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Northern China Heat Pump Application With the Digital Heating Scroll Compressor

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This paper addresses a low ambient heat pump application with the Digital Heating Scroll compressor. The Digital Heating Scroll compressor utilizes enhanced vapor injection technology and is an improved version of the earlier design of Digital Scroll compressor. The enhanced compressor design expands the system operating envelop to a much lower evaporating temperature area. At low ambient heat pump condition, the system still delivers excellent heating capacity, good efficiency and robust reliability. This new technology offers a reliable, comfortable and efficient heating solution for northern China heat pump application. Field test data at a Beijing apartment is presented.

Keywords: Digital Heating Scroll compressor, enhanced vapor injection (EVI), central AC heat pump

1. Introduction

Air conditioning industry grows rapidly in China. Majority of the air-conditioning units sold in China are heat-pump. Heat pump is widely used in southern and central part of China as a major heating device. In the north, where the weather is much colder, e.g., the lowest ambient temperature is below –15°C, the central boiler is the major heating source. Figure 1 shows the distribution of different heating technologies in China. The upper gray color is for central heating and the mid black color is for heat pump. With the rapid economy growth, the energy conservation and environment protection is becoming increasingly important in China. The China government plans to reform the charge scheme of the central heating. Currently the heating charge is a fixed amount determined by floor area for a whole winter season. In coming future, the heating charge will be calculated by actual usage. An efficient, comfortable and clean heating solution is in great need. It is well proven that the heat pump has those advantages. Firstly, heat pump combines heating and cooling systems together to save installation cost. Secondly, it is a much cleaner technology comparing to the current one (Central heating is provided by coal-burning thermo-plants).

Figure 1: Location Distribution of Heating Technology

The Digital Heating Scroll compressor is the improved version of existing Digital Scroll compressor. It is equipped with enhanced vapor injection technology (EVI). The Digital Scroll compressor has been well proven to have both high efficiency and robust reliability in the field. In addition to its efficiency and reliability advantages, the Digital Heating Scroll compressor is a custom-made design to provide an efficient, comfortable and clean heating solution for Northern China area.

2. The Digital Heating Scroll Compressor Design

2.1 The Challenge

For northern heat pump application, the compressor should be able to run in extremely low ambient temperature reliably for many years. When normal scroll compressor running at –15 °C ambient temperature, the highest allowed scroll temperature is 180°C, exceeding that maximum temperature the mineral oil can withstand (less than 150°C). If oil discomposes or charring occurs, the scroll could fail in a very short duration. Meanwhile, the normal scroll compressor can't provide sufficient heating capacity as required. The heating capacity at –15 °C is only 55% of its rated cooling capacity, much lower than demand.

There are some studies showing the EVI technology provides a good solution. EVI technology is similar to a two-stage cycle with inter-stage cooling. In a refrigeration cycle system, the high-stage of compression is accomplished by extracting a portion of the condenser liquid and expanding it through an expansion valve into a plate heat exchanger or flash tank acting as a sub-cooler. The superheated vapor is then injected into an intermediate vapor injection port in the scroll compressor, which helps reduce the scroll element temperature when it compresses the

very low-pressure suction gas. Also it can dramatically enhance the heating capacity by 20% and the EER by 14% at –15°C ambient temperature with R22 refrigerant. [1][2]

2.2 The Compressor Design

Figure 2 indicates the Digital Heating Scroll design. A Teflon tube with the fiberglass sleeve connects the outlet fitting and the scroll, acting as vapor injection path. Since the pressure drop for most of heat exchanger or flash tank is very low, the inter-stage pressure entering the scroll compressor vapor injection port depends mainly on the pressure drop between the HX (or flash tank) and the compressor injection port location. For good performance, this pressure drop should be minimized. [1] The smooth tube shape helps to minimize the pressure drop. Another Design consideration is the 1mm travel for the upper scroll motion during loading and unloading. With this motion the flexible tube connection the upper scroll to the compressor shell must withstand the 1mm displacement for tens of million cycles. This flexible tube is selected to withstand the fatigue stress for long life.

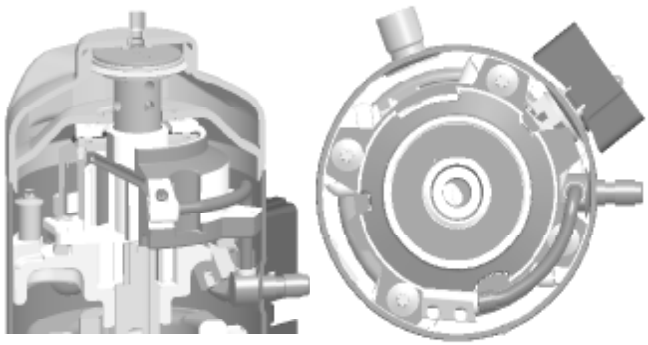

Figure 2: Digital Heating Scroll Design

As mentioned above, the compressor has to be reliable running in extremely low ambient temperature of –20 °C. For reliability consideration, the lowest evaporating temperature is down to –30 °C. Figure 3 is the operating envelop of the Digital Heating Scroll compressor with 15 years of design life.

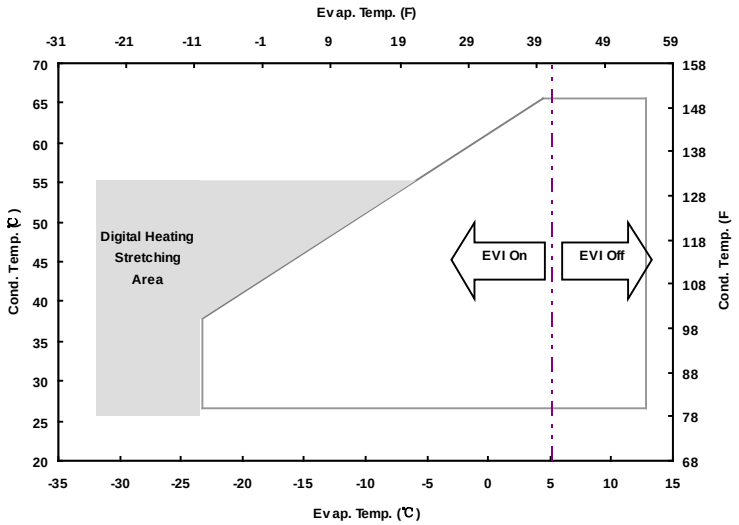

Figure 3: the Digital Heating Scroll Compressor Envelop

3. The Performance Of the Digital Heating Scroll Compressor

Figure 4 is showing the performance gain of the Digital Heating Scroll compressor at 45 °C condensing temperature compared to a Digital Scroll compressor. At –30°C evaporating temperature (-20 °C ambient temperature), the heating capacity is about 22% higher than non-vapor injection scroll compressor. The heating COP is 15% higher. The heating capacity gain is going up as the evaporating temperature going down.

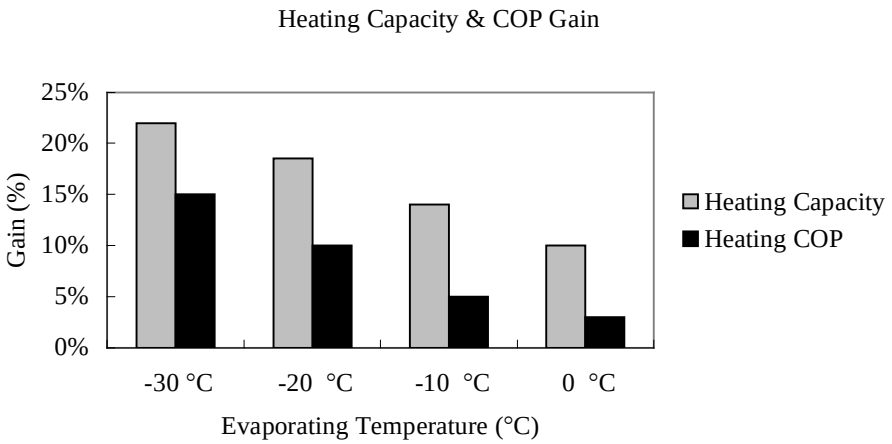

Figure 4: Heating Capacity Gain and Heating COP Gain (6HP, R22, 45°C CT, 8.3K SC, 5.6K SH, 50Hz)

As discussed above, EVI technology is the major contributor to enhance heating capacity and efficiency for the Digital Heating Scroll compressor. There are some other factors considered for performance improvement.

3.1 The Dynamic Reed Valve

When the compressor is running in a cold winter for heating, the compression ratio is much higher than the built-in geometry compression ratio of the scroll (under-compression). The high pressure at the top cap cavity allows reverse flow to the scroll at the moment that the discharge cavity opens to the discharge port, which causes increased compression work. In the Digital Heating Scroll compressor, a specific design dynamic reed valve is used to isolate the scroll discharge pocket from the top cap cavity. The valve only opens when discharge cavity pressure is higher than the outside pressure. This reed valve can also improve efficiency by 5% at –15°C outdoor ambient temperature. This efficiency improvement will be more at lower ambient temperature, <-15°C.

3.2 The Diameter and Length of Vapor Injection Path

The diameter and length of the vapor injection path is optimized for performance. If the volume of the injection passage is not big enough, the capacity gain can't be fully recognized. If it is too big, it will cause excessive re-expansion loss when vapor injection function is turned off.

3.3 The Vapor Injection Location

The location of vapor injection is another important parameter for performance optimization. A lower-pressure location generates more capacity gain while a higher-pressure location provides more efficiency gain. The final location is decided by considering both effects.

3.4 The Motor Design

The motor design of the normal air conditioning scroll compressor typically addresses the cooling requirements. In the motor design of the Digital Heating Scroll compressor, the light load condition is also taken into consideration to provide better motor efficiency for heating.

4. The Reliability Of the Digital Heating Scroll Compressor

As we know, the reliability is a big challenge for the compressor running at the extremely low ambient temperatures. The EVI technology could help to reduce scroll temp to safe level. While new reliability concerns arise with the EVI technology applied.

4.1 The Fatigue Stress Challenge

The vapor injection accessory is one of the moving components. The fatigue stress from the compressor start and stop cycle and the 1mm pop-off movement of the fixed scroll is a reliability concern. The flexibility design of the tube is intended to reduce the fatigue stress. Different life tests are designed to verify the reliability of the vapor injection accessory.

4.2 The Lubrication Failure Concern

As we know, extremely high scroll temperature will cause the break of the lubricant. There is another situation to cause lubrication problem. For example, when the compressor is running on the left corner of the envelope (-25/130F), only vapor injection is not sufficient to reduce the scroll temperature to safe limit and some liquid has to be injected to cool the scroll. When the vapor is injected into the scroll pocket, the oil sticking on the scroll element surface may be washed out or diluted. When the compressor is running at a low ambient temperature, the mass flow is quite small and the lubricant brought into the scroll cavity is limited. The lubrication is a concern even the scroll temperature is within safe level. In order to address this concern, two reliability tests are designed. The first is to inject some quantity liquid into the scroll sets to simulate the abnormal situation of 'wet' injection. The second is to simulate the scroll temperature marginally lower than its safety limit. It is proved that the Digital Heating Scroll compressor could withstand both the oil wash-away and the oil dilution challenge.

4.3 The Motor Design Challenge

When the compressor runs at the top left corner of envelop, the mass flow is very low. Even though the return gas temperature is relatively low, the motor may still encounter cooling issue. The Digital Heating Scroll compressor is used for cooling in high ambient temperature too, running at the top right corner of the envelope. There is a confliction for the motor protector design to satisfy both light load condition and high load condition. If the motor is designed too strong (saturated), then the current at light load condition may be too high, which will cause the protector trip too early. If the motor is too weak, it could not keep running at high load condition. This challenge should be considered especially in single-phase motor design. The motor and its protector combination are selected very carefully to ensure the compressor can run safely in the entire operating envelope.

4.4 The Flood Start Challenge

The flood start is always a challenge for compressor. It overloads the tube, the reed valve, the scroll elements and many other components. The Digital Heating Scroll compressor is with the compliance design for liquid handling to minimize the effect of flood start. All the components are designed carefully. And its reliability is proven by accelerated flood start life test.

A set of comprehensive reliability tests is developed to verify some important reliability test points, such as "high compression ratio", "maximum pressure difference" and "defrost condition" and so on.

5. The Field Application of the Digital Heating Scroll Compressor

After performance and reliability are confirmed by the lab study, a central AC (multi system) heat pump was built with the Digital Heating Scroll compressor and was installed in Beijing city of China for field test in the winter of 2005.

5.1 The Unit Design

The central AC heat pump system is the same as the normal heat pump system except the vapor injection accessories are added. The detailed unit design is shown in Figure 5. A receiver acts as the flash tank to provide the extra sub-cooling. Two electronic expansion valves control the vapor injection pressure and mass flow based on the

compressor running condition and discharge line temperature. A solenoid valve is used to switch on/off the vapor injection.

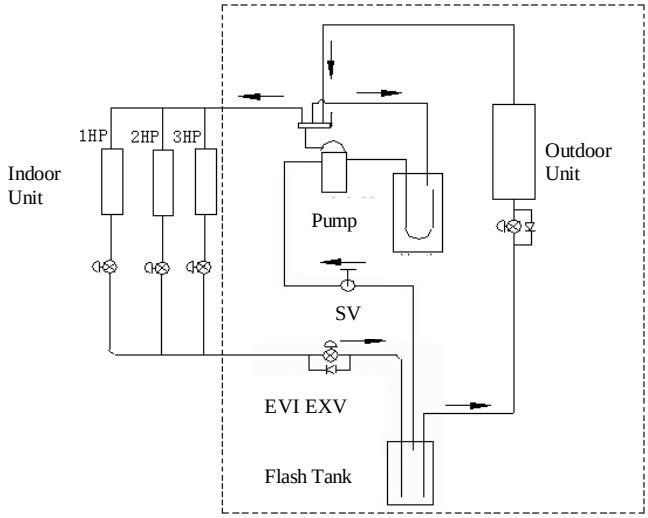

Figure 5: Central AC Heat Pump System Layout

5.2 The Field Test Results

Before field installation, the central AC heat pump system was tested in a certificated testing lab. The performance meets the expected heating capacity and high efficiency specification, as shown in Table 1.

Table 1: Performance Data of 6Hp Central AC Heat Pump with R22

	Outdoor Condition	Indoor Condition	Heating Capacity	Heating Capacity Gain	Heating COP	Heating COP Gain
	Dry-Bulb	Dry-bulb	(KW)	(%)	(W/W)	(%)
1	-3°C	20 °C	14.95	13.4%	2.50	0.7%
2	-10 °C	20 °C	12.80	21.0%	2.34	1.6%
3	-20 °C	20 °C	9.91	34.1%	1.94	6.0%

Two units were installed in an apartment with two floors. The refrigeration parameters were monitored. For the whole winter, all the room temperature can be maintained within comfortable range of 18~25 °C. The highest air temperature was 43 °C. The lowest ambient temperature during the testing period was -9.8°C with comfortable air outlet temperature at 38.9°C. The compressor was running stable and healthy at all time. Figure 6 is showing the Indoor and outdoor temperature history of 3 days.

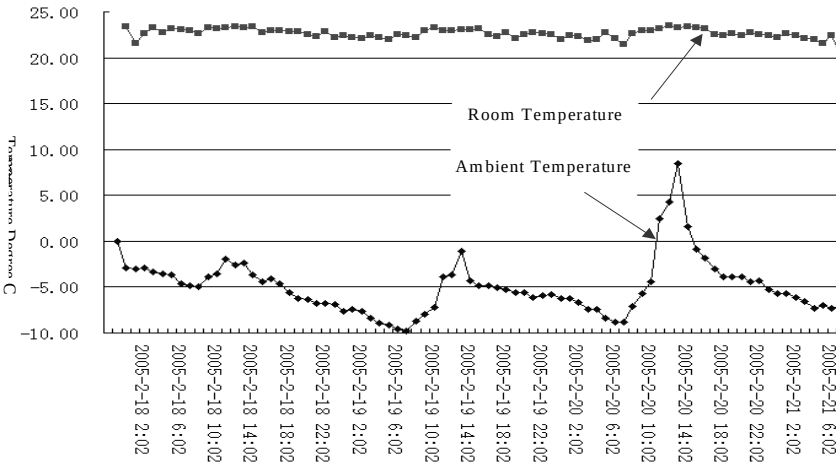

Figure 6: Room Temperature Vs. Ambient Temperature

6. Summary

The Digital Heating Scroll compressor is an improved design of the Digital Scroll compressor. The vapor injection technology and other optimized design modifications offer a versatile means for improving the heating capacity and efficiency and extending the operation envelop of the Digital Heating Scroll compressor. It provides a clean, comfortable and reliable heating solution with high efficiency for Northern China heat pump application. The compressor also has other application possibilities such as the heat pump water heater and low temperature refrigeration systems.

References:

[1] Warren L. Beeton, Hung M. Pham, 2003, Vapor Injection Scroll Compressor, ASHRAE Journal, April 2003, p. 1~2.
[2] Ma Guoyuan, Yan Qisen, 2003, Thermodynamic Behavior of Scroll with Economizer For Heat Pump, Refrigeration Transaction, March 2003, p.3~4.