solar heat was as an auxiliary heat source.

Summary

No system design can be a guarantee against potential failure, and additional protective devices obviously add to the first cost of the unit. However, based on the critical nature of the application, and the generally unsatisfactory field performance of many heat pumps in the past, in our judgment it is in the best interests of the ultimate user, the unit manufacturer, and Copeland to adhere to the above minimum design standards.

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