1976

Design Considerations for Heat Pump Compressors

J. F. Horn

P. H. Scharf

DESIGN CONSIDERATIONS FOR HEAT PUMP COMPRESSORS

JAMES HORN, MANAGER HERMETIC COMPRESSOR DESIGN AND PRODUCTION ENGINEERING
PHILIP SCHARF, MANAGER HERMETIC COMPRESSOR ENGINEERING
COPELAND CORPORATION, SIDNEY, OHIO

INTRODUCTION

The increased cost of energy for heating purposes makes the heat pump system more and more attractive. The economy of operation of the heat pump will create high demand for this equipment in the next few years. This may well be the fastest growing segment of the air conditioning industry.

Good system design and use of reliable components is essential for the success of a heat pump. Operating conditions are more severe and the system will be utilized two to three times longer each year than a conventional air conditioner.

With these added requirements in mind we will explore the design of compressors developed especially for heat pump systems.

HEAT PUMP SYSTEM CONDITIONS

(1) Operating Hours

In Northern climates, a heat pump compressor may be required to operate up to seven times longer each year than that required for air conditioning only (see Figure 1). The operating time for a typical location will be increased by a factor of three.

(2) Evaporating and Condensing Temperatures

A heat pump compressor must be capable of operating under a wide range of system conditions - from air conditioning to extreme heat pump conditions. The standard by which air conditioning compressors have been rated for many years (see Figure 2), is 130°F condensing temperature and 45°F evaporating temperature.

At the A.R.I. standard for rating heat pumps (Figure 3), a heat pump system is very effective and yields a high coefficient of performance. Here the condensing and evaporating temperatures are approximately 110°F and 30°F respectively. This condition and the air conditioning standard are ideal conditions for the compressor.

A typical application condition (Figure 4), would be a 20°F outdoor ambient with an evaporating temperature of 5°F. For a compressor isolated in a separate compartment in the outdoor coil cabinet, the ambient temperature would be about 45°F to 50° F.

A severe environment condition would be a low evaporating temperature occurring along with a high condensing temperature (see Figure 5). This condition could result from an outdoor ambient temperature of 0° to -10°F, and restricted air flow over the indoor coil. Here the compressor could experience evaporating and condensing temperatures in the range of -15°F and 110°F, respectively.

(3) Pressure Ratios

The pressure ratio is defined as the absolute discharge pressure divided by the absolute evaporating pressure. In air conditioning systems, the pressure ratio seldom exceeds 4 to 1. In heat pumps, the ratio may exceed 8 to 1 as indicated by Figure 6.

Pressure ratios are a major consideration in heat pump compressor design. As the ratio increases, bearing lubrication and discharge valve temperatures may be adversely affected. Figure 7 shows a worn rod-wrist pin bearing. This is a bearing that provides long life when operating on cooling only systems but has a limited life at the higher pressure ratios experienced under heating conditions. Figure 8 shows a valve plate that has been operating at excessive discharge gas temperature. The deposits are products of oil breakdown. Accumulation of such deposits will eventually prevent proper valve closing and result in loss of performance.

(4) Liquid Refrigerant Return

Compressors may be subjected to excessive liquid return during the defrost cycle if the system does not have adequate provision to control liquid flow to the compressor. Liquid flooding is characterized by a severe drop in compressor oil sump temperature.

Excessive liquid refrigerant in the compressor oil sump can have these damaging effects:

Slugging - mechanical stress on valves, gaskets, piston-rod assemblies;

Loss of oil - violent "boiling" of the refrigerant in the oil sump may carry the oil out in the form of foam;

Dilution of the oil - floodback may dilute the oil to the extent that bearing failure will result;

Piston seizure - rapid change in temperature may result in loss of piston-to-cylinder clearance and piston failure.

(5) Low Ambient Temperature Operation

Low outdoor ambients produce low evaporating pressures and light loads on the compressor. On single phase motors, light loads impress high voltages on the run capacitor.

Cold starts after a long shut down may be damaging to a compressor if the crankcase heater is not completely effective. If liquid refrigerant is allowed to accumulate in the oil sump it may dilute the oil and prevent adequate bearing lubrication. If sufficient liquid accumulates it can result in mechanical damage to valves, gaskets, etc.

(6) Fault Conditions -

Loss of refrigerant - Heat pumps have more complex refrigerant circuitry and more opportunity for system leaks to occur. As refrigerant is lost from the system, the load on the compressor is reduced. The reduced load allows the motor to run at increased speeds which increases the current in the auxiliary winding and may cause severe overheating. This occurs at a time when the motor cooling medium (the refrigerant) is in short supply. If the motor protector is responsive to this condition, it will shut the motor off before the motor temperature reaches a danger point. However, if this condition goes undetected for an extended period of time, the life of the protector could be in jeopardy. Since heat pumps have auxiliary resistance heaters, which can supply the entire heating requirement, a malfunctioning heat pump system may go undetected for an extended period of time.

Blocked condenser - Dirty indoor air filters increase condensing temperature and the pressure ratio that the compressor must operate under.

HEAT PUMP COMPRESSOR DESIGN

(1) Connecting Rod-Wrist Pin Bearing

High pressure ratios frequently experienced in heat pump operation impose greater requirements on the wrist pin bearings. The wrist pin is a low surface velocity bearing that relies on load reversal to aid in its lubrication. High pressure ratios reduce the load reversing action, which starves the pin bearing of oil. The wear shown in Figure 7 was induced by operating the compressor in heating mode with the evaporating temperature at -15°F and the oil sump temperature above 250°F.

The bearing surface area must be increased to compensate for less favorable lubrication. We have found from our development work that wrist pin bearing areas must be increased 20% to 40% from air conditioning only compressor designs.

(2) Pistons

A sudden drop in the oil sump temperature may cause the cylinder to "shrink" at a faster rate than the piston, resulting in loss of running clearance and piston-to-cylinder seizure. Sudden temperature drops in the oil result from inadequate liquid control during the defrost cycle. Pistons with rings have greater running clearance and have the ability to survive such thermal shock.

(3) Oil

The hazards of liquid refrigerant in the heat pump compressor oil sump were listed under "heat pump operating conditions". The oil commonly used in air conditioning systems mixes readily with liquid refrigerant and can be carried from the compressor when excessive floodback occurs. The heat pump compressor may frequently be subjected to excessive liquid return, therefore, an oil that is easily carried out of the compressor becomes a design concern.

"White oil" (a highly refined mineral oil) has an anti-foaming quality that makes it a good candidate for heat pump compressors. System tests with strategically located sight glasses dramatically demonstrate white oil's ability to stay in the compressor oil sump under flooding conditions that will carry out standard air conditioning oil. The compressor experiences less dilution of the oil and no loss of lubrication.

(4) Motor Protection

Since the heat pump compressor is called on to operate three times longer each year and under more varied and adverse conditions, the role of the motor protection system becomes more significant. A common and successful protection design for air conditioning systems is a device that senses the combined current of the main and auxiliary motor windings and is located to thermally respond to high winding temperatures at low currents. However, to fully protect the compressor at the various heat pump system conditions, additional requirements must be placed on the motor protection system.

Internal motor protectors are now available that can respond to high currents in the main and auxiliary windings independently. The protector has two heaters, one in series with each winding circuit. A comparison of the two types of motor-protector circuits can be seen in Figure 9.

The addition of the auxiliary winding heater provides these benefits:

Limits high auxiliary winding temperatures that may occur from light loads and high line voltages;

Protects the compressor motor against sticking start relay contacts. This is the first device of this type to accomplish this protection;

Protects the compressor motor against a shorted run capacitor; when the current in the auxiliary winding becomes excessive, the compressor is shut off. This also includes protection for "off cycle heat", where the auxiliary winding is utilized to provide crankcase heat. Normally, a shorted capacitor in the off cycle heating mode would burn out the phase winding; and,

Faster response to loss of refrigerant from the system. Under low ambient temperature conditions a single heater protector may not respond fast enough to prevent auxiliary winding burnout.

These four design attributes make a heat pump compressor more reliable than a conventional air conditioning compressor.

COMMENTS ON SYSTEM DESIGN

Good compressor design is not always sufficient to insure reliable heat pump operation. As would be expected, heat pump reliability is to a substantial degree also a function of the system design. In developing heat pump compressors, four potential problem areas were noted.

(1) Superheat

At low evaporating temperatures the compressor valveplate temperature becomes very high, this causes oil breakdown and carbon deposits on the valve. Superheat of gas entering the compressor must be kept to a minimum to control valveplate temperatures. Capillary tubes or special low temperature controlled flooding expansion valves can provide the desired minimum superheat.

(2) Compression Ratios

High compression ratios adversely affect lubrication of bearings and provide high temperatures at the valveplate. Compression ratios should be controlled to reasonable limits for long system life. Compression ratios can be limited by coil size and cut-off pressure controls. A compression ratio of 6 to 1 is a good design guide.

(3) Liquid Floodback

Excessive floodback during the heating mode dilutes the compressor oil. Excessive floodback during defrost poses the additional hazard of carrying the oil out of the compressor. Floodback can be controlled by proper selection of accumulators.

(4) Low Ambient Operation

Typical compressor performance curves with 10° superheat are shown in Figure 10. Note that these curves are cut off at the limit of safe operating temperatures with this amount of superheat. At low ambient temperatures, the stresses resulting from high compression ratios can create excessive valveplate, motor, and oil temperatures.

In order to operate within safe limits at low ambients, it is necessary not only to reduce superheat to a minimum but actually to flood a controlled amount of liquid refrigerant to the compressor. The compressor protector is designed to trip and stop compressor operation should safe limits be exceeded.

CONCLUSION

Heat pump systems require compressors that will operate reliably under a wide range of conditions. Compressors with a proven record on air conditioning systems may be inadequate for heat pump systems.

Compressor design improvements described here, coupled with good system design will result in an effective and reliable heat pump.

HEAT PUMP OPERATING HOURS

CITY	COOLING	HEATING	TOTAL
NEW ORLEANS	1480	840	2320
MEMPHIS	1260	2030	3290
LAS VEGAS	2430	1570	4000
ST. LOUIS	1010	2990	4000
CHICAGO	580	3620	4200

FIG. 1

CONVENTIONAL AIR CONDITIONING RATING CONDITIONS

EVAPORATING TEMP. 45° F
CONDENSING TEMP. 130° F
AMBIENT TEMP. 95° F
RETURN GAS TEMP. 95° F

FIG. 2

HEAT PUMP "RATING" CONDITION

EVAPORATING TEMP. 30° F
CONDENSING TEMP. 110° F
AMBIENT TEMP. 47° F
LIQUID TEMP. 95° F
RETURN GAS TEMP. 40° F

FIG. 3

TYPICAL HEAT PUMP APPLICATION CONDITIONS

EVAPORATING TEMP. 5° F

CONDENSING TEMP. 95° F

AMBIENT TEMP. 20° F

RETURN GAS TEMP. 15° F

FIG. 4

SEVERE ENVIRONMENT HEATING CONDITIONS

EVAPORATING TEMP. -15° F

CONDENSING TEMP. 110° F

AMBIENT TEMP. 0° F

RETURN GAS TEMP. -5° F

FIG. 5

COMPRESSOR PRESSURE RATIOS

EVAP. TEMP.	COND. TEMP.	PRESS. RATIO
45°	130°	3.4
30°	110°	3.4
5°	95°	4.6
-15°	110°	8.6

FIG. 6

WORN ROD BEARING

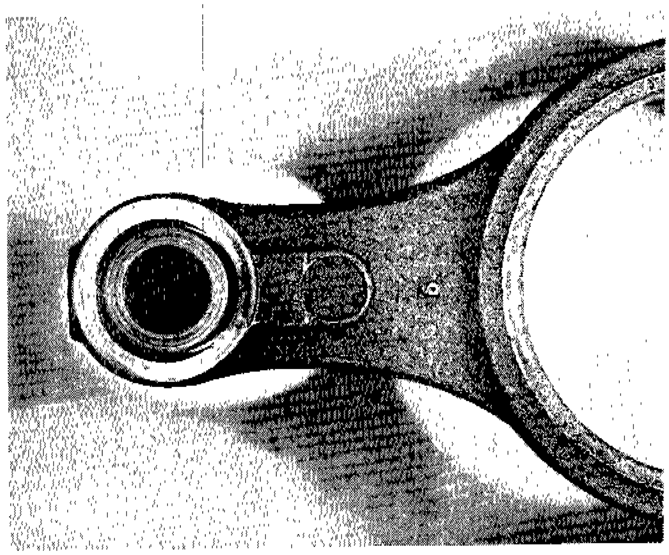


FIG. 7

VALVEPLATE WITH EXCESSIVE COKING

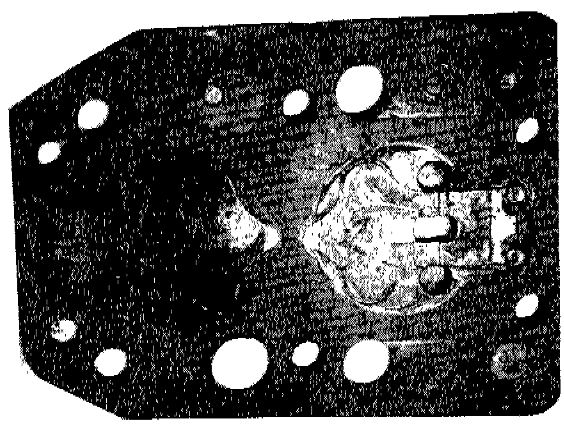


FIG. 8

MOTOR PROTECTOR CIRCUITS

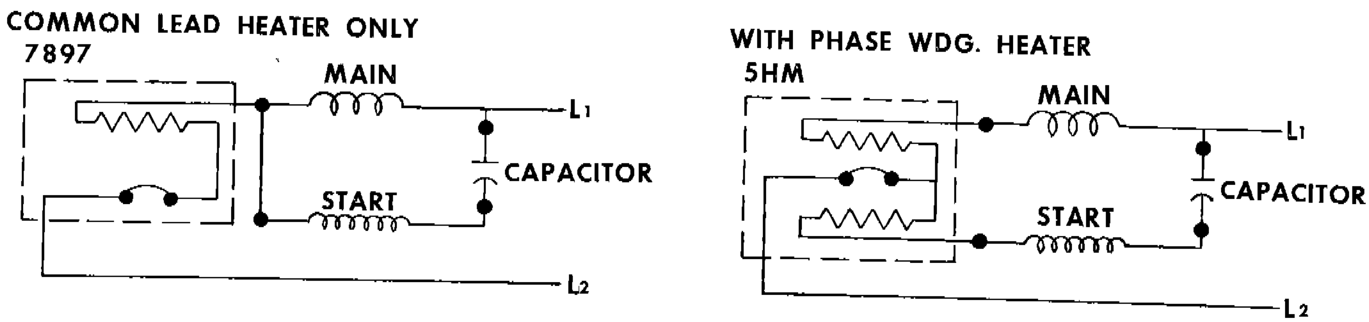
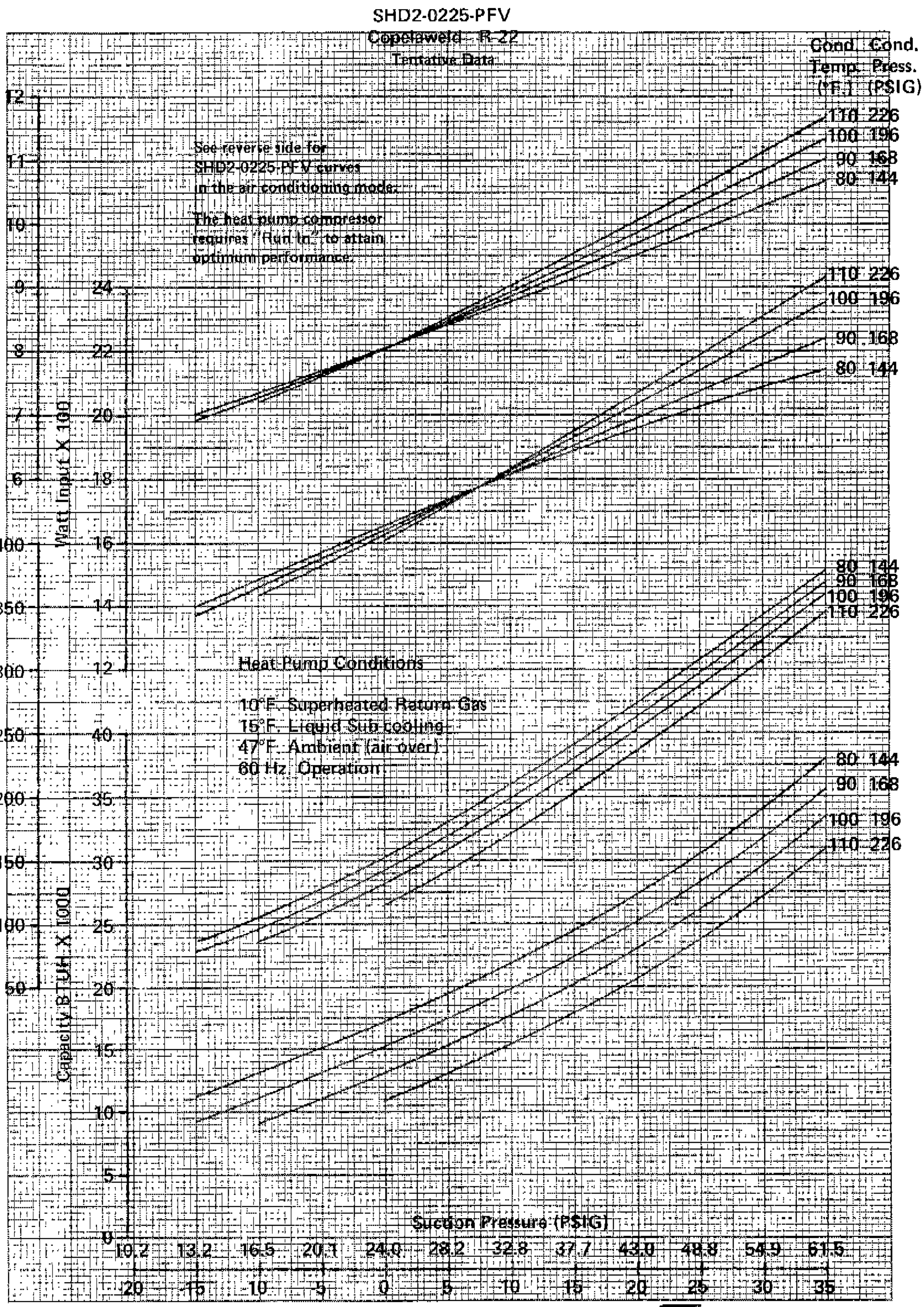


FIG. 9

HEAT PUMP PERFORMANCE CURVES



ION

SPECIFICATION NUMBER
76-16 Issued 1-76
(Supersedes 74-56)

Copeland®
COPELAND CORPORATION SIDNEY OHIO 45365

FIG. 10