Performance Simulation Analysis of Modular Heat Dissipation Unit

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Abstract. In this paper, GT suite software is used to model the cooling system of military special vehicles with multiple power sources. The power drive system is composed of main engine, auxiliary engine and four hub motors. By constructing modular cooling unit, the volume of radiator and the layout of cooling unit are changed. While the total volume of radiator is unchanged, the cooling capacity of cooling system is improved. Firstly, the problem is simplified and modeled by high-temperature and low-temperature double circuit. The main engine with power of 600kW and auxiliary engine with power of 200kW are combined into a high-temperature circuit. The water temperature of the circuit is higher, about 90 ºC; Four hub motors with power of 440kw and their electrical components are combined into a low temperature circuit. The water temperature of this circuit is about 60 ºC. By modifying the volume, layout and number of radiators, the temperature of the dual circuit is analyzed, and it is found that when the total radiator volume remains the same, the cooling effect of the multi-radiator layout is better.

1. Overall Design of Cooling System
The power drive system of hybrid electric vehicle studied in this paper is composed of main engine, auxiliary engine and driving motor. The main engine is a six cylinder engine with 600kW power and V-shaped cylinders; The auxiliary engine is a two cylinder engine with 200kW power and horizontally opposed arrangement; Each motor is a hub motor with a power of 110KW, which integrates the power device, transmission device and braking device into the hub. The overall structure of the vehicle is shown in Fig.1. The vehicle can be driven by the main engine and auxiliary engine separately or jointly. The cooling system needs to meet the heat dissipation requirements of each heat source component of the system under different driving forms.

Based on the modular design concept, a modular heat dissipation unit is constructed for the multi-power source hybrid vehicle, and the cooling system heat dissipation performance simulation analysis is performed based on GT-Suite software to realize the optimization of the scheme. First, the heat dissipation value of each heat source component needs to be determined, and then the high and low temperature dual circuit method is used to establish the equivalent steady-state model of each heat source[1-2].
1.1. Determination of Heat Dissipation of Heat Source Components

The heat dissipation is the design input of the cooling system, but in the initial stage of the scheme design, it is often impossible to obtain accurate heat dissipation. Therefore, during the layout of the cooling system scheme, the overall auxiliary system needs to estimate the heat dissipation according to the specific heat dissipation rate and efficiency of the engine. Diesel engine energy distribution is roughly distributed according to the following proportions: the output mechanical power, that is, the effective power, accounts for about 40%; the water heat dissipation is composed of the intercooler heat dissipation, the oil heat dissipation and the water jacket heat dissipation, accounting for about 25%; Exhaust heat dissipation accounts for about 30%; the remaining items account for about 5% [3-4]. Combining the effective power of the main and auxiliary machines can deduce the specific value of the heat dissipation demand, \( P_{\text{main}} = 375\, \text{kW} \), \( P_{\text{aux}} = 125\, \text{kW} \), as shown in the following table 1.

| Energy distribution                  | Main engine performance value (kW) | Auxiliary engine performance value (kW) |
|-------------------------------------|-----------------------------------|----------------------------------------|
| Effective power (40%)               | 600                               | 200                                    |
| Water heat dissipation (25%)        | 375                               | 125                                    |
| Exhaust heat dissipation (30%)      | 450                               | 150                                    |
| Remaining items (5%)                | 75                                | 25                                     |
| Total power (100%)                  | 1500                              | 500                                    |

The efficiency of the in-wheel motor mainly fluctuates in the range of 83% to 88%. For convenience, the efficiency of the motor is taken as 85% to consider the determination of heat dissipation. The total power of the four in-wheel motors with a power of 110kW is 440kW, that is, \( P_{\text{total}} = 440\, \text{kW} \), and the motor efficiency \( \eta = 0.85 \). Then the heat dissipation of the motor is:

\[
P_{\text{Motor}} = P_{\text{Total}} \times (1-\eta) = 66
\]

Taking the heat dissipation of electrical components as \( P_e = 5\, \text{kW} \), the total heat dissipation of the cooling system is:

\[
P_{\text{Total}} = P_{\text{Main}} + P_{\text{Auxiliary}} + P_{\text{Motor}} + P_{\text{Electrical}} = 571
\]

1.2. Steady State Analysis Model

Due to the different temperature levels of the power electronic equipment and the engine cooling system, the cooling requirements of the auxiliary engine circuit are different from those of the conventional engine cooling system, and two independent cooling loops are required to meet the requirements of each power source. The high-temperature cooling loop is used to dissipate heat from the main engine and auxiliary machines, and the low-temperature cooling loop is used to dissipate heat from the motor. In order to determine the flow and temperature response, a steady-state analysis of the
auxiliary cooling system is carried out. Considering the different layout schemes of the radiator, the equivalent steady-state models of the main and auxiliary high-temperature loops and the equivalent steady-state models of the low-temperature loops of the motors and electrical components are established.

Fig. 2–4 are the schematic diagrams of the equivalent steady-state models of the main and auxiliary high-temperature loops of the three cooling unit arrangements. Fig. 5–7 are the equivalent low-temperature loops of the motors and electrical components of the three cooling unit arrangements. Schematic diagram of the steady-state model.
2. Establishment of One-dimensional Model of Cooling System

This article uses GT-COOL software to establish a one-dimensional performance model of the cooling system, where the type of coolant is eg1-5050 (50% of the volume is ethylene glycol), the flow rate of the coolant in the high temperature loop is 750L/min, and the low temperature loop. The coolant flow rate is 200L/min, where EngineBlock is the host module, which is regarded as heat source 1, and the heat dissipation is 375kW; APU (Auxiliary Power Unit) is the auxiliary engine module, which is regarded as heat source 2, and the heat dissipation is 125kW; MotorBlock is the motor module, which is regarded as heat source 3, with a heat dissipation capacity of 66kW; Inverter is an inverter, regarded as heat source 4, with a heat dissipation capacity of 5kW. The dimensions of the radiators Rad_1 and Rad_2 are 950×501×57mm, the dimensions of the radiators Rad_3 and Rad_4 are 234×639×33mm, and the outside temperature is 25°C. The relevant parameters of the fan and water pump are shown in Table 2 and Table 3.

According to the overall modular design concept, the high and low temperature dual loop dual heat dissipation unit plan, the high and low temperature dual loop four heat dissipation units on the same side layout plan (the two heat dissipation units in the same loop are on the same side of the auxiliary machine/motor), The high and low temperature dual loop four heat dissipation units are arranged on different sides (the two heat dissipation units in the same loop are located on both sides of the auxiliary machine/motor). The specific model is shown in Fig. 8~10.

| Fan speed | 4400rpm |
| Blade diameter | 640mm |
| Blade depth | 143mm |
| Moment of inertia of fan | 0.025kg•m² |

| Volume flow | 750L/min |
| Initial temperature | 77°C |
| Coolant | eg1-5050 |
| Inlet diameter | 80mm |
| Outlet diameter | 80mm |
Figure 8. High and low temperature double loop double cooling unit layout

Figure 9. Layout of high and low temperature double loop four heat dissipation unit on the same side

Figure 10. Layout of high and low temperature double loop four radiators on opposite side

Figure 11. Temperature inside tube of high and low temperature double loop double cooling unit layout

3. Comparative Analysis of Multiple Layouts
The steady-state analysis of cooling system is carried out by GT-COOL software to predict the temperature and pressure levels in different positions of cooling circuit. The performance of the cooling system can be further improved by comparing the cooling effect of different cooling unit layout.

3.1. Layout of Double Cooling Unit
Fig. 11 is the pipeline temperature diagram of the double cooling unit layout. It can be found that with the high and low temperature double loop double cooling unit configuration, the temperature of the high temperature loop is 95.2 ºC, and the temperature of the low temperature loop is 57.7 ºC, which basically meets the requirements. Fig.12 and figure 13 are the heat dissipation distribution and flow distribution respectively. We can find that the heat dissipation and energy distribution in the two loops are better, which can meet the requirements to a certain extent.
3.2. Layout of Four Heat Dissipation Units on the Same Side

Fig. 14 is the temperature diagram of the tube with four heat dissipation units on the same side. With this configuration, the temperature of the high temperature loop is 93.4 °C, and the temperature of the low temperature loop is 53.2 °C. Under the condition that the total volume of the radiator remains unchanged, the volume of the radiator is divided into two, and the layout form of the double heat dissipation unit is changed into four heat dissipation units, and different forms of layout are carried out, which greatly improves the heat dissipation effect. Compared with the double radiator arrangement, the high temperature loop reduces by 1.8 °C and the low temperature loop reduces by 4.5 °C. Fig. 15 and Fig. 16 are the heat dissipation and flow distribution diagrams. The heat dissipation and flow distribution between the two loops are better, that is, under the condition of constant radiator volume, after optimizing the layout of the radiator, the required requirements can be met.
3.3. Layout of Four Cooling Units on Different Sides

Fig. 17 is the temperature diagram of the tube with four heat dissipation units arranged on different sides. It can be seen that the temperature of the high temperature loop is 91.7 °C, and the temperature of the low temperature loop is 53 °C. This kind of arrangement also keeps the total volume of the radiator unchanged, divides the volume of the radiator into two parts, and changes the layout form of double cooling units into four cooling units, but the two radiators on each loop are located on both sides of the host and motor respectively. Compared with the double cooling unit arrangement, the high temperature loop reduces 3.5 °C and the low temperature loop reduces 4.7 °C. Fig. 18 ~ 19 are the heat dissipation and energy distribution in the two loops are better, which can meet the requirements.

3.4. Analysis of Calculation Results

Compared with the simulation results of 3.1, 3.2 and 3.3, it can be seen that changing the layout of the cooling unit has a significant impact on the performance of the cooling system under the premise of the same radiator volume. The results show that the cooling effect of the scheme with high and low temperature double circuit four radiators is better than that of the scheme with high and low temperature double circuit and double cooling units, and the optimization effect of the different side
layout of the four cooling units is the best. Compared with the arrangement with double cooling units, the temperature of the high temperature circuit is reduced by 3.5 ºC, the optimization percentage is 3.7%, and the temperature of the low temperature circuit is reduced by 4.7 ºC, the optimization percentage is 8.1%. Table 4 shows the comparison of the temperature in the tube of the three arrangements, and table 5 shows the optimization effect of the two four heat dissipation unit arrangements compared with the double heat dissipation unit arrangement.

### Table 4. Comparison of temperature in pipe of three layout forms

|                      | High and low temperature double loop double cooling unit | High and low temperature double loop four heat sink on the same side | Different side of high and low temperature double loop four heat dissipation unit |
|----------------------|--------------------------------------------------------|---------------------------------------------------------------------|----------------------------------------------------------------------------------|
| High temperature loop temperature | 95.2 ºC                                                 | 93.4 ºC                                                             | 91.7 ºC                                                                         |
| Low temperature loop temperature   | 57.7 ºC                                                 | 53.2 ºC                                                             | 53.0 ºC                                                                         |

### Table 5. Optimization effect relative to double cooling unit scheme

|                      | High and low temperature double loop four heat dissipation unit on the same side | Different side of high and low temperature double loop four heat dissipation unit |
|----------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Temperature optimization percentage of high temperature loop | 1.9%                                                                             | 3.7%                                                                             |
| Temperature optimization percentage of low temperature loop   | 7.8%                                                                             | 8.1%                                                                             |

4. **Conclusion**

In this paper, the cooling system of military special vehicles is taken as the research object, and the influence of different heat dissipation unit layout on the cooling system performance is analyzed. The vehicle power drive system is composed of main engine, auxiliary engine and motor, and its cooling system is composed of high and low temperature double circuit. According to the different radiator layout, it is divided into high and low temperature double circuit double cooling unit layout, high and low temperature double circuit four cooling unit layout on the same side and high and low temperature double circuit four cooling unit layout on the opposite side. The results show that, under the premise of the total volume of the radiator remains unchanged, the cooling effect of the high-temperature and low-temperature dual loop four heat dissipation unit with different side layout is the best. Compared with the dual heat dissipation unit layout, the high-temperature loop temperature is reduced by 3.5 ºC, the optimization percentage is 3.7%, and the low-temperature loop temperature is reduced by 4.7 ºC, the optimization percentage is 8.1%.

Using the high and low temperature double circuit four heat dissipation unit with different side layout can further improve the performance of the cooling system, and reduce the size and quality of the radiator while achieving the same heat dissipation effect. In the future, with the total volume of the radiator unchanged, different layouts of the radiator can be simulated to get the optimal layout of the radiator.

5. **References**

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