

A Heat-Pump Air Conditioner based on Waste Heat Recovery Strategy for Hybrid Vehicles

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Abstract. How to improve fuel range and efficiency is one of most important targets for hybrid Vehicles. As one solution, heat-Pump air conditioner has more advantages than traditional air conditioner, such as high heating efficiency and range extension. A new Heat-Pump air conditioner based on waste heat recovery strategy is presented in this paper. A heat exchanger between engine circuit and air conditioner circuit provides waste heat recovery. The new structure is built and simulated on a software-in-loop platform, which is based on KULI and Matlab/Simulink. Simulation results indicate that platform provide us higher COP (Coefficient of Performance) and rapid response time.

1. Introduction

Hybrid vehicles are becoming more and more popular in Low-carbon vehicle market as energy efficiency and cost remain the main obstacles to get dominant position. Air conditioner plays important role as the second largest energy-consumer in automobile. Heat pump air-conditioner is adopted more widely to achieve high efficiency, especially in winter-heating condition. At the same time, its flaw is obvious, such as pre-warm before start is necessary at low temperature, and relatively high cost. [1-2]

In this paper, a heat exchanger is added between engine circuit and air conditioner circuit, which provides waste heat recovery. Main exchanger parameters, such as area, structure, material, tube, are calculated and simulated through a software-in-loop platform based on KULI and Matlab/Simulink. The most obvious difference between the new simulation environment and other simulation platform is that the former integrated thermal system and electronic control system. Therefore, it is possible to design, adjust and simulate both of them simultaneously, which provides us more flexibility, efficiency and low cost.

2. Schematic Theory

2.1. System Structure

The heat pump air conditioner system employs two condensers and one evaporator. Inside condenser acts as auxiliary heating source. The main structure is shown as Figure.1. An evaporator is added between engine cooling circuit and air conditioner circuit. In winter condition, ambient temperature is about 0°C~10°C, air conditioner circuit receives spare heat from evaporator, which can be exchanged with driver cab condenser through heat media.



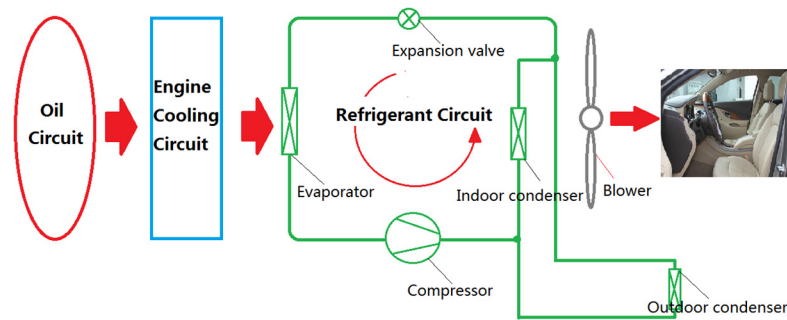


Figure 1. Schematic diagram of heat transfer mechanism

This policy increases the heat source with the utilization of engine waste heat, which obviously lifts the input temperature of indoor condenser. So, in order to keep target cab temperature, the system consumes less compressor power.

2.2. Refrigerant

Normally, R-134a is used in vehicle air conditioner. In paper [3-5], performance of air conditioner filled with R-152a and R-134a are compared. The results of experiment show that there is no significant difference between performance and heat capacity, therefore, R-134a is adopted. Main approach of this paper is to utilize the waste heat of engine, motor and battery. After analytical calculation, only one heat source is adopted due to heat capacity reason.

3. Thermal analysis

The key element of the suggested system is the thermal exchanger between engine cooling system and air conditioner system. Equation (1) describes the thermal transmission result. dQ_{air} is heat mass rate; $dA_{air-side}$ is air mass rate.

$$dQ_{air} = \alpha_a (t - t_{surface}) dA_{air-side} \quad (1)$$

Equation (2) reveals thermal exchange between refrigerant [4]. σ is condense coefficient of vapor condensing; x is the air humidity set by evaporator income gate temperature; $x_{S,surface}$ is air humidity decided by lower surface temperature of evaporator.

$$d\dot{m}_K = \sigma (x - x_{S,surface}) dA_{air-side} \quad (2)$$

When surface temperature is saturated, vapor stream disappeared and air humidity reduces, it could be described as equation (3). [6]

$$d\dot{m}_K = -\dot{m}_{t,air} dx \quad (3)$$

4. Modelling

An integration modelling approach is presented, which is built up of several steps as follows. Firstly, a thermal load model is constructed. Secondly, one-dimension model of whole heat management system is established. Thirdly, the thermal model of whole vehicle is launched and simulated. In every step, models are abstracted from experiment data and theoretical analysis. After several iterations, accurate parts models and system model make it possible to develop whole thermal vehicle system at lower cost and convenient to make sustainable improvement. KULI and Matlab act as the software platform. Thermal parameters and control policy can be adjusted at the same time. The main structure is shown in Fig.2.

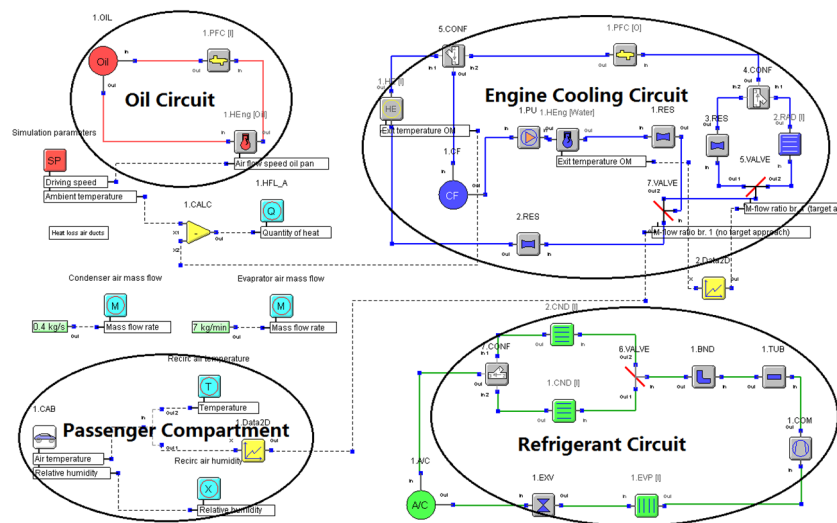


Figure 2. Overall heating model of air condition heat pump system

5. Experiment

In order to acquire accurate simulation results, we aligned simulation data with testbench data. If there is huge gap between them, model will be revised until error is below $\pm 5\%$. Compressor motor is SV-IG5A, rated power is 12 KW. Temperature, pressure and mass flow rate is tested in experiment to evaluate the heat pump performance. Ambient temperature is 0-20.0°C.

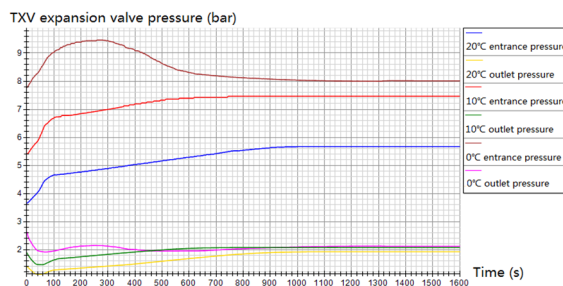


Figure 3. TXV expansion valve pressure drop curve

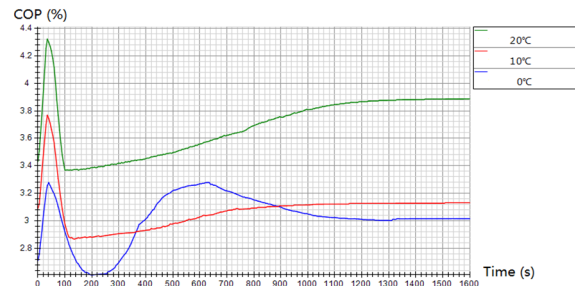


Figure 4. COP Diagram at 0°C 10°C 20°C

Compressor power, heating ability and COP(Coefficient of Performance) curve at different ambient temperature are shown in Fig 3. TXV aims for pressure control and then outside temperature control. It is easy to find out that pressure drop is bigger at temperature 0°C, therefore COP is small. When ambient temperature decreases from 20°C to 0°C, COP reduced about 24%. COP is about 3.28 when ambient temperature is 0°C in the system. As a comparison, the highest COP of traditional heat pump system in this condition is about 2.5. The performance of proposed system improved about 31.2%.

During the whole working condition, the max COP value is 4.32, above class 1 level of national standard 3.6. According to the simulation result at ambient temperature of 10°C, heat output mass is about 3.77Kw, which beyond the system heating requirement.

6. Conclusion

An air conditioner approach for hybrid vehicle is presented in this paper, which is based on waste heat recovery policy between engine and air conditioner circuit. This solution is simulated with KULI and Matlab. Experiment results indicate that outside temperature of condenser and evaporator and air mass rate increase when ambient temperature and ambient condenser air mass flow increase. COP increases

when temperature of condenser lifts. But when ambient temperature drops to 0°C, the performance becomes worse. In that condition, PTC should be added, or another refrigerant should be selected. [7]

Acknowledgments

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