Experimental Study on HVAC System for Electric Vehicles

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Abstract

An HVAC (heating ventilation and air conditioning) system for electric vehicles based on heat pump technology is designed and set up in this paper. Unlike the existing HVAC system for vehicles using fossil fuel, this experimental HVAC system can work in heat pump mode rather than directly heating the PTC thermistor by electricity when heating is needed. This experimental HVAC system takes use of parallel flow exchangers, enclosed DC vortex compressor and the low voltage DC speed controller, which is used for controlling the compressor’s working frequency. After the experimental system is set, the influence of compressor’s speed and the environmental temperature to the performance of the HVAC system are tested and researched in refrigeration mode and heat pump mode respectively. Parameters like the compressor’s power input, the system’s refrigeration/heating capacity, and the coefficient of performance (COP) varied with compressor’s speed are recorded. Curves of those parameters are drawn and the reasons of their changing trends are analyzed respectively. The testing results of this experimental HVAC system are compared with references’ results. According to the testing results, this experimental HVAC system can achieve better refrigeration and heating effects, and the cooling performance of the system increases with compressor speed; Part of the outside heat-exchanger gets frosted when the system works in heat pump mode, but the COP remains greater than 1, which means this experimental HVAC system is more energy-saving than the existing HVAC systems which are directly heating PTC thermistor by electricity for heating; In addition, compared with the sliding-vane compressor, the vortex compressor used in this paper has a better comprehensive performance and hence has a better application prospect.

Keywords: HVAC System for Electric Vehicles; Experimental Research; Vortex Compressor; Heat Pump; Energy Saving

1. Introduction

As the energy crisis problems and environmental problems increasingly draw people’s attention as each day passes by, the development of automobiles using fossil fuel faces more and more challenges. At the same time, the position of automobiles in both transportation and daily life is rising gradually [1]. Electric vehicles attracts the worldwide attention because it not only has no air pollution and low noise, but also can reduce fossil fuel consumption [2-5]. In order to ensure the driving safety and riding comfort of electric vehicles, it is necessary to develop HVAC system suitable for electric vehicles. However, the HVAC system for electric vehicles differs from the HVAC system for common automobile using fossil fuel on these two aspects: First, the latter one’s compressor is driven by the car’s engine through the belt, while the former one’s compressor is driven by the battery individually, its speed thus has nothing to do with the running speed of the vehicles itself; Second, the latter one can use engine’s waste heat for heating or defrosting, while the former one has no waste heat to use, so that it faces greater difficulties in heating mode.

In order to promote the application of electric vehicles and to reduce environmental pollution, it is important to research how to improve battery’s capacity and develop efficient energy storage battery, as well as reduce the energy consumption of the electric car’s accessory equipment [6]. The HVAC system consumes the second most energy except for the engine, so undoubtedly reducing its energy consumption is the most urgent and effective measure to take. In order to reduce energy consumption of HVAC system for electric vehicles, the key point is to develop compressors which have lightweight and high efficiency [7]. In addition, the problems of the existing HVAC system for electric vehicles like having no heating function or having rather low heating efficiency are severe. Aiming at these problems,
this paper carried out the research on HVAC system used in electric vehicles based on enclosed vortex compressor and parallel flow heat exchangers, and some useful conclusions are obtained.

2. HVAC system setup

In order to test and research the performance of the HVAC system for electric vehicles, an HVAC system for electric vehicles based on heat pump technology is designed and set up in this paper. Unlike the existing HVAC system for vehicles using fossil fuel, this experimental HVAC system for electric vehicles can work in heat pump mode when it is needed for heating. This experimental HVAC system takes use of the enclosed DC vortex compressor and the low voltage DC speed controller, which is used for controlling the compressor’s working frequency. Other than the vortex compressor, this experimental HVAC system took use of parallel flow heat exchangers, H type expansion valves and a four-way valve.

2.1. Operating principle

The schematic of this experimental HVAC system is shown in Figure 1. As shown in figure 1, this experimental HVAC system is divided into refrigeration and heating modes. In refrigeration mode, the four-way valve is powered off, the high-pressure entrance-D is connected to exit-C, when the working medium comes out from the compressor, it enters the outside heat exchanger-8 (works as condenser in refrigeration mode), becomes condensed and releases its latent heat outside environment, after that, because of the check valve-7, it can only come into the expansion valve-3, becomes throttled and expanded, then it enters the inside heat exchanger-1 (works as evaporator in refrigeration mode), gasified and absorbs the heat of the inside cabin, then it finally gets back into the compressor; In the heating mode, the four-way valve is powered on, and the entrance-D is connected to exit-E, so when the working medium comes out from the compressor, it enters the inside heat exchanger-1 (works as condenser in heat pump mode) first, becomes condensed and releases latent heat to the inside cabin, after that, because of the check valve-2, it can only goes into the expansion valve-6, gets throttled and expanded, then enters the outside heat exchanger-8 (works as evaporator in heat pump mode) and evaporated, then comes back into the compressor and finishes the heating cycle.

![Figure 1. Schematic of the experimental setup](image)

2.2. Vortex compressor and controller

This HVAC system took use of the vortex compressor, which was mainly formed by static vortex disk, dynamic vortex disk, frame, cross slip ring and crankshaft, etc. The basic structure is shown in Figure 2. The dynamic and static vortex disk keep an eccentric distance when installed, and each forms a series of same crescent volumes after geared. These crescent volumes change their dimensions periodically as the dynamic vortex disk rotates, and the suction, compression and exhaust process are realized [8]. As
compressor works, gases in each crescent volume are compressed along the vortex type line. Vortex line types such as the circle involute, the spiral of Archimedes, variable cross section are widely seen, and the circle involute vortex line type is extensively used because it is easily machined and has good performance [9]. Considering that the performance of the compressor is greatly influenced by its speed [10], this paper took use of speed adjustable enclosed vortex compressor, which can dynamically changes its speed according to heat load, and has advantages of high volumetric efficiency, compact structure, light weight, and low operation noise, etc.

The compressor’s speed is controlled by low voltage DC speed controller, which takes advantage of technology of DC motor frequency conversion, and needs no inverter link, so it can save more energy compared with AC frequency conversion technology. The rotor of DC motor is permanently magnetic, so it can dispense the current consumption generally caused by the rotor of three-phase AC asynchronous motor. Therefore, the power factor from the power supply to the motor of DC speed controller is higher than AC frequency speed controller, and more energy will be saved with the appliance of the low voltage DC speed controller [11]. Besides, the compressor can be driven by 24V/48V DC power, which can be supplied by the on-board batteries, hence the inverter and the transformer can be omitted. By this way, not only the complexity and energy consumption of this HVAC system is decreased, but also the safety in operation is improved.

![Structure of vortex compressor](image)

**Figure 2.** Structure of vortex compressor

### 2.3. Other components

Both the inside and outside heat exchangers are parallel flow heat exchangers, which are of high thermal efficiency, compact structure and light weight. The HVAC system also takes use of the H type expansion valves, which can match load demands by fine tuning the valve opening size, which is closely relevant to the throttling temperature and pressure. Above all, all parts of this HVAC system have been vastly produced, which means the cost can be controlled and the large-scale production can be ensured in the future. The photo of the experimental HVAC system is shown in Figure 3.
3. Testing conditions and procedure

The test was carried out in the standard enthalpy difference laboratory by testing the import and export air enthalpy difference, and the precision of temperature is controlled by ±0.2 °C. During the test, the air volume of inside and outside heat exchanger is 220m³/h and 2000m³/h respectively. The working medium of this experimental system is R134a. Considering that the COP is influenced by the environmental condition, and after referring the industry standard like QC/T657-2000 “Automotive air conditioning refrigerating unit testing method” and QCT656-2000 “Automotive air conditioning refrigerating unit performance requirements” and GB7725-2004 “Room air conditioner” and so on, this paper adopts test conditions shown in Table 1. In each temperature, the compressor’s speed is changed from 1800 r/min to 3600 r/min in turn, and testing points are set at every other 300 r/min. When the enthalpy potential laboratory temperature meets balance, parameters like the compressor power input, the Capacity of Refrigerating/Heating, and COP are tested and recorded, and the curves of these parameters are drawn.

<table>
<thead>
<tr>
<th>inside dry/wet bulb temperature</th>
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<td>27°C/19°C</td>
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4. Results and discussion

Figure 4 shows the refrigeration capacity varied with the compressor speed in different outside dry bulb temperatures. As shown in Figure 4, the refrigeration capacity increases with the compressor speed, in addition, the refrigeration capacity decreases with the outside temperature at a certain compressor speed.

Figure 5 shows the COP of refrigeration. As shown in Figure 5, the COP of refrigeration increases with the compressor speed. Because the mobility of the working medium inside the heat exchanger increases with the compressor speed, when the compressor speed increases, the turbulent effects inside the heat
exchanger is strengthened, and the heat exchanging efficiency is promoted, hence the COP is increased.

![Figure 4. Refrigeration capacity varied with compressor speed](image)

![Figure 5. Refrigeration COP varied with compressor speed](image)

Figure 6 shows the COP of this experimental HVAC system using vortex compressor compared with the COP of system using sliding-vane compressor [12]. As shown in Figure 6, in the first half of the curve when the compressor speed is low, the COP value of vortex compressor is slightly lower than that of sliding-vane compressor, and the difference decreases as compressor speed increasing. When compressor speed reaches approximately 2600 r/min, the COP values of those two compressors are equal. As compressor speed continuously increased, the COP value of sliding-vane compressor gradually slows down increasing and eventually remain unchanged, while the COP value of vortex compressor keeps linearly increasing. The trend of the curves is resulted from the structure characteristics of the compressor itself. As for the vortex compressor, the leakage clearance between the dynamic and static vortex disk is longer than the sliding-vane compressor, hence the time used for compressing gas is longer when the compressor works in a low speed, as a result, the internal leakage is larger than the sliding-vane compressor. However, as the compressor speed increasing, on one hand, this decreases the internal leakage and increases the compressing efficiency of the vortex compressor, because the time of compressing is shortened; on the other hand, for the sliding-vane compressor, the friction between the sliding vane and the wall increases dramatically as the compressor speed increases. Moreover, when the sliding-vane compressor reaches a certain speed, the power input are mainly turned into friction heat, which donates nothing good for COP promotion, even destroys the compressor as the friction heat accumulated. In a word, compared with sliding-vane compressors, the vortex compressor can achieve better performance at higher compressor speed.
Figure 6. COP comparison of different compressors

Figure 7 shows the heating capacity varied with the compressor speed in heat pump mode. As can be seen from Figure 7, the heating capacity increases with the compressor speed at first, after that, when the compressor speed reaches about 2400r/min, the heating capacity stops increasing. It also can be seen from the figure that the heating capacity increases with the outside temperature at a certain compressor speed. The increasing stagnation of the heating capacity is mainly because of the frosting on part of the outside heat exchanger surface. The outside heat exchanger works as evaporator in heating mode. The R134a temperature of throttling decreases as compressor speed increased, and the R134a gets into the evaporator after throttling. As a result, the surface temperature of outside heat exchanger decreases as compressor speed increases. When the surface temperature gets lower than the frosting temperature, there will be frosting on the surface of outside heat exchanger. At the end of the curves, the heating capacity approximately remains constant, because after frost is coagulated, the evaporator heat exchanging efficiency is mainly affected by the thermal resistance of frost layers, and increasing compressor speed contributes little to heat exchanging efficiency.

Figure 7. Heating capacity varied with compressor speed

Figure 8 shows the heating COP varied with the compressor speed. The heating COP declines with the compressor speed at the end of the curves, because the heating capacity remains unchanged when the compressor speed is higher than 2400r/min while the power input of the compressor increases severely. It also can be seen from the Figure 8 that when the compressor speed is low, the COP remains greater than 1 after all, even though part of the outside heat exchanger is frosted. This shows that heating by heat pump has lower energy consumption than by directly heating PTC thermistor with electricity. Furthermore, the compressor of HVAC system for electric vehicles is directly driven by car battery, namely the compressor rotating speed is not connected to the driving speed, hence the compressor speed
can be set on an optimal value, which maximizes the heating COP.

![Graph showing Heating COP varied with compressor speed](image)

**Figure 8.** Heating COP varied with compressor speed

5. Research prospect

For compressor controlling, taking use of DC variable frequency technology and intelligent sensor control system, which can make compressor speed dynamically changed with vehicles’ inside heat load, is a developing trend. Parallel flow heat exchanger can obtain good performance when works as condenser in HVAC system for electric vehicles, but it is easily frosted when works as evaporator. Researching on how to advance the anti-frosting capability and keep the COP at a high level is an important direction in the future. In order to relieve frosting problem in HVAC system, some measures can be taken, for example, adding defrost operation circuit, changing the outside heat exchanger structure to facilitate the discharging of condensed water and researching anti-frost fin coating materials, etc. In addition, study on applicability matching of compressor and heat exchanger, maximizing the performance capability of compressor and heat exchanger should also be conducted.

6. Conclusions

An experimental HVAC system for electric vehicles based on enclosed vortex compressor and parallel flow heat exchangers is set in this paper, and low voltage DC speed controller is utilized to control the compressor speed. The working performances varied with compressor speed in different environmental temperatures are tested in a series of outside temperatures, and the conclusions are as follows:

1. The experimental HVAC system in this paper can achieve effective refrigerating, and the COP of refrigeration increases with compressor speed. When the outside dry/wet bulb temperatures are 30°C/20°C respectively and the compressor speed is 3600r/min, the COP of refrigeration reaches 2.1, which is 30% higher than values from references.

2. In heating mode, part of the outside heat exchanger is frosted when the compressor speed is rather high, but the COP value of heating can be bigger than 1 regardless of frosting. Considering that the compressor speed of HVAC for electric vehicles is independent from the running speed of vehicles itself, the compressor speed can be controlled in optimal level, so heating by HVAC system has lower energy consumption than by wildly used method that directly heating PTC thermistor with electricity.

3. The COP of enclosed vortex compressor utilized in this paper linearly increases with compressor speed. Though the COP of vortex compressor is slightly lower than the COP of sliding-vane compressor when the speed is rather low, the former is higher than the latter when compressor speed reached higher than 2600r/min, and the amount of the difference increased as compressor speed. Hence, from this point of view, the vortex compressor has a better application prospect than the sliding-vane compressor.
7. Acknowledgements

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8. References