Thermostating system with intelligent management for electric vehicles

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Abstract. The article considers an optimum temperature regime maintenance method of the electric vehicles aggregates. Technical solutions for the creation of an intelligent thermostatic system are proposed. Vehicle equipped with the optimum temperature maintenance system developed during current research was placed under tests.

1. Introduction
The experience of electric vehicles operation in the Russian Federation in recent years reveals not only problems associated with the essential charging infrastructure, but also with low performance indicators, such as the mileage and the time necessary for charging [1, 2]. However, these indicators are the criterion of an electric vehicle applicability in everyday life, when it will not be only a concept car, but also mass-market car. Weather factors alone do not greatly constrain the use of an electric vehicle. Much more important circumstance is associated with the need to use power-consuming systems and devices designed to provide a comfortable and safe movement in winter. Exactly due to activation of many consumers the vehicle’s mileage reduces to 50 km at negative temperatures.

It is obvious that the Russian versions of electric vehicles created by domestic and foreign manufacturers need special equipment. Even serial cars with internal combustion engines are often equipped with special "Russian packages" which include, for example, other characteristics of the wheels suspension and less sensitive neutralization systems to fuel quality.

2. Main part
Taking into account the specific operation conditions, a modular thermostating system of power electrical components was developed [3, 6, 7]. The general view of the developed liquid thermostating system is shown in Figure 1.
Figure 1. Schematic diagram of the thermostating system for electric vehicle components.

The coolant – unit 1 carries out maintenance of the temperature. This unit is a liquid-air radiator comprising an electric fan. It receives the cooling liquid from the common (main) discharge circuit of the coolant discharge from all aggregates of the vehicle. The coolant temperature at the inlet to the unit is regulated by a liquid electric valve (1V) in the open-close mode according to the temperature sensor values (1 Tout) based on the coolant temperature at the cooling radiator exit.

In the charger circuit 6, the regulation is carried out by a temperature sensor (6 Tout) and an electric valve (6 Vout) in the open-close mode.

In the inverter circuit 5, control realized by a temperature sensor (5 Tout) and an electric valve (5 Vout) in open-close mode.

In the motor circuit 4 the temperature is maintained by a temperature sensor (4 Tout) and an electric valve (4 Vout) in open-close mode.

Thermostating of the traction battery (TB) 3 is carried out using a liquid-air heat exchanger with a fan, which is located in the battery case and works constantly when the ignition is on. This cooling method is optimal for such design [3, 4, 5].

When the electric vehicle ignition is switched on, the electric pump of the cooling system is switched on before starting the movement. Circulation of the coolant is carried out in the full mode of the electric pump, through all pressure pipelines of all vehicle aggregates and constant discharge into the common bypass circuit through the expansion tank. In this circuit, the coolant discharge is carried out continuously regardless the temperature control regimes in each circuit of all units to ensure removal of the steam-air mixture from the used units.

Regulation of the temperature state in each unit is provided by a change in the flow rate of the heat carrier, which is discharged into the common liquid circuit of the main vehicle radiator. At the same time, when the specified coolant temperature is reached at the radiator unit input, the total heat release is provided by using an electric fan.

Further adjustment of the each unit temperature regime is carried out in an automatic mode, using temperature sensors, by changing the flow rate of the each unit coolant separately, by opening and closing the regulating electric valves.

To ensure the set temperatures in the winter and summer period, the system uses the electrical heater and the electrical cooler of liquid. The developed intelligent thermostating control system allows automatic monitoring of the entire system and makes optimal decisions to maintain the specified parameters (Figure 2).
The most dependent climatic conditions component in vehicle is the TB. Let's consider the basic modes of maintaining the optimum temperature.

a) At the TB average temperature from 15 °C to 35 °C an electric valve (3 \text{ V}_\text{in}) is constantly open; the valve 3 \text{ V}_\text{out} operates in the open-close mode from the temperature sensor 3 \text{ T}_\text{battery}. The valves 3 \text{ V}, 8 \text{ V}_\text{out}, 7 \text{ V}_\text{out} and 9 \text{ V}_\text{mech} are closed. Heat carrier circulation is taking place through the main radiator and expansion tank 10 (Figure 3).

b) At the TB temperature below 15 °C a liquid preheater 7 is turned on; and simultaneously opens the electric valve 7 \text{ V}_\text{out}, 3 \text{ V} and 3 \text{ V}_\text{out}; the electric valve 3 \text{ V}_\text{in} is closed. In this case, the valve 8 \text{ V}_\text{out}, 9 \text{ V}_\text{mech} should be closed. The liquid temperature at the heater outlet is maintained by a temperature sensor 7 \text{ V}_\text{out} in the heater operating mode switch on-switch off. The heating mode is switched off by the sensor 3 \text{ T}_\text{battery} when the temperature reaches 15 °C. Then the system is regulated according the algorithm "a" (Figure 4).
c) At the TB temperature above 35 °C a liquid cooler 8 is switched on; and simultaneously the valve 8 V-out and 3 V opens, valve 3 V-in, 7 V-out, 9 V-mech closes. The liquid temperature in the liquid cooler is maintained by the coolant in the range –10 ± 5 °C. When the required TB temperature is reached the sensor 3 T_battery turns off the cooling system. Then the system is regulated according the algorithm "a" (Figure 5).

To ensure the microclimate in the passenger compartment, it is possible to use "b" and "c" modes with the heating and cooling of the TB. In this case, it is necessary to open the valve (9 V_mech). At the separate interior heating mode a liquid electric heater (7) must be switched on separately, an electric valve (3 V) must be closed and the mechanical crane 9 V_mech must be opened.

The developed thermostating system was implemented on an electric vehicle prototype based on the "Lada Kalina". The reequipped vehicle is shown in Figure 6.
Figure 6. Vehicle equipped with the developed thermostating system. (A – general vehicle view, B – under hood space, C – vehicle front part bottom view, D – vehicle front part top view, D – electric heater of liquid, E – cooler of liquid).

The TB is located at the top of the engine compartment, attached to the power frame. The electric motor and inverter are installed in the bottom part, under the TB and fixed to the same frame. The charger is installed in the floor tunnel. The electric heater of liquid is located on the right side of the bumper, in front of the front wheel and the coolant cooler on the left under the hood. Such arrangement of the thermostating system elements is rational and operable for a given vehicle.

After assembling and setting of all necessary systems, laboratory road tests were conducted at the Dmitrov Test Center of FSUE "NAMI" (Figure 7).
Figure 7. Tests at the Dmitrov Test Center FSUE "NAMI" (A, B – laboratory tests; C, D – road tests).

Main tests and operability measurements of the thermostating system were carried out on the chassis dynamometer. Load parameters for the stand were obtained on the test center roads. On the chassis dynamometer, two main tests of the thermostating system were carried out:

- tests of the thermostating system when the vehicle is moving according to the mixed cycle;
- tests of the thermostating system with uniform movement of the vehicle.

At the mixed cycle tests the vehicle movement chart is shown in Figure 8.
The vehicle was installed on the chassis dynamometer, monitoring and recording systems were switched on. Three mixed cycles were conducted in a row, all received data were recording on the PC. Figures 9 – 12 show the data on the coolant temperature drop at the inlet and outlet of the vehicle aggregates.

**Figure 8.** The vehicle movement chart in the mixed cycle.

**Figure 9.** Temperature drop at the inlet and outlet of the motor.
Figure 10. Temperature drop at the inlet and outlet of the inverter.

Figure 11. Temperature drop at the inlet and outlet of the TB.

Figure 12. Energy consumption for moving in mixed cycles.
After analyzing the obtained data, at vehicle movement in the mixed cycles, the following conclusions can be made:

- thermostating system ensures stable vehicle operation;
- aggregates temperature satisfies the manufacturers requirements;
- thermostating system effectively removes heat to the environment.

After conducting the series of drives in the mixed cycle, the tests continued at constant speeds 40 km/h and 80 km/h for 10 minutes each. The obtained data on the coolant temperature drop at the inlet and outlet of the motor, inverter and TB are presented in Figures 13 – 16 respectively.

**Figure 13.** Temperature drop at the inlet and outlet of the motor.

**Figure 14.** The temperature difference at the inlet and outlet of the inverter.
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3. Conclusions
The ability to adapt the thermostating system to the external operation conditions and the vehicle components operating conditions allows speaking about "intellectual" control. Complex tests of the vehicle equipped with a new thermostating system confirmed the developed circuit operability for connecting and regulating the components temperature. The laid down principles should be used at creating thermostating systems for electric vehicles, since it allows to redistribute heat fluxes more
rationally. Modularity of the design implies full or partial use on vehicles, operating in various climatic and road conditions.

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