DESIGN AND PERFORMANCE ANALYSIS OF MOTOR PHASE CHANGE HEAT STORAGE HEAT PUMP SYSTEM FOR NEW ENERGY VEHICLES

by

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Original scientific paper
https://doi.org/10.2298/TSCI2402287D

Based on the work of air conditioners for new powerful cars, the author created a heat pump air conditioner with various functions, such as cooling and heating passengers, cooling and preheating the battery, defogging, defrosting, and PTC heating. Developed basic components of AC heat pumps such as scroll compressor model, running condenser model, combined evaporator model, plate evaporator extended valve model, and radial basis function neural network model for predicting compressor volumetric efficiency and isentropic efficiency. The accuracy of the gas-flow, gas-flow, and plate evaporator simulation model was verified. The maximum error between the experimental and simulated values of compressor power, heat exchanger, and system COP in various operating models is 0.34~10.09, which is consistent with the experimental results. correct and can be used for ventilation pump research. Also, an operational simulation analysis platform was used to analyze the performance of the heat pump and study the system characteristics. It is clear that this system provides more warmth to the occupants in the defrost mode, and current research on the operation of the air conditioning pump is based on the first law of thermodynamics.

Key words: *new energy vehicles, motor phase change heat storage, analysis, performance analysis platform*

Introduction

In the mid-20th century, the environmental damage and fuel consumption exceeded demand, which prompted people to rethink the use of new energy cars and re-focus on developing new energy sources.In the coming decade, major advances in propulsion and electrical technology will continue to support the development of new energy vehicles. Energy consumption is one of the most important factors in the automotive sector, and the design of new energy vehicles is simpler than conventional petrol cars [1]. Because cars no longer have internal combustion engines, it means that they no longer require any fuel injection systems, complex engine control mechanisms, and peripheral devices connected to the engine and transmission, which reduces the number of components and enhances the reliability of the entire vehicle. On the other hand, compared to internal combustion engines, drive motors have higher efficiency. The overall efficiency of power transmission from the battery to the drive shaft of the drive motor is about 70%, while the efficiency of traditional internal combustion engine vehicles transmitting power to the wheels is only 5-10% [2].

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For developers of electric vehicle air conditioning systems, analyzing and designing through experiments requires a significant amount of time and cost, and some extreme operating conditions are extremely difficult to achieve through experiments. Therefore, currently, most designers use simulation methods to study the performance of air conditioning systems under different operating conditions. However, there are relatively few simulation platforms for electric vehicle air conditioning systems, most of the simulation studies are focused on a single passenger compartment cooling mode.

Literature review

For new energy vehicles, batteries and motors have replaced traditional engines, which makes it impossible for them to use engine waste heat for heating in winter. Therefore, new heating methods need to be adopted, and compressors cannot be driven by the engine anymore [3]. Therefore, it is necessary to replace compressors that can be driven by electricity, in order to adapt to these changes, researchers have proposed different structural forms of air conditioning systems. Currently, there are mainly several forms of air conditioning systems for new energy vehicles. Piao *et al*. [4] proposed a steam jet heat pump that utilizes an electric motor to exhaust hot air and ambient air. This system is applied to pure electric vehicles to improve the excessive energy consumption of the air conditioning system when the ambient temperature is below –15 °C, thereby affecting the vehicle's driving range. Mehrpooya [5] have developed a new integrated system for solar renewable hydrogen production, power generation, and hot water, and have conducted a precise thermodynamic evaluation. The structure developed consists of a four step CuCl thermochemistry cycle and an ORC cycle to generate electricity. The heat required is provided by centralized solar power station and latent heat based heat storage. Yu *et al*. [6] proposed a new hybrid power generation system that combines DG with compressed thermal energy storage (CHEST) using sensible and latent energy storage. Due to the waste heat recovery of exhaust gas and cooling water, the overall efficiency of the proposed system can be further improved.

The core component of PTC electric heaters is a positive temperature coefficient thermistor. When the temperature exceeds a certain level, the resistance value will increase step by step, and when the ambient temperature decreases, the resistance value also decreases, leading to an increase in heat generation. This characteristic makes PTC electric heaters energy-saving. At present, the PTC electric heater system mainly has two forms: air heating and water heating. In terms of structure, the system replaces the heating core in the air conditioning box of the traditional automobile air conditioning system with the PTC electric heater. Other structures remain unchanged, but the temperature of the air heated by the PTC air heater is high, and the thermal comfort is poor. Because of its high working voltage, there is a potential safety hazard when placed in the air conditioning box [7]. The air outlet of the PTC heater is more gentle than that of the air heating PTC heater, and the thermal comfort is better. In addition, the high voltage water heating PTC heater does not need to be placed in the air conditioning box, which is safer. At present, many new energy vehicles at home and abroad, such as TESLA MODEL S, Fox, BYD Qin*, etc.*, use PTC heaters for heating, and scholars at home and abroad have conducted a lot of research on PTC heaters.

On the basis of the current research, developed the basic components of air conditioning heat pump, such as vortex compressor model, running condenser model, combined evaporator model, plate evaporator extension valve model, RBF neural network model, used to predict the compressor volume efficiency and equientropy efficiency, verify the gas-flow, gas-flow, the accuracy of the plate evaporator simulation model.

Design of a phase change heat storage heat pump system for electric motors in new energy vehicles

Research on functional requirements of motor phase change heat storage systems for new energy vehicles

The working environment of the motor phase change heat storage system is complicated, and it is related to many working conditions a new type of electric vehicle, which has the function of cooling and heating of the passenger cabin, heating of the battery, cooling and heating of the battery, dehydrating, defrosting, and PTC heater, can be used in complicated working conditions. The author has designed a new energy vehicle heat pump air-conditioning system, which has better thermal comfort of the passenger compartment under the defrosting mode, and can simultaneously or separately cool and heat the passenger compartment and battery.

Figure 1 illustrates the schematic diagram of a new type of energy vehicle heat pump air-conditioning system. The system can be used to change the operating mode of the HVAC in different modes by using electromagnetic valve and three way valve.

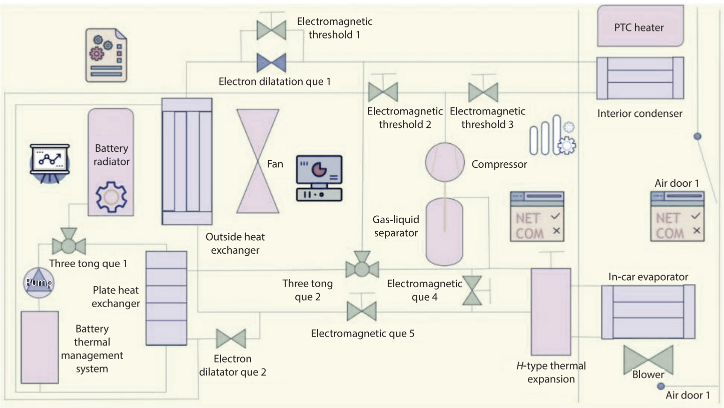

Figure 1. Schematic diagram of the electric vehicle heat pump air-conditioning system

Simulation model of vortex compressor

The compressor of pure new energy vehicles can no longer be driven by the engine, but directly uses the motor to drive. The scroll compressor is widely used by the air conditioning system of new energy vehicles with its advantages of high volumetric efficiency, smooth operation, simple structure, light weight, small volume, full electric drive, and high reliability, The new energy vehicle motor phase change heat storage system studied by the author uses a vortex compressor for operation [8]. In the simulation process of air conditioning systems, the compressor, as the core component of the air conditioning system, has a much higher requirement for the accuracy of its simulation model than other components, usually, a 1% error in the compressor simulation model results in an error of approximately 0.7% in the air conditioning system. Another model is the compressor system simulation model, which is mainly used in the simulation of air conditioning systems. This model does not need to understand the internal structural parameters of the compressor when used, and is mostly based on experimental data for simulation. The commonly used model of compressor system consists of AHRI10 coefficient model and compressor efficiency model. The proposed physical model for the compressor efficiency model is shown in eqs. (1)-(3).

Calculation equation for mass-flow rate of vortex compressor:

$$\dot{m}_{\mathrm{com}} = \frac{\eta_{\mathrm{v}} v_{\mathrm{th}} r_{\mathrm{com}}}{v_{\mathrm{suc}}} \tag{1}$$

where $\dot{m}_{\mathrm{com}}$ [kgs^{-1}] is the mass-flow rate of the compressor, η_{v} – the volumetric efficiency, v_{th} [m^3 per tonne] – the theoretical engine displacement, r_{com} [rps] – the compressor speed, and v_{suc} [m^{3}kg^{-1}] – the suction specific volume.

Equation for calculating the power of a scroll compressor:

$$W = \frac{\dot{m}_{\mathrm{com}}\left(h_{\mathrm{dis}} - h_{\mathrm{suc}}\right)}{f_Q} \tag{2}$$

where W [kW] is the power consumption of the compressor, h_{dis} [kJkg^{-1}] – the exhaust enthalpy, h_{suc} [kJkg^{-1}] – the suction enthalpy, and f_Q – the heat loss coefficient (which can be regarded as a constant, usually between 0.9 and 1.0). The exhaust enthalpy can be calculated:

$$h_{\mathrm{dis}} = h_{\mathrm{suc}} + \frac{h_{\mathrm{dis|s}} - h_{\mathrm{suc}}}{\eta_{\mathrm{s}}} \tag{3}$$

where $h_{\mathrm{dis|s}}$ [kJkg^{-1}] is the exhaust enthalpy under isentropic compression and η_{s} – the isentropic efficiency.

The eq. (3) can be used to calculate the mass-flow rate, power consumption, and outlet state of the compressor. Currently, polynomial functions, neural network models, and other commonly used compressor efficiency fitting methods are commonly used. When fitting the compressor efficiency, the neural network model has a stronger fitting ability than the polynomial function. Some scholars use the back propagation neural network model to fit the compressor efficiency, but the learning speed of the back propagation neural network is slow, and it is not suitable for occasions with high real-time, so the author uses a simpler structure and faster rate of convergence, radial basis function (RBF) network, which can approach any function.

The RBF neural networks are divided into two types: generalized networks and regularized networks. Generalized networks are suitable for training with a large number of samples, but their theoretical accuracy is lower than that of regularized networks, due to the relatively small number of training samples used by the author, regularization networks with higher theoretical accuracy can be selected. The characteristic of regularization networks is that the number of hidden nodes is equal to the number of input training samples, the author directly selects the node center value to be the same as the training sample value. After determining the center of the hidden node, it is necessary to calculate the output of the hidden layer [9]. The function used to calculate the output of the hidden layer is the radial basis function, which is often recorded as:

$$\phi(x, y) = \phi\left(\|x - y\|\right) \tag{4}$$

where $\|x - y\|$ is the 2-norm, $\phi(x, \mathrm{y})$ – the output value of each node, x – the any input vector, and y – the any node. Common radial basis function mainly include the following: Gauss distribution function, Multi Quadric inverse function, thin plate spline function, and the author chooses to use Gauss distribution function:

$$\phi(x, y) = \exp\left(-\frac{\|x - y\|^2}{2\sigma^2}\right) \tag{5}$$

where

$$\sigma = \frac{d_{\max}}{\sqrt{2n}} \tag{6}$$

where $d_{\max}$ is the maximum distance between the selected nodes, and n is the number of hidden nodes.

After calculating the output of the hidden layer, the pseudo inverse method can be used to obtain the weight of the training sample based on the expected target value:

$$w = G^{+}d \tag{7}$$

where

$$G = \left\{g_{ki}\right\} \text{ and } (\bullet)^{+}$$

are the pseudo inverse, which can be obtained by singular value decomposition and g_{ki} is the output value of the k^{th} input vector at the i^{th} hidden node, and d represents the output vector.

The calculated weights can be used to predict the output values corresponding to the input vectors in non-training samples, and the accuracy of the neural network model can also be verified by comparing the predicted output values with the actual values. The volumetric efficiency and isentropic efficiency of compressors are generally functions of suction pressure, discharge pressure, evaporation temperature and condensation temperature. The author analyzes and compares the accuracy of neural network models under different input combinations to determine the best way to use RBF neural network to fit compressor efficiency.

In order to determine the best fitting method when using RBF neural network to fit the compressor volumetric efficiency, the author takes 400 odd digit groups as neural network training data from 800 groups of experimental data provided by the compressor manufacturer, and establishes neural network models with input variables of suction pressure/discharge pressure, condensation temperature/pressure ratio, and evaporation temperature/pressure ratio, respectively, and 400 sets of even digit data were taken to verify the fitting effect of the three established RBF neural networks. Therefore, the author selects the fitting variable with the smallest fitting error as the neural network model of evaporation temperature/pressure ratio efficiency as the fitting model of compressor volumetric efficiency.

Analysis of motor phase change heat storage system for new energy vehicles

When the cooling system of the new electric car heat pump is working, not only the energy conversion process, but also the negative energy process, which is characterized by the parameters that determine the positive energy. It represents a theoretical upper limit for the conversion of a particular form of energy into useful work under certain environmental conditions, and so far most research on wind turbine cooling has been defined from an energy perspective, but not from an energy perspective. By determining the location, size and location of energy losses, the quality can be better determined – thus providing guidance for improvement, so the author uses the method of studying heat pump air conditioners to obtain guidance for showing the quality of the system from a power quality perspective. This section mainly introduces the principle of the analysis of the heat pump air-conditioning system. General expression of First law of thermodynamics:

$$\Delta E = \left(\Delta E\right)_{Q} + \left(\Delta E\right)_{W} + \left(\Delta E\right)_{M} \tag{8}$$

where (ΔE)Q, $(\Delta E)_{W}$, $(\Delta E)_{M}$ can be obtained from the following equation:

$$(\Delta E)_Q = q, (\Delta E)_W = -w, (\Delta E)_M = h_i - h_o$$

where (ΔE) [kJkg^{-1}] is the specific energy change of components in the motor phase change heat storage system, q [kJkg^{-1}] – the heat exchange of components in the motor phase change heat storage system during cyclic operation, and W [kJkg^{-1}K^{-1}] – the power exchange of components in the Motor phase change heat storage system during cyclic operation.

The general expression of Second law of thermodynamics:

$$\Delta A = (\Delta A)_Q + (\Delta A)_W + (\Delta A)_M - I_{\text{in}} \tag{9}$$

where $(\Delta A)_Q$, $(\Delta A)_W$, and $(\Delta A)_M$ can be obtained from the following equation:

$$(\Delta A)_Q = \int \delta q \left(1 - \frac{T_0}{T}\right) = q\left(1 - \frac{T_0}{T_m}\right),\ (\Delta A)_W = -w + p_0 \Delta V$$

$$(\Delta A)_M = h_i - h_0 - T_0 (s_{\text{i}} - s_{\text{o}})$$

where ΔA [kJkg^{-1}] is the change in the damping value of the components of the motor phase change heat storage system, $(\Delta A)_Q$, $(\Delta A)_W$, and $(\Delta A)_M$ [kJkg^{-1}] are the external cause of the temperature change of components caused by heat exchange, power exchange, and mass exchange during the cycle operation of the motor phase change heat storage system, respectively, I_{in} [kJkg^{-1}] is the internal cause of the value change in the motor phase change heat storage system caused by irreversible factors inside the components during cyclic operation, T_m [K] – the average temperature of the refrigerant, T_0 [K] – the ambient temperature, P_0 [kPa] – the environmental pressure, ΔV [m^3] – the volume change of components in the motor phase change heat storage system during cyclic operation, and $s_{\text{i}}/s_{\text{o}}$ [kJkg^{-1}K^{-1}] – the specific entropy of the inlet/outlet refrigerant of the motor phase change heat storage system during cyclic operation.

The thermodynamic process in any component is stable flow, so ΔE and ΔA are both 0.

The simplified calculation equation for compressor wear:

$$I_{\text{com}} = -T_0 (s_{\text{com,i}} - s_{\text{com,o}}) \tag{10}$$

where I_{com} [kJkg^{-1}] is the wear and tear of the compressor, $s_{\text{com,i}}$ [kJkg^{-1}K^{-1}] – the specific entropy of the compressor inlet refrigerant, and $s_{\text{com,}}$o [kJkg^{-1}K^{-1}] – the specific entropy of the compressor outlet refrigerant. For heat exchangers, there is no power exchange, so $(\Delta E)_W$ and $(\Delta A)_W$ are 0. After simplification, the calculation equation for evaporator losses:

$$I_{\text{eva}} = q_{eva}\left(1 - \frac{T_0}{T_{\text{eva,m}}}\right) + h_{\text{eva,i}} - h_{\text{eva,o}} - T_0 (s_{\text{eva,i}} - s_{\text{eva,o}}) \tag{11}$$

Due to the much lower heat loss between pipe-lines and valves compared to other components, the heat loss between pipe-lines and valves can be ignored in the analysis process. The heat loss generated by heat exchange is mainly affected by the heat exchange temperature difference. Generally, the larger the heat exchange temperature difference, the greater the heat loss.

Experimental results and analysis

When establishing a model of a motor phase change heat storage system, the author referred to the mode of using one evaporator in work as the single evaporator mode and used the same algorithm, while the mode of using two evaporators in work was referred to as the dual evaporator mode and used the same algorithm. When the motor phase change heat storage system is operating in the passenger compartment heating mode, fresh air and partial fresh air can be selected as the air inlet methods for the interior condenser of the vehicle to heat the passenger compartment. The figs. 2(a)-2(c) illustrates the variation of the compressor power, the heating capacity and the system COP at various compressor speeds when the intake air volume of the condenser in the vehicle is 280 m^3 per hour [10]. From the diagram, it can be seen that the compressor power and the heating capacity rapidly increase with the increase of the ambient temperature, whereas the COP of the system is rapidly reduced, as shown in the preceding analysis,it can be seen that the variation tendency of the heating capacity due to the variation of the inlet air temperature of the exterior evaporator and the interior condenser is opposite. Therefore, auxiliary heating devices can be appropriately matched according to the heating capacity that can be achieved at different ambient temperatures for heating.

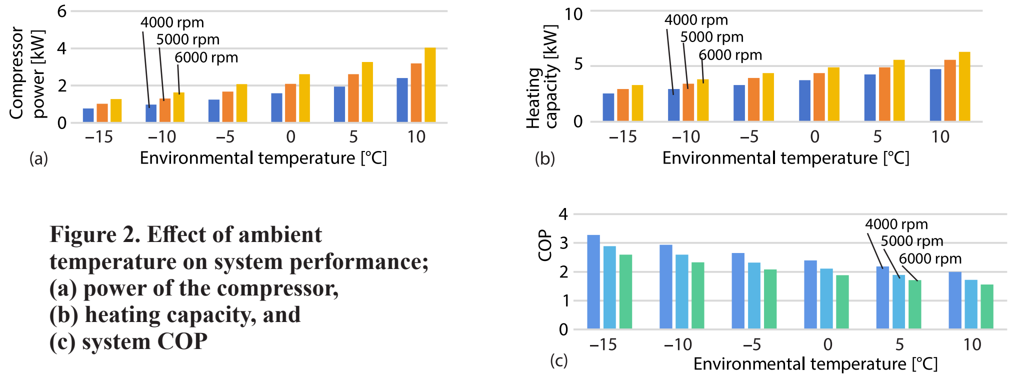

Figure 2. Effect of ambient temperature on system performance; (a) power of the compressor, (b) heating capacity, and (c) system COP

In order to study how the air inlet volume of the internal condenser in mixed passenger heating mode affects the performance of the heat pump air conditioner, the air inlet volume of the internal condenser in the passenger compartment heating mode was performed while making other parameters. changed, the changes in compressor capacity, heating capacity and system COP were investigated. Figures 3(a)-3(c) shows the variation of compressor power, heat capacity and system COP with the inlet air volume of the condenser machine at different compressor speeds at –10 °C. It can be seen from the figure that as the inlet air volume of the condenser car increases, the compressor power gradually decreases and the heating capacity increases gradually, because the air volume of the condenser car increases and the heat exchange increases. The capacity of the condenser machine and the heating capacity increase. The cooling sweat process in the condenser machine is faster, and the amount of liquid coolant increases, which reduces the pressure, sweat pressure and temperature of the sweat. A decrease in sweat pressure causes a decrease in ventilatory output. When the compressor speed is constant, the

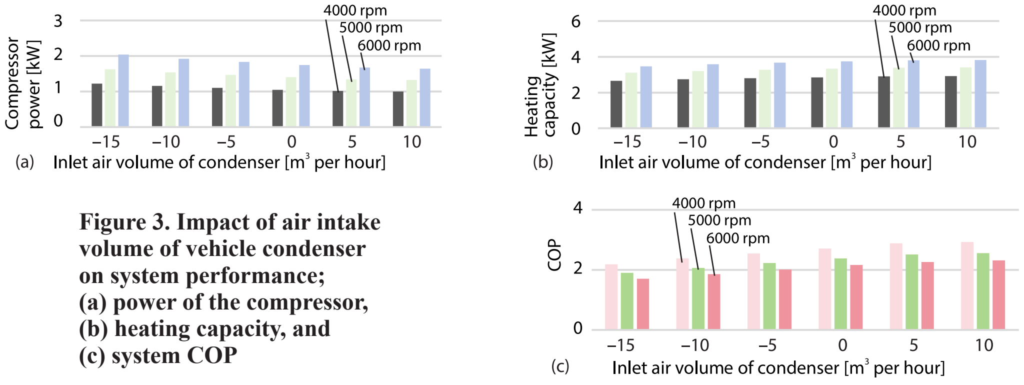

Figure 3. Impact of air intake volume of vehicle condenser on system performance; (a) power of the compressor, (b) heating capacity, and (c) system COP

suction force of the compressor decreases, and the decrease in suction pressure increases the specific suction volume of the compressor, reduces the mass-flow of the refrigerant, and reduces the energy consumption of the compressor.

Conclusion

Using a special overheating algorithm, the author created an experimental model of a single-evaporator and a double-evaporator air conditioning pump. For a single-type evaporator, the system balance is determined depending on whether the compressor flow rate and the expansion valve flow rate are equal, and for a dual-type evaporator, the system balance is determined depending on whether the superheat corresponds to the specified parallel evaporator and plate evaporator. Research has shown that increasing the air consumption of the condenser machine will increase its heat generation capacity, but it will also reduce the voltage of the condenser machine. Due to certain reasons, it may affect the comfort of the human body. Therefore, when adjusting the air volume of the condenser in the machine, it is necessary to comprehensively consider these two factors to choose the best possible result. When the air conditioner maintains the same outlet temperature in the cabin, using half of the fresh air is energy-saving.

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Paper submitted: June 26, 2023
Paper revised: August 29, 2023
Paper accepted: September 26, 2023

Published by the Vinča Institute of Nuclear Sciences, Belgrade, Serbia.