

Research paper

Powertrain preheating system of tracked hybrid electric vehicle in cold weather

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HIGHLIGHTS

- A novel preheating method was proposed for heavy duty tracked HEV.
- Thermal energy in preheating system is produced by the PMSM in driving system.
- This method can achieve preheating target by its own components without any adding.
- Analyzing low temperature performance of power battery and select its capacity.

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ABSTRACT

In order to make sure that the heavy duty tracked vehicle can work in various conditions, especially severe cold weather, preheating system of powertrain should be adopted, and a novel preheating system is presented for the tracked hybrid electric vehicle (HEV) in which heat is generated by the low-speed drive motor. The new preheating system can meet the need of cold start without adding any additional device. The characteristic of heat generation by motor is tested when the rotor of motor is rotated in very low speed. The heat loss from power cabin to external environment has been simulated, and the relevant test has been done to verify the simulation results. Combining the characteristic of heat generation and heat loss situation about preheating system, the heat transfer model of preheating system was implemented by MATLAB. The total energy required for preheating in different ambient temperature was calculated by this model. The results showed that: the minimum heating power was 70 kW and energy required was about 180 MJ when the HEV worked in $-46\text{ }^{\circ}\text{C}$. If lithium ferrous phosphate (LFP) battery was used in power system, the minimum battery capacity is about 290 A h.

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1. Introduction

In order to make sure the heavy duty tracked vehicle can work in various conditions, especially severe cold weather, cold start problem in winter must be resolved in design stage of vehicle. Generally, the auxiliary heating method is used to solve the cold start problem in cold weather [1,2]. Under the condition of very low ambient temperature, if the vehicle is not started and parked out of door for a long time, the lubricating oil of vehicle would have higher viscosity and lower lubrication, and starting the engine in this condition would bring fatal damage to the engine and the power train would suffer serious attrition, which will have tremendously

impact on the performance of vehicle [3–6]. Based on the different structures and working environments of vehicle, the auxiliary heating method is widely used [7,8]. For the traditional heavy duty tracked vehicle, fuel fired heater is a universal method of auxiliary heating. The fuel is sprayed into boiler and fired to generate heat, and then with turning on the cycling pump, the heat is transferred to the engine and other transmission components by cooling liquid. When the engine and transmission component are heated to a proper temperature for engine to start and work normally, the fuel fired heater stops working.

Compared to traditional propulsion systems, hybrid electric vehicle (HEV) has many advantages such as improved fuel economy, better acceleration performance, low acoustic signature and exportable electric power [9], which are very suitable for the tracked vehicle. For the tracked HEV, installing a traditional fuel fire heater can meet the need of cold start in winter, but this kind of

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preheating system will occupy some space and make the crowded power cabin more crowded. Authors in this article propose a novel preheating method for heavy duty tracked HEV in which heat is produced by the permanent magnet synchronous motor (PMSM) in driving system. When the rotor of motor is rotated in very low speed, most of input electric energy is transformed into thermal energy [10]. Base on the cycle of lubricating and cooling system, the heat generated by motor was transferred to the whole power train and preheat every components. With this method, we can achieve the same purpose of preheating by using its own components without adding any additional device. Motor electric preheating technology can eliminate all parts of traditional fuel heating system, such as fuel fired heater, fuel supply tube, air inflow and exhaust gas outflow pipes. There are lots of merits about motor electric preheating method, such as non-complicated system, high heating power supply, easy control, resource reusing, space and money saving, and so on.

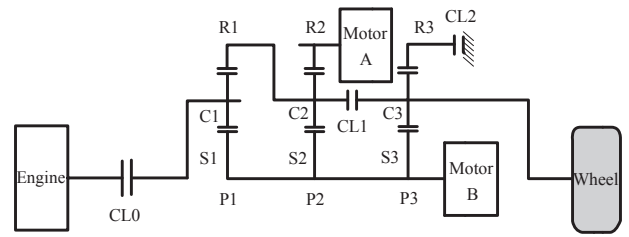
In the preheating process of heavy duty tracked vehicle power train, lots of heat will be lost through the surface of power cabin. That heat loss process exists in several different heat transfer forms. The heat will be transferred from engine and gear box to power cabin surface by means of radiation, conduction on joints and small space nature convection, and then the heat transfers to environment by cabin surface. The way of heat transfer mentioned above can be neglected in vehicle cooling system design, but it is the main way for preheating system to lose energy in cold weather, so it is necessary to consider the lost energy accuracy when designing the preheating system.

In this article, structural analysis of dual-mode electromechanical compound transmit system which is used in power train of heavy duty tracked HEV has been done, the cooling system of tracked HEV which matches well with transmit system is designed to realize the electric preheating by motor, only adding some valves and pipes. The characteristic of heat generation by motor is tested when the rotor of motor rotates in very low speed. In order to obtain the heat loss rate from power cabin to external environment, CFD has been used to simulate the heating process and the simulation result has been verified by experiment. Combining the heat generation and heat loss situation of preheating system with parameters of engine cabin components, the heat transfer model of preheating system implemented by MATLAB is used to calculate the total energy required in preheating process under different ambient temperature. At the same time, energy losses and heating efficiency can be obtained for different heating powers. Finally, the minimal battery capacity of preheating system can be determined.

2. Working principle of powertrain in heavy duty tracked HEV

The dual-mode electromechanical compound transmit system is used in power train of heavy duty tracked HEV, Fig. 1 displays the structure of the transmit system.

From Fig. 1, it can be seen that the dual-mode electromechanical compound transmit system is mainly composed by three planetary gears and two motors. Through different connection statuses of clutch CL1 and CL2, transmission can be switched between two modes respectively. Transmit mode one is a low speed mode in which CL2 is engaged and CL1 is released. In this case, the transmission ratio is determined by the speeds of motor A and motor B. In the condition of same engine speed, the speed of wheels can change with the speed of motors. The other transmit mode is a high speed mode in which CL1 is engaged and CL2 is released, and the working principle of this mode is same as that of mode one.



P-planetary gear, S-sun gear, R-ring, C-carrier, CL-clutch,

Fig. 1. Structure of dual-mode transmit system.

3. Design of cooling system and preheating system

Aiming at the heavy duty tracked HEV, the cooling system is designed with two coolant cycles and two independent cooling fans. One cycle is the high temperature cycle which is cooling the engine and charge air cooler. Another cycle is the low temperature cycle which is cooling the motors, lubricating oil and motor controller. The cooling system schemes are designed and shown in Fig. 2. For the purpose of preheating by reusing cooling system components, some pipes and valves are added. The working states can be switched between cooling and preheating by controlling the status of valve 1 and valve 3.

In the driving condition, cooling system is working; motor radiator is connected with cooling cycle. When the power system need preheating in cold weather, the preheating cycle is connected with low temperature cycle by changing the state of valve 1 and valve 3. The heat which is generated by motors and controller is transferred to the engine and lubricants heat exchanger, so the power train preheating can be realized.

4. Heat generation characteristic of motor

Using permanent magnet synchronous motor (PMSM) in the driving system of heavy duty HEV is the trend in recent years, which has many merits such as high efficiency, high power density, better performance on speed control and so on [11]. On the running process of motor, the power losses include core loss, copper loss, mechanical loss and miscellaneous loss. Core loss is generated in permanent magnet rotor and copper loss is generated in stator coil. Those power losses are changed into thermal energy mostly. When the rotor of motor rotating in a low speed, core loss and copper loss are the main power loss, other losses are ignored in the motor heating generation process.

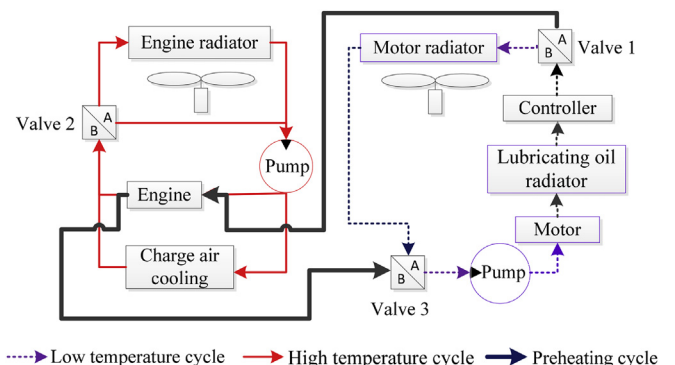


Fig. 2. Cooling cycle of motor heating preheating system.

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