INFLUENCE OF ELECTRONIC EXPANSION VALVE ON HEATING PERFORMANCE OF VEHICLE HEAT PUMP SYSTEM

by

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In this paper, based on the regulation characteristics of electronic expansion valve, an experimental platform is built for studying a vehicle heat pump system. Under an ultra-low temperature condition of –10 °C, the influence of the superheat setting value of the electronic expansion valve on the main heating performance parameters of the system is analyzed. The results show that when the superheat setting value of the main valve increases from 2 K to 8 K, the discharge temperature of the compressor increases, the heating capacity of the system decreases by 12.6%, and the compressor power decreases by 15.9%. When the superheat setting value of make-up valve increases from 15 K to 30 K, the discharge temperature of the compressor increases, the heating capacity of the system decreases by 17.7%, and the compressor power decreases by 22.0%.

Key words: *automotive heat pump, electronic expansion valve, superheat, heating performance*

Introduction

In recent years, the problems of energy security and environmental pollution have become increasingly serious, and pure electric buses have the advantages of energy saving and emission reduction, so they have received key national support and priority development. As the main power-consuming equipment of pure electric passenger cars, heat pump systems severely restrict the safety, reliability, cruising range and application range of the entire vehicle [1, 2]. The heat pump system of electric buses operates in a large temperature area all year round, especially when the system is running in a low temperature environment, not only is the energy efficiency ratio seriously attenuated, but there are also safety issues such as excessive compressor discharge temperature and discharge pressure [3]. By controlling the superheat setting value of the electronic expansion valve, the opening degree of the expansion valve is adjusted, and at the same time, the system refrigerant mass-flow is further effectively adjusted, so as to achieve matching working conditions and improve the heating performance and stability of the system [4]. Therefore, it is of great significance to study the regulation characteristics and control strategies of the electronic expansion valve of the heat pump system.

In response to these problems, many experts and scholars have conducted a lot of research, and much achievement was obtained. Choi *et al.* [5] studied the influence of electronic

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expansion valve and capillary tube on the heating performance of heat pump system, and found that the feedback adjustment of electronic expansion valve can accurately control the superheat degree and effectively improve the heat pump heating performance coefficient. Wang *et al.* [6] studied the influence of the electronic expansion valve on the heating performance of the electric vehicle CO_2 heat pump system under low temperature conditions, and pointed out that the opening degree of the electronic expansion valve needs to be comprehensively controlled by the compressor discharge temperature and superheat. A reasonable opening degree is to ensure that the system has the focus of efficient comprehensive performance. Beghi *et al.* [7] studied the regulation characteristics of the electronic expansion valve, and finally established the knowledge base and control rules for the superheat control of the heat pump system. Pan *et al.* [8] experimentally studied the effect of the electronic expansion valve on the defrosting characteristics of the heat pump system, and found that the electronic expansion valve with a larger valve port diameter has a better defrosting effect in the early stage. Li *et al.* [9] conducted an experimental study on the operation law of the electronic expansion valve of the heat pump system with supplemental air. Zhang *et al.* [10] experimentally studied the influence of the electronic expansion valve on the stability of the evaporator superheat, and finally obtained the minimum steady-state superheat curve of the electronic expansion valve. Qin *et al.* [11] studied the control strategy of the expansion valve of the CO_2 heat pump system and found that compared to the conventional superheat control method of the expansion valve, controlling the opening of the expansion valve through the exhaust temperature is much stable and effective. Li *et al.* [12] conducted an experimental study on the dynamic performance of a heat pump system using an electronic expansion valve, and the results showed that in the early heating process, setting the electronic expansion valve to a large opening can improve the system performance and heating capacity, but the opposite is true in the later heating process. Yan *et al.* [13] used an electronic expansion valve to control the evaporator outlet superheat, and studied the influence of the evaporator outlet superheat on the performance of automobile air conditioning, COP, and other parameters, the results show that the evaporator capacity increases with the decrease of the evaporator outlet superheat. Tao *et al.* [14, 15] also experimentally studied the influence of different electronic expansion valve control methods on the heating performance of the heat pump system. Pek *et al.* [16] used numerical-graphical method to optimize a heat pump heating system. Thermal response to sudden temperature change for the electronic expansion valve is also important for its safe operation, Liu, *et al.* [17] found that the thermal oscillation due to a sudden thermal shock, that is the temperature changes periodically. He *et al.* [18] studied the effect of a temperature jump on the fluid property. To control the temperature optimally, we need a control model [19, 20].

The aforementioned documents have all studied the influence of the electronic expansion valve on the performance of the heat pump system, indicating that the regulation characteristics of the electronic expansion valve directly affect the heating performance of the heat pump system. Our research group built a medium-pressure air-supplemented electric bus heat pump air-conditioning experiment platform based on R410A. Under ultra-low temperature conditions as low as –10 ℃, by changing the superheat setting value of the main circuit electronic expansion valve and the supplementary circuit electronic expansion valve, we will analyze the influence of the expansion valve superheat setting value on the system exhaust temperature, heating capacity, compressor power, and COP, so as to provide experimental data reference for subsequent product performance optimization [21-23].

System principle

The principle of the vehicle heat pump system is shown in fig. 1. The system consists of an electric compressor, an outside heat exchanger, an inside heat exchanger, a main expansion valve, a supplementary expansion valve, an economizer, an accumulator, a filter drier, a gas-liquid separator, and a four-way reversing valve, solenoid valve and one-way valve, *etc.* The working principle of the system is explained as follows. The high temperature and high pressure refrigerant vapor discharged by the electric compressor is condensed by the condenser in the car, and it flows to two circuits after the economizer. One circuit is to flow through the main circuit expansion valve, the evaporator outside the car, and the gas-liquid separator and then enter the compressor. The other branch circuit is throttled by the supplementary expansion valve and then flows through the economizer again. Finally, it enters the medium pressure supplementary port and merges with the main refrigerant compressed to the intermediate pressure. Finally, the merged refrigerant is compressed and discharged, completing a complete medium-pressure supplemental air heating cycle.

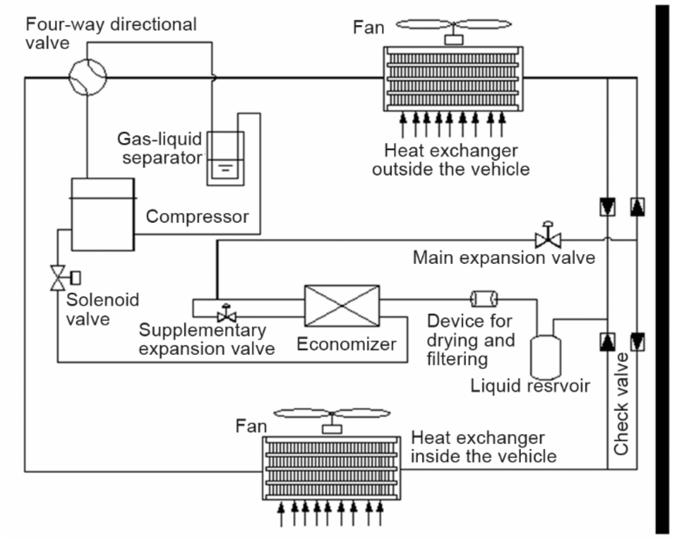

Figure 1. Principle of vehicle heat pump system

Test device

This experimental platform is built in the enthalpy difference laboratory, and the performance test of the vehicle heat pump system is carried out by using the air enthalpy difference method. The compressor used in this experiment is a fully enclosed DC variable frequency scroll compressor, and parallel flow micro-channel heat exchangers are used for the heat exchangers inside and outside the car, and a low-noise centrifugal fan is selected for the heat exchanger fan inside the car, and heat exchange outside the car. The fan adopts an axial fan that can operate in both directions. In this experiment, the temperature sensor and pressure sensor installed at the outlet of the evaporator and the exhaust port of the compressor are used to collect the superheat signal, and feedback adjustment is used to control the opening of the expansion valve. The main circuit and supplementary circuit electronic expansion valve body and driver are shown in fig. 2. The parameters of main circuit and auxiliary circuit electronic expansion valve are shown in tab. 1.

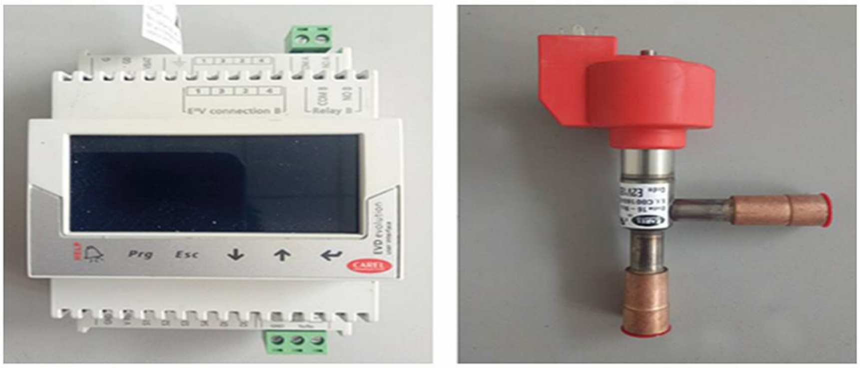

Figure 2. Valve body and actuator of electronic expansion valve

Table 1. Parameters of electronic expansion valve

	Model	Refrigerating capacity [kW]	Driver	Opening adjustment range [%]	Refrigerant
Main valve	E2V-24	21.7	EVD evolution	10~100	R410A
Make up valve	E2V-14	7.7	EVD evolution	10~100	R410A

Operating condition of test

In this experiment, we use China national standards GB/T-21361-2017 for Automotive Air Conditioner and QC/T 657-2000 for automotive air conditioning refrigeration equipment experimental method to select test conditions, as shown in tab. 2. According to the experiment of the refrigerant charge amount, the optimal charge amount of the system refrigerant R410A is determined to be 10.81 kg, and the compressor speed is 4000 rpm.

Table 2. System test conditions

Test conditions	Ambient temperature outside the car		Ambient temperature inside the car		Main valve superheat setting value	Compensation valve superheat setting value	Air supply mode
	Dry bulb temperature	Wet bulb temperature	Dry bulb temperature	Wet bulb temperature			
Ultra-low temperature heating	–10 °C	–	20 °C	15 °C	2 K	–	No air supply
					5 K		
					8 K		
	–10 °C	–	20 °C	15 °C	5 K	15 K	Air supply at medium pressure
						20 K	
						25 K	
						30 K	

Result analysis

Figure 3 shows the influence of the main valve superheat setting value on the compressor discharge temperature. It can be seen from the figure that as the main valve superheat setting value increases, the compressor discharge temperature increases. When the superheat setting values are 2 K, 5 K, and 8 K, the compressor discharge temperature is 91.8 °C, 97.2 °C, and 103.5 °C, respectively. Figure 4 shows the influence of the main valve superheat setting value on the heating capacity. It can be seen from the figure that as the main valve superheat setting value increases, the system heating capacity decreases. When the main valve superheat setting value changes from 2 K, the system heating capacity is reduced from 9.85-8.61 kW, a 12.6% reduction.

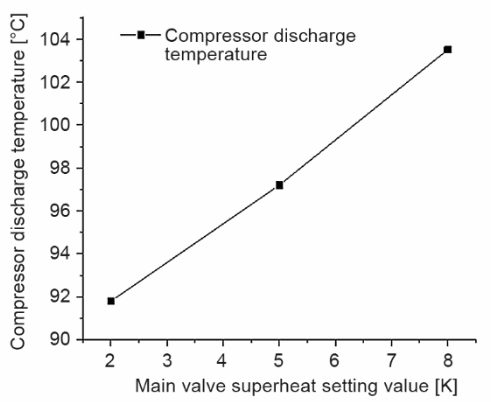

Figure 3. Influence of superheat setting value of main valve superheat setting value

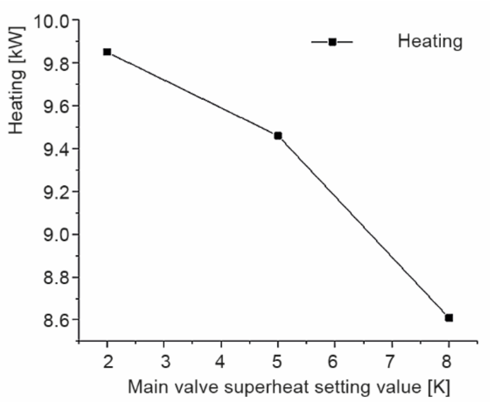

Figure 4. Influence of superheat setting value of main valve on heating capacity

Figure 5 shows the influence of the main valve superheat setting value on the compressor power. It can be seen from the figure that as the main valve superheat setting value increases, the compressor power decreases. When the main valve superheat setting value increases from 2-8 K, the system compressor power is reduced from 3.71-3.12 kW, a decrease of 15.9%. Figure 6 shows the influence of the main valve superheat setting value on the system COP. It can be seen from the figure that as the main valve superheat setting value increases, the system COP first increases and then decreases. When the main valve superheat setting value increases from 2-5 K, the system COP increases from 2.65-2.81, an increase of

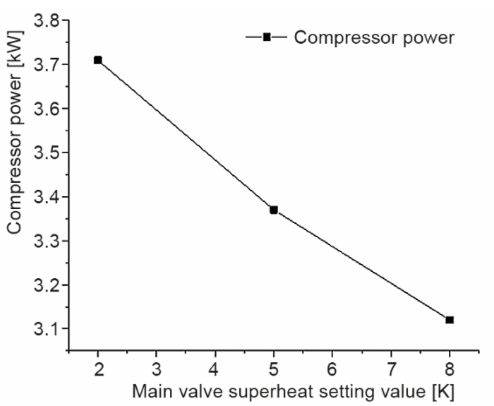

Figure 5. Influence of superheat setting value of main valve on compressor power

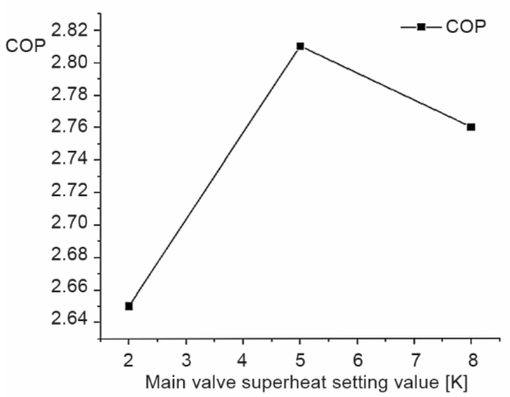

Figure 6. Influence of superheat setting value of main valve on COP

6.0%. When the main valve superheat setting value increases from 5-8 K, the system COP decreases from 2.81-2.76, a 1.8% reduction.

Figure 7 shows the influence of the set value of the compensation valve superheat on the compressor discharge temperature. It can be seen from the figure that with the increase of the main valve superheat setting, the compressor discharge temperature rises accordingly. When the valve superheat setting values are 15 K, 20 K, 25 K, and 30 K, respectively, the compressor discharge temperature becomes 74.98 ℃, 81.29 ℃, 86.34 ℃, and 89.51 ℃, respectively. Figure 8 shows the influence of the superheat setting value of the compensation valve on the heating capacity. It can be seen from the figure that as the setting value of the compensation valve superheat increases, the system heating capacity decreases. When the main valve superheat setting value changes from 15-30 K, the system heating capacity is reduced from 11.57-9.22 kW, a decrease of 17.7%.

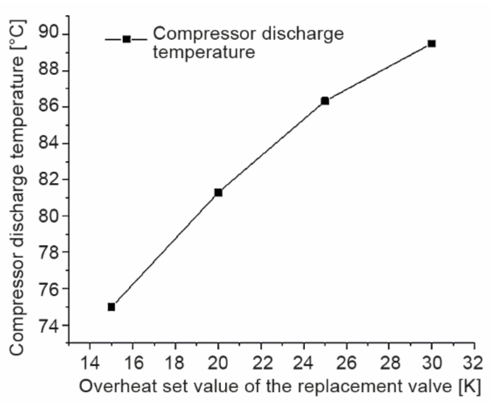

Figure 7. Influence of superheat setting value of make-up valve on exhaust temperature of compressor

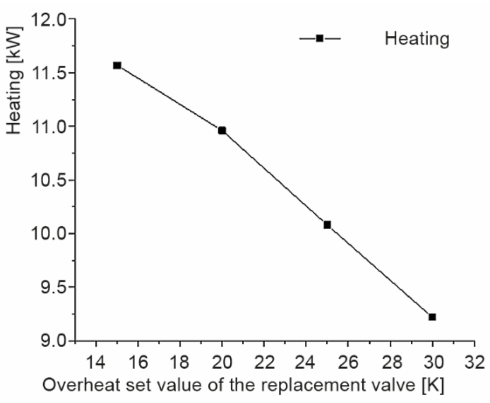

Figure 8. Influence of superheat setting value of make-up valve on heating capacity

Figure 9 shows the influence of the superheat setting value of the compensation valve on the compressor power. It can be seen from the figure that as the setting value of the compensation valve superheat increases, the system compressor power decreases. When the

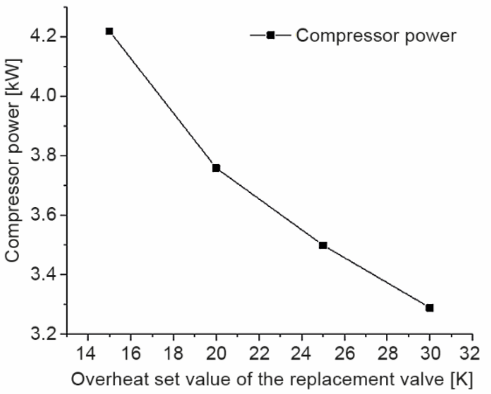

Figure 9. Influence of superheat setting value of make-up valve on compressor power

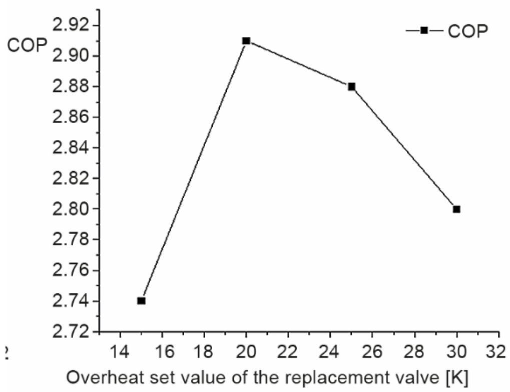

Figure 10. Influence of superheat setting value of make-up valve on COP

main valve superheat is set from 15-30 K, the system heating capacity is reduced from 4.22-3.29 kW, a reduction of 22.0%. Figure 10 shows the influence of the set value of the compensation valve superheat on the system COP. It can be seen from the figure that as the set value of the compensation valve superheat increases, the system COP first increases and then decreases. When the compensation valve superheat setting value increases from 15-20 K, the system COP increases from 2.74-2.91, an increase of 6.2%. When the compensation valve superheat setting value increases from 20-30 K, the system COP reduces from 2.91-2.8, a decrease of 3.8%.

Conclusion

This paper uses a pure electric passenger car heat pump air conditioning system, under different electronic expansion superheat setting value control methods, the system heating performance is systematically tested, the main conclusions are as follows.

- When the main valve superheat setting value increases from 2-8 K, the compressor discharge temperature rises accordingly, the system heating capacity reduces by 12.6%, the compressor power reduces by 15.9%. When the main valve superheat setting value is 5 K, the system COP reaches the maximum value of 2.81.
- When the superheat setting value of the compensation valve increases from 15-30 K, the compressor discharge temperature increases, the system heating capacity decreases by 17.7%, the compressor power decreases by 22.0%. When the set value of the compensation valve superheat is 20 K, the system COP reaches the maximum value of 2.91.
- The heating performance of the system can be effectively improved by adjusting the superheat setting value of the expansion valve. When the main valve superheat setting value is 5 K and the compensation valve superheat setting value is 20 K, the system heating performance reaches its optimal condition.

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