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ABSTRACT

With the wide promotion of energy saving and environmental protection, the working efficiency of Room Air Conditioner (RAC for short) system become more and more important, in addition, to improve the function of RAC on the living comfort, the demand of heating capacity especially at low ambient temperature condition of RAC become a urgent issue needs to be resolved.

Firstly, the purpose of this paper was introduced. Then, the relative techniques like DC inverter, variable volume, gas injection were simply analyzed. Thirdly, a new coupling compressor with these three techniques to satisfy both high efficiency and heating capacity demands was indicated. Moreover, the detail design of the coupling compressor was described. At last, the prototype compressor was designed and assembled to validate the effect on RAC system.

According to the test result, this coupling compressor has significant effect on RAC system as we expectation. The maximum heating capacity increasing up to 185% by compare to the base system at -15℃ ambient temperature condition, which can reduce half time to achieve the same room temperature rising. Furthermore, the Annual Performance Factor (APF for short) efficiency of the RAC system increased by about 6%.

1. INTRODUCTION

Recently, with the advancement of RAC industry, people are focusing on the energy saving and the comfort function like high heating capacity of the RAC system. It is not too difficult to achieve high efficiency or high heating capacity for a RAC system. However, how to achieve both high efficiency and high heating capacity at one RAC system is still an important issue for the engineers.

There are different advanced techniques like DC inverter technique, variable volume technique and gas injection technique, etc. have been published for the RAC. Among these techniques, the DC inverter technique and gas injection technique have good effect on energy efficiency. For the heating capacity issue, when RAC system working at low ambient temperature condition, the evaporate temperature become very low which result in the low mass flow of refrigeration circulation, and then the heating capacity significantly decrease. In this case, the increase of running frequency and compressor displacement will make up the problem.

However, each single of these techniques has disadvantages like, the DC inverter technique has the limitation of maximum running frequency so that limit the heating capacity increase, the variable volume technique of the compressor has good heating capacity improvement but has the problem of low running efficiency, the gas injection technique has good efficiency but limited by the heating capacity increase and a uneconomic structure of the compressor and RAC system, etc.

2. THE PRINCIPLE AND SCHEMES OF COMPRESSOR

Refer to both the energy efficiency and heating capacity requirements of the RAC system, the target of the new solution has two parts, one is achieve good increase in system APF efficiency, the second one is the high heating capacity at low ambient temperature.

In order to satisfy both high efficiency and high heating capacity demands of the RAC system, a new compressor which we called coupling compressor will designed, it adopts all the DC invert technique, variable volume technique and gas injection technique in one compressor. This coupling compressor collecting the advantages while repairing the disadvantages of the three techniques which expected to has good effect on energy efficiency and significantly increases of heating capacity at low temperature at the same time.

2.1 The principle of DC inverter technique

There are two kinds of frequency conversion technique used in compressor, one is DC inverter technique, and another is AC inverter technique. The DC inverter technique is wildly used in compressor because of the better efficiency.

The principle of DC inverter technique is shown as figure 1. By the process of rectification, filtering and inverting, the power source 200V/50Hz will change to 3 phases with 120°difference rectangular wave current supply to the stator winding of BLDC compressor. With both the current and rotor location signals, the controller electrifies the 3 phase winding one by one to driving the motor in compressor.

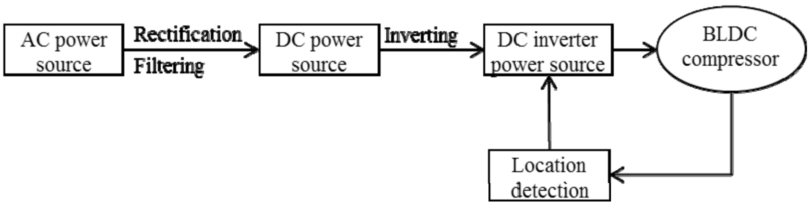

Figure 1: Principle of the DC inverter driver

The DC motor has higher efficiency than the fix speed motor. Furthermore, by the application of DC inverter technique, the compressor can adjust the power consumption by change the running frequency according to the RAC requirement to achieve high efficiency operation. This not only improves the efficiency of the air conditioner at different working conditions but also makes the room more comfortable with the stable room temperature.

2.2 The principle of gas injection technique

There are two popular gas injection designs for rolling piston compressor. The first one called Roller Rotation Control (RRC for short) as shown in figure 2: the gas injection valve set on the bearing surface, the open and close and anti-backflow of the gas injection is controlled by the position of the roller. The structure of RRC is very simply and without clearance volume makes it is easy application and high efficiency. However, the RRC structure is limited by the roller thickness.

The second one is the Check Valve Control (CVC for short). The gas injection valve is set on the cylinder nearby the discharge port. The valve open and close is controlled by the pressure difference of the valve. When the pressure in cylinder is lower than injection pressure, the valve open, the gas inject into cylinder. When the pressure in cylinder is higher than injection pressure, the valve close to prevent gas back-flow. The CVC has more injection quality than RRC. However, it has more complex structure, and the efficiency is affect by its clearance volume.

The principle of the gas injection is two-stage like refrigeration circulation as shown in Figure 3. The liquid refrigerant out from the condenser through the first expansion valve become the two-phase flow into the gas-liquid separator which is separated as gas and liquid. Hereinto, the liquid will go to the evaporator after the second expansion while the gas with middle pressure will directly inject into the compressive chamber of the cylinder.

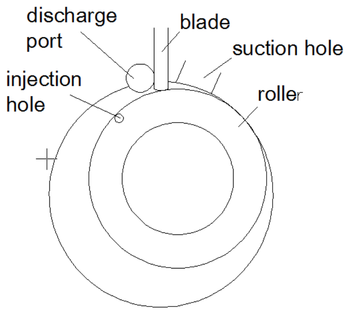

Figure 2: Diagram of RRC structure

In this gas injection process, the gas inject into the cylinder has middle pressure means the power consume to make this part of gas from the suction pressure to the middle pressure is avoid so that the circulation efficiency improving. In addition, because the gas from the gas-liquid separator is saturated gas which has lower temperature than the gas in compressive chamber, when these two kinds of gas mixed, the discharge temperature drops so that the compressor reliability improving.

According to the structure, by considering both the efficiency and reliability, we adopt the RRC and CVC design to the two cylinders in the compressor respectively.

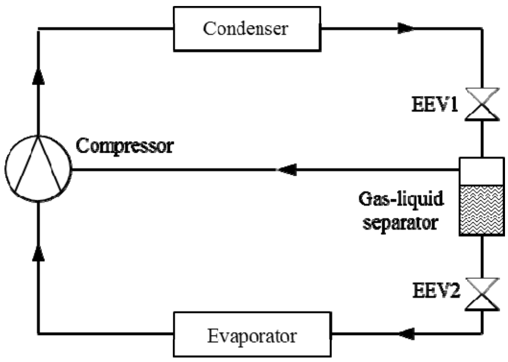

Figure 3: System schematic diagram and circling P-h drawing

By adjust the injection pressure and angle, the injection design is optimized to improve the gas quality inject into the cylinder. The injection quality can be calculated as the equation 1 below.

$$M_j = \alpha \times \frac{\pi d^2}{4} \times \sqrt{2 * \frac{p_j - p_0}{\rho}} \times \frac{\theta}{360 \times f} \tag{1}$$

Hereinto, M_j is the injection mass flow, p_j is the injection pressure, p_0 is the pressure in compressive chamber before injection, ρ is the gas density in compressive chamber before injection, α is the injection coefficient, θ is the injection angle, f is the running frequency of the compressor.

According to the equation 1, the injection quality has direct proportion to the injection port area.

The injection pressure calculates as below equation 2.

$$p_m = \sqrt{p_c \times p_e} \tag{2}$$

When $p_j > p_m$, the dryness in gas-liquid separator decrease, then the gas content reduce which may cause the risk of liquid injection. On the contrary, if $p_j < p_m$, the injection quality decrease which cause less effect on efficiency improve.

2.3 The principle of two cylinder variable volume technique

The variable volume technique means the compressor can adjust the working displacement at different conditions, it's usually using in a two cylinder rolling piston compressor. When system is working at low capacity condition, the compressor will working at one cylinder mode which we called partial volume model, here this working cylinder we called constant cylinder. When system is working at high capacity condition, the compressor will working at two cylinder model which we called full volume model, here the second cylinder we called alterable cylinder.

The alterable cylinder drawing is shown in Figure 4. There are two kinds of alterable cylinder control schemes, in both schemes, a pressure input which can switch to suction pressure or discharge pressure is necessary for the alterable cylinder.

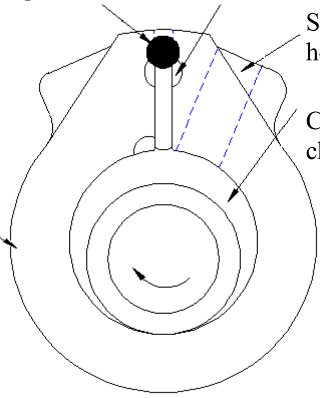

Figure 4: Drawing of alterable cylinder structure

For the first one, the alterable cylinder is controlled by the pressure change in the blade back chamber. Normally, it is necessary to add a blade hold component to fix the blade at the upper position. In this scheme, the blade back chamber must sealed from the pressure in the compressor case, when the pressure in the chamber is suction pressure, the alterable cylinder is idling while when the pressure in the chamber is discharge pressure, the alterable cylinder in operation condition.

In the second scheme, the alterable cylinder is controlled by the change the suction pressure, when suction normally, the alterable cylinder in operation condition while when suction hole connect to discharge pressure, the alterable cylinder unload. This scheme also needs a blade hold component.

2.4 Integrate design

According to the analysis above, the outlines of the integrate design include below points.

a. Adopted multi-increment design, combine the DC inverter technique, variable volume technique and gas injection technique together to improve energy efficiency and heating capacity at low ambient temperature conditions.

b. Different gas injection design for the two cylinders, the constant running cylinder use CVC injection design to enhance efficiency while the alterable cylinder applied the RRC structure to increase heating capacity. These two gas injections are using the same one injection supply path.

c. To achieve gas injection in alterable cylinder, the alterable cylinder adopted the variable volume scheme of change suction pressure as well as RRC injection with a non-return flap valve design. The non-return flap valve is to prevent back-flow in case of the alterable cylinder idling, when the pressure in alterable cylinder chamber is discharge pressure which is higher than injection pressure.

The two cylinders of the prototype compressor designed as equal displacement of 9.8 (cm^3/rev) to match a nominal 3500W cooling capacity room air conditioner using R410A refrigerant. This air conditioner used to applying a compressor with displacement of 10.8 (cm^3/rev).

The structure of the coupling compressor is shows in figure 5. The alterable cylinder is set as the lower cylinder. Compare to normal two cylinder compressor, there are two added small accumulator at the outside of compressor case, one is for the alterable cylinder and another one is for the gas injection. One head of the alterable cylinder accumulator connect to the cylinder suction hole and another head connect to the outlet of a three-way valve. The two input inlets of the three-way valve respectively connect to the main accumulator suction pipe and the compressor discharge pipe.

When the three-way valve input discharge pressure, the alterable cylinder is idling and its injection closed. However, the alterable cylinder and its gas injection are working if the three-way valve input suction pressure. The upper cylinder is a constant running cylinder so that the gas injection also at constant working status.

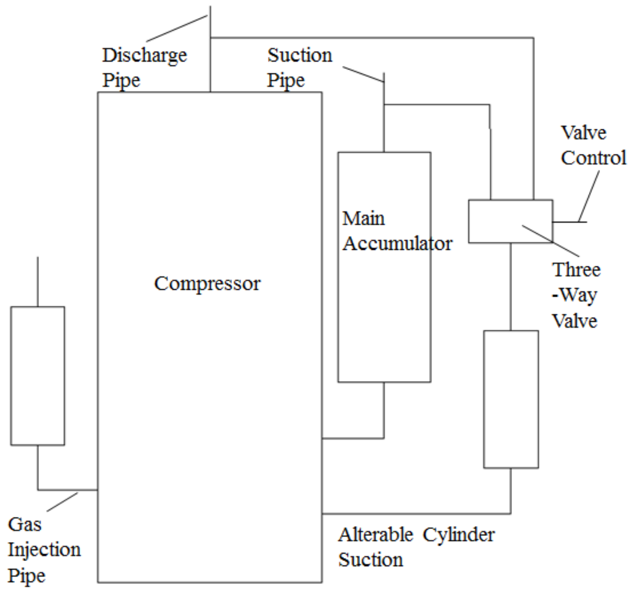

Figure 5: Diagram of coupling compressor structure

3. EXPERIMENTAL VERIFICATION

According to the design above, the prototype compressor is assembled. Firstly, the compressor performance was tested on the calorie meter. The result shows that this coupling compressor has equivalent performance (without gas injection) as the normal two cylinder compressor.

Then, we matched the coupling compressor and the normal two cylinder compressor on the same RAC system. The test conditions include the APF conditions and a super low temperature heating condition which are shown in table 1. At the RC, MC, RH, MH conditions, the compressor is working at partial model, at the LH and SLH conditions, the compressor is working at full volume model.

Two systems were tested, one is an original nominal 3500W air conditioner we called 35S which for the APF efficiency testing. When tested the SLH condition, because the prototype compressor has much bigger displacement than normal compressor used in 35S system, to release the heating capacity limit by the heat exchanger, we changed the condenser to a bigger one with 5100W capacity which was called 51S.

Table 1: APF testing conditions

Test Conditions		APF Conditions					Super Low temp. Heating (SLH)
		Rating Cooling (RC)	Middle Cooling (MC)	Rating Heating (RH)	Middle Heating (MH)	Low temp. Heating (LH)	
Indoor dry/wet temp.	℃	27/19	35/24	20/15	20/15	20/15	20/15
Outdoor dry/wet temp.	℃	35/24	27/19	7/6	7/6	2/1	-16/-15

The result of APF conditions as shown in figure 6. Compare to the result of normal two cylinder compressor one, the efficiency of all APF conditions were improved especially at the low temperature heating condition, the COP is about 22% higher than the base. After calculated, the APF efficiency improved 6% compare to the base one which means the coupling compressor has very good effect on the air conditioner system improvement.

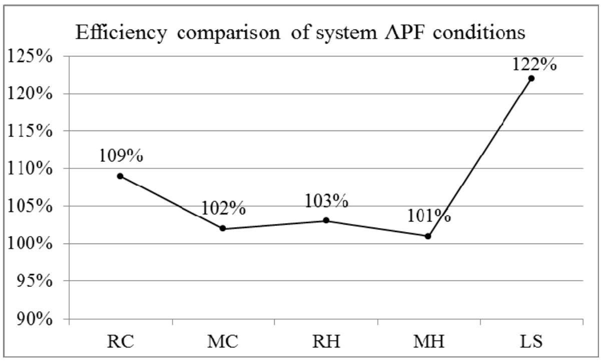

Figure 6: APF efficiency comparison

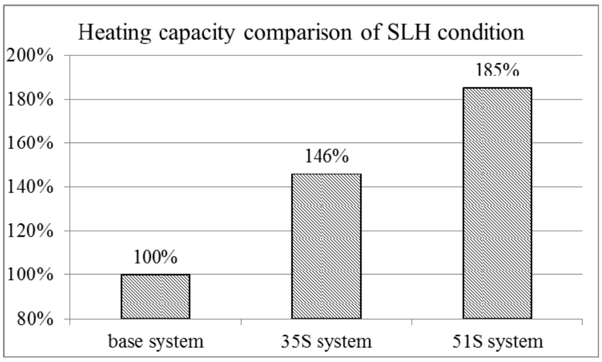

Figure 7: SLH condition comparison

The figure 7 shows the heating capacity result at SLH condition. Compare to the base system, when the system is 35S, the heating capacity improved about 46% while the 51S system was about 85%. This result means that for this coupling compressor, the condenser capacity of 35S is not big enough. In addition, when we test with the 51S system, the wind outlet temperature can up to 50℃ with enough air flow which will satisfy the heating requirement of the air conditioner customers. According to this result, we can apply this coupling compressor in a big system like 51S to obtain higher heating capacity, or match on the normal 35S system to achieve both high efficiency and high heating capacity.

4. CONCLUSIONS

According to the problem of the low heating capacity of room air conditioner especially at low temperature condition, as well as to satisfy the high efficiency requirement, this paper advanced a coupling compressor with DC inverter technique, variable volume technique and gas injection technique together, which can solve all the issues. The test result shows that, with this coupling compressor, the APF conditions efficiency of the room air conditioner system improves 6%, in addition, the maximum heating capacity increment of the system at -15℃ achieves about 85%, which has significant effect as the expectation.

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