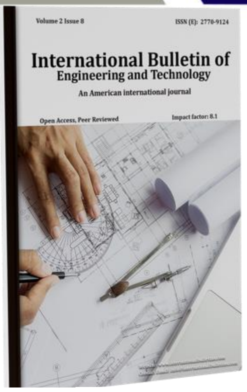

ANALYSIS OF SYSTEMS USED IN MODERN ELECTRIC VEHICLES

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Annotation. An electric vehicle is a type of transport that uses electricity as an energy source and is driven by a traction electric motor.

The energy that drives a vehicle can be obtained from several sources, including: from on-board batteries and chemical energy of accumulators (electric vehicles, electric buses, etc.);

An electric vehicle is a vehicle that is driven by one or more electric motors that operate not from an internal combustion engine, but from an independent source of electrical energy (batteries, fuel cells, capacitors, etc.).

Keywords: electric car, battery, batteries, BYD automobile company, hybrid car.

Temperature control system for electric vehicle components. When individual units of an electric vehicle (hereinafter referred to as EV) are operating, they heat up due to the influence of magnetic fields, friction of moving parts and chemical processes. In addition, the wires carrying the current, as well as all other electrical and electronic components, heat up.

Another problem is the battery cooling system, which heats up during operation. To ensure optimal performance and long service life, traction batteries must only operate within a certain temperature range. For example, the core temperature of lithium-ion battery cells during operation should not exceed 40° C. If this temperature limit is exceeded for a long time, the battery ages very quickly.

This also applies to nickel-metal hydride batteries, but they are less sensitive to heat - the cells can withstand temperatures of up to 50° C. Under heavy load, during movement, with frequent temporary discharge / charge cycles or during high-speed charging with high currents, the battery heats up very much.

If necessary (for example, in versions for countries with cold climates, including the Republic of Belarus), automakers use air conditioning to heat the battery while driving or to heat the battery modules during prolonged periods of inactivity, for example, using an electric heater. The battery cooling cycle is more suitable for battery heating in EVs, especially since it is easy to supply electricity to the heater via the charging connection. The electric motor also heats up during operation, although to a lesser extent than the battery.

Thermal regulation is also necessary for the inverter. When the inverter is working, it converts high-voltage alternating current into high-voltage direct current, which generates a lot of heat. Therefore, it has channels for cooling water inside, which reduces the operating temperature of the inverter due to the circulation of cooling water.

At the same time, a cooling system operating in the "heat pump" mode (such as an inverter air conditioner in the rooms) is able to provide comfort in the cabin with minimal energy costs. For an EV to operate at a particularly high level of efficiency, the temperature of the electric motor, power electronics and battery must be maintained within a temperature range that is optimal for efficiency. This requires a complex thermal control system. Typically, the cooling system of an electric motor is divided into circuits, each of which has its own coolant (low-temperature coolant), coolant pump, thermostat and coolant shut-off valve. A special heat exchanger (chiller) is used in addition to the one responsible for controlling the temperature of the battery. The cooling circuit also includes the refrigerant circuit of the air conditioning system. A high-voltage coolant heater ensures control of the main battery temperature at low outside temperatures. At low temperatures, the coolant is heated by a high-voltage auxiliary heater. If the temperature is too high, the coolant combined with the coolant and coolant circuits cools the coolant even more.

EV battery cooling systems can be divided into four types:

• active, which uses a liquid to cool and heat the battery cells (additional battery heaters are possible);

• active, which uses air to cool and heat the battery, but without interacting with the individual cells (additional cell heaters are possible);

• passive, with heat dissipation through the battery case;

• immersion cooling with a special coating without using liquid or air cooling systems

• immersion cooling (by immersion in water)

The active liquid cooling system of the entire EV is shown in Figure 1.

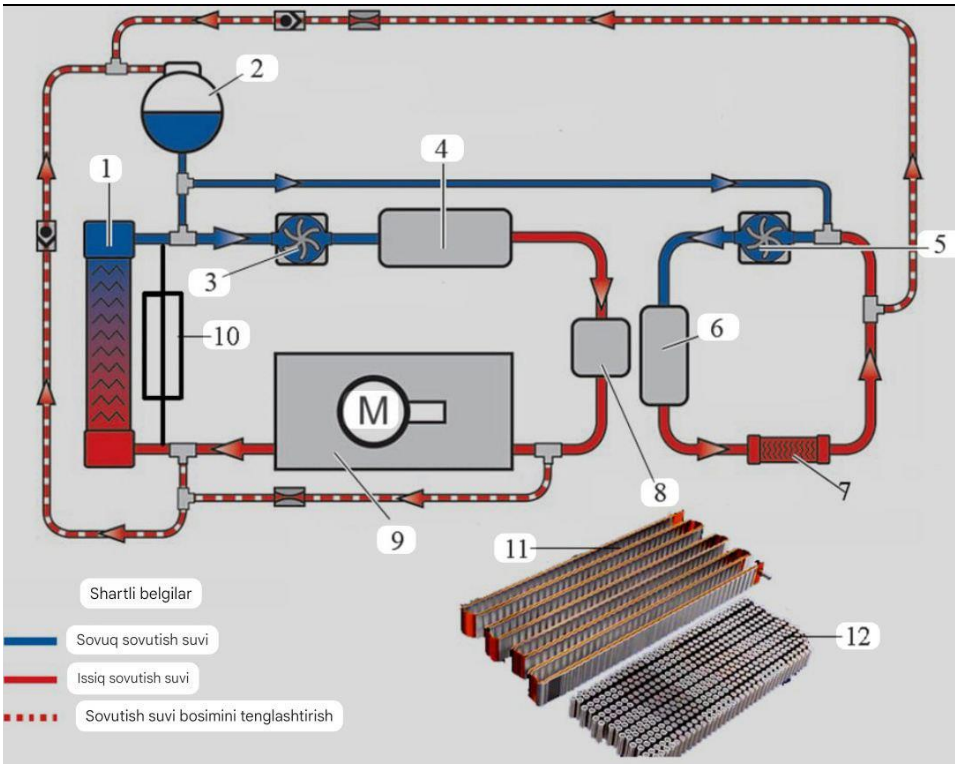
The temperature of the coolant is monitored and regulated by the engine control unit. The liquid cooling circuit includes the following components:

• high-voltage battery;

• three-phase electric drive (electric motor);

• high-voltage battery charger;

• electric motor power and control electronics unit, including an inverter.



Pic. 1. Electric vehicle cooling system:

1 - radiator; 2 - expansion tank; 3.5 - coolant circulation pump; 4 - power and control electronic unit; 6 - high-voltage heating element; 7 - heater heat exchanger; 8 - charger; 9 -

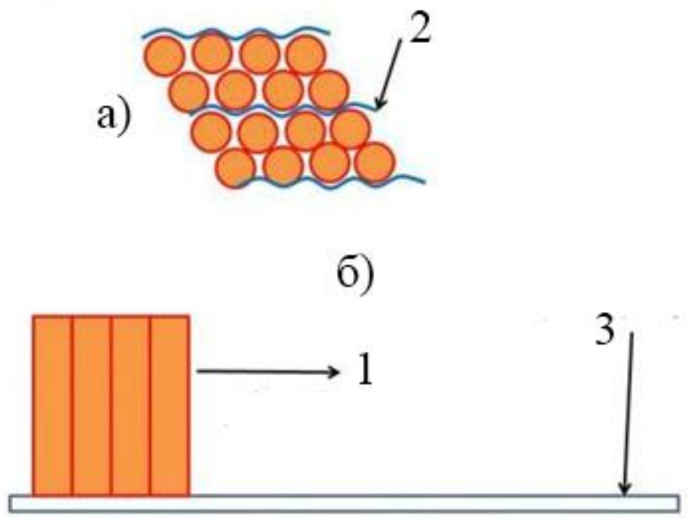
three-phase alternating current electric motor; 10 - high-voltage battery; 11 - metal pipes; 12 - elements of the high-voltage battery

To cool the battery cells, a glycol coolant is used, which passes through metal pipes 11 and the gaps between the cells 12. The heated glycol passes through a radiator installed in the front of the car and is cooled.

Heating the battery at low temperatures helps to ensure the guaranteed battery life. At very high ambient temperatures, an additional air conditioning system can be used to cool the batteries.

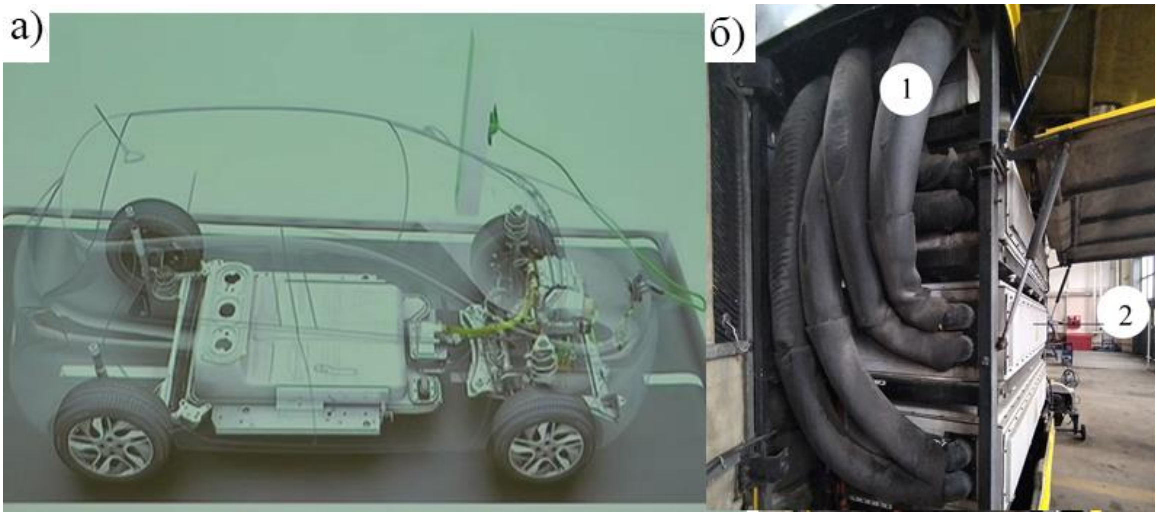
Cooling traction batteries. Cooling of traction batteries can be liquid, air, passive, submerged, or underwater.

A general diagram of a Tesla liquid battery is shown in Pic. 2 above. Here, the coolant flows through metal tubes between rows of chambers. Tesla batteries also use a cooling system with a massive plate of ethylene glycol located below the chambers (Pic. 3). Thin aluminum plates run between the rows of chambers to increase cooling efficiency.



Pic. 2. Modified cooling system for Tesla P100 D battery: a - top view; b - side view; 1 - chambers; 2 - thin aluminum plate; 3 - main cooling plate with ethylene glycol

Air-cooled battery EV. This cooling system is available in Renault Zoe batteries. Cooling is provided through ventilation holes in the rear of the vehicle (Figure 3, a). There is one air intake and two air exhausts for ventilation. The battery has its own air conditioner, which maintains the required temperature inside the housing. The cooled or heated air is supplied by a fan.



Pic. 3. Air cooling of traction batteries:

a - Renault Zoe; b - Belkommunmash electric bus; 1 - air ducts;

2 - lithium-ion batteries

Air cooling of ion batteries (gravity batteries) is also used in Belkommunmash electric buses (Pic. 3, b).

EV with passive battery cooling. Passive cooling means that there is no separate air conditioning or forced air circulation inside the battery, and the heat is dissipated through the housing (Pic. 4).

The battery contains resistive heaters that are activated when the temperature drops suddenly while the car is charging.

Pic. 4. Nissan Battery Passively Cooled Sheet

Battery Immersion Cooling Technology. The technology, called immersion cooling, relies on coating batteries with a dielectric cooling gel called MIVOLT, which is used as electrical insulation in other applications.

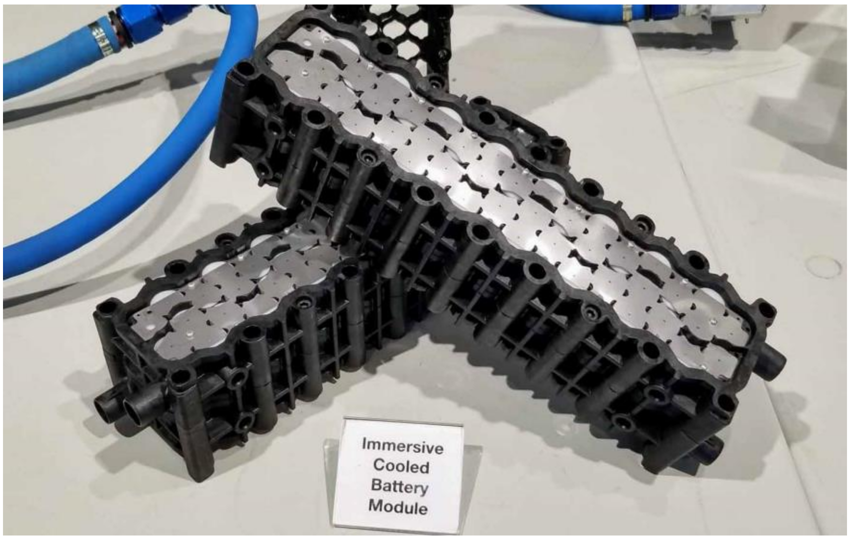
This technology can extend battery life in EVs, allowing them to accept higher charging currents without overheating, and shorten charging times closer to the time of filling the fuel tank.

Modern liquid cooling systems rely on pumped cooling plates to circulate ethylene glycol or other coolant. Immersion cooling technology replaces bulky and heavy liquid and aircooling systems. With simpler and cheaper cooling systems, EVs can use larger capacity batteries that charge faster and retain power for longer. MIVOLT coolant is also biodegradable, unlike ethylene glycol, which is used as a coolant in most internal combustion engines. Audi EVs also use quattro batteries (pic. 5). It uses a dielectric gel to cool the quattro battery, which is located under each cell and transfers waste heat evenly through the battery housing to the coolant, providing heat exchange between the cooling system and the battery.

Pic. 5. Audi quattro battery

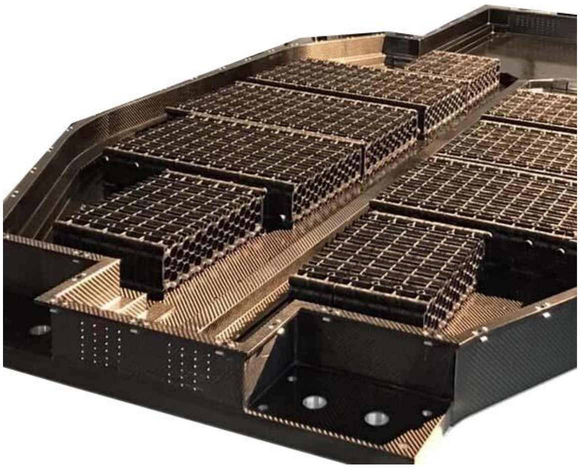
The Audi quattro battery, consisting of modular cells, provides the Audi Etron with a range of 330 km at a speed of 90 km/h in winter.

Immersion battery cooling technology. The XING Mobility Battery System is the world's first battery system to use immersion cooling technology (Pic. 6). This technology uses Noves 7200 Engineered Non-conductive Fluid, a fluid developed by 3M to remove heat from supercomputers and other equipment. The XING Mobility battery system provides higher power, longer service life. This cooling method is most popular in data centers today and is already used to cool batteries in Miss R EVs.



Pic. 6. Blocking the immersion cooling coil

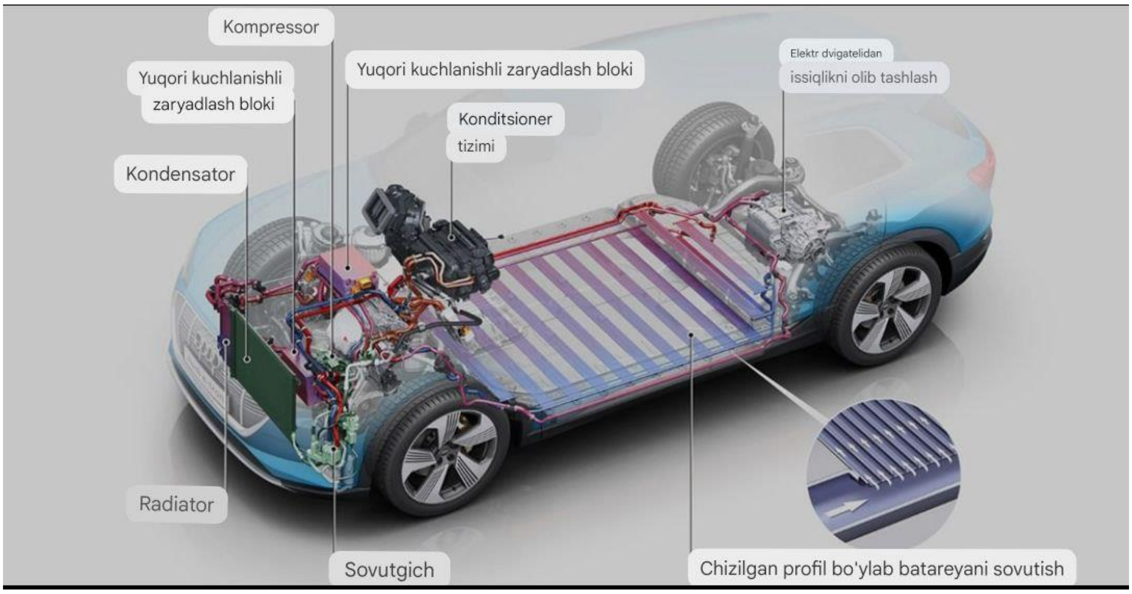
Built on a unique micromodule, the XING Mobility battery (Figure 7) folds up Lego-style to meet more than 5,000 size and shape requirements without special design. The design also allows for very fast delivery and deployment.



Pic. 7. XING mobility battery

With simpler and cheaper cooling systems, EVs can use larger batteries that charge faster and last longer. MIVOLT coolant is also biodegradable, unlike ethylene glycol, which is used as coolant in most gas engines.

Cooling circuits. In fact, EV cooling systems can use several circuits with different cooling systems. For example, the cooling system of the Audi EV (Pic. 8) consists of four independent circuits served by a single compressor. The fluid circuit of the propulsion battery is located just below it. The coolant in the circuit is supplied through fine drains that are poured into aluminum cross members.

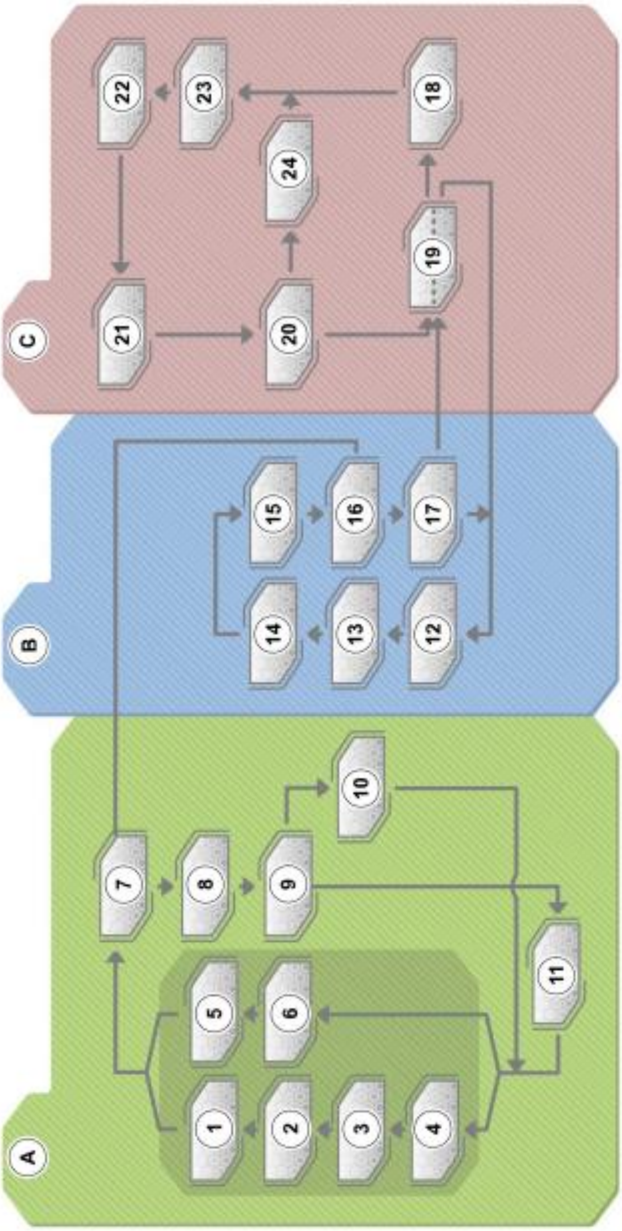


Pic. 8. Audi electronic cooling system

The more powerful the batteries, the more appropriate it is to use a relatively complex coolant and refrigerant circuit. The entire cooling system is divided into several circuits, each of which has its own radiator (low-temperature radiator), coolant pump, thermostat and coolant shut-off valve. The cooling circuit of the air conditioning system is also integrated into the system through a special heat exchanger (chiller).

Another example is the cooling system of the I-PACE EV, which uses an advanced temperature control system to not only provide a comfortable environment for the driver and passengers, but also, more importantly, to constantly maintain the ideal operating temperature for the high-voltage battery (20-25°C). The temperature control system uses a combination of a modern air conditioning system that includes liquid cooling, heat exchangers and a heat pump process. This ensures optimal performance of the high-voltage battery for maximum range in all conditions. The I-PACE has three cooling circuits: the electric drive circuit (9L), the internal circuit (3L), the high-voltage (HV) battery circuit 7L, which contain a total of 19 liters of glycol-based coolant.

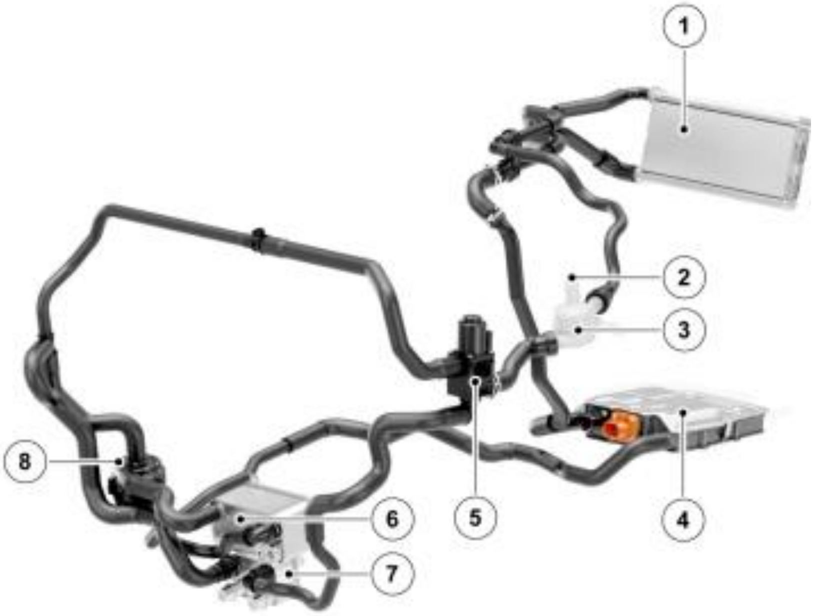
The three circuits operate independently of each other and are controlled by different control units. Each of them is equipped with its own independently controlled electric coolant pump and solenoid (valve) or proportional valve. The circuit diagram is shown in picture 9.



Pic. 9. Diagram of the I-PACE electric vehicle cooling system:

A – electric drive circuit; B – internal circuit; C – high-voltage battery circuit (HV); 1 – battery charger control unit (BCCM); 2 – front inverter; 3 – battery charger control unit (BCCM); 4 – DC/DC converter; 5 – rear EDU; 6 – rear inverter; 7 – coolant expansion tank (electric drive circuit); 8 – electric coolant pump (electric drive circuit); 9 – proportional coolant valve; 10 – electric drive cooler; 11 – electric drive radiator; 12 – electric coolant pump (internal circuit); 13 – surface condenser; 14 – high-voltage heater; 15 – heating radiator; 16 – receiver cup; 17 – solenoid valve; 18 – high-voltage battery cooler; 19 – high-voltage battery heat exchanger; 20 – solenoid valve; 21 - electric coolant pump (high-voltage battery circuit); 22 - coolant expansion tank (high-voltage battery circuit); 23 - high-voltage battery.

The cabin coolant circuit (Pic. 10) has two functions: maintaining a comfortable environment for the driver and passengers and, if necessary, providing additional cooling/heating in the battery cooling circuit.



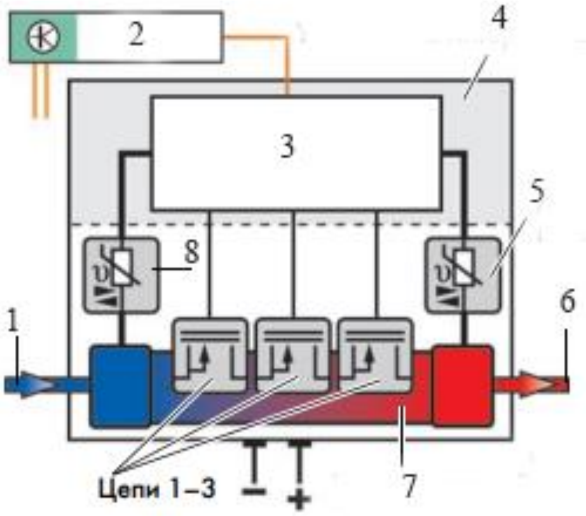
Pic. 10. Internal coolant circuit

1 - heating radiator; 2 - expansion tank connection; 3 - receiver cup; 4 - high-voltage coolant heater (HVCH); 5 - solenoid valve; 6 - surface condenser; 7 - high-voltage battery heat exchanger; 8 - electric coolant pump

The cabin circuit is a sealed cooling system, which is filled from the connection in the electric drive coolant expansion tank through the intake window of the cabin circuit. The interior circuit is controlled by the heating, ventilation and air conditioning control unit.

Since the EV does not have an internal combustion engine that provides sufficient residual heat to heat the coolant, the coolant is heated, if necessary, by a special high-voltage coolant heating element 4.

The high-voltage heating element is connected to the high-voltage network via a high-voltage cable (Fig. 11). The heating element also has a connector for connecting to the on-board 12 V network and for communicating via the LIN bus (container) with the climate control unit that controls the operation of the high-voltage heating element. In this case, the temperature at the inlet and outlet is measured by two separate temperature sensors. The output power can be controlled from 0 to 100%. The request for a specific output power value is converted by the high-voltage heating element control unit into control signals for individual circuits. The high-voltage heating element usually includes three heating circuits. Circuits 1 and 2 are controlled by a pulse-width modulated signal (PWM). Circuit 3 can be turned on or off depending on the required heating power.

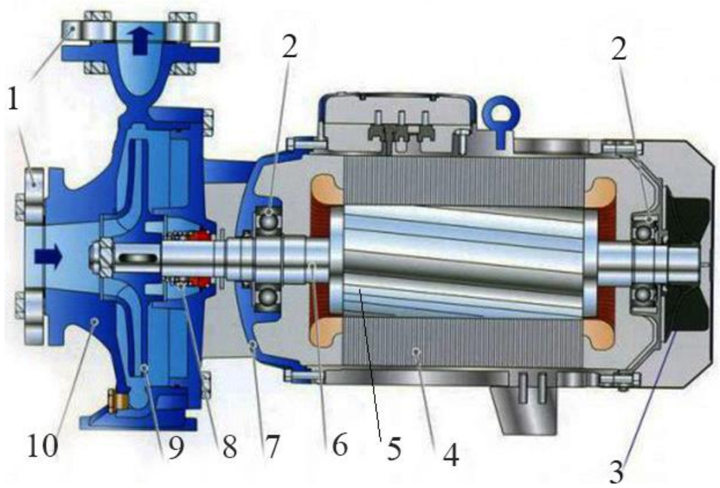


Pic. 11. Diagram of a high-voltage heating element:

1 - coolant inlet; 2 - control unit for the climate control system; 3 - control unit for a high-voltage heating element; 4 - LIN interface control; 5 - temperature sensor at the coolant outlet; 6 - coolant outlet; 7 -; 8 - temperature sensor at the coolant inlet.

During operation of the electric coolant pump, the coolant flows through the circuit as follows: the electric pump (Pic. 11) 8 through the coolant surface condenser 6. From the surface condenser, the liquid is supplied to the high-voltage coolant heater 4. The coolant then flows through the heater core 1, where heat is transferred to the passenger compartment and then to the receiver window 3. The receiver window removes air from the coolant and discharges it into the expansion tank of the electric drive. The coolant is either directed directly to the pump 8 or, depending on the requirements of the high-voltage battery circuit, passes through the battery heat exchanger 7 under the action of the solenoid valve 5. The coolant in the internal circuits is separated from the coolant in the high-voltage battery circuit. The high-voltage battery coolant heat exchanger is a liquid heat exchanger with two separate internal circuits.

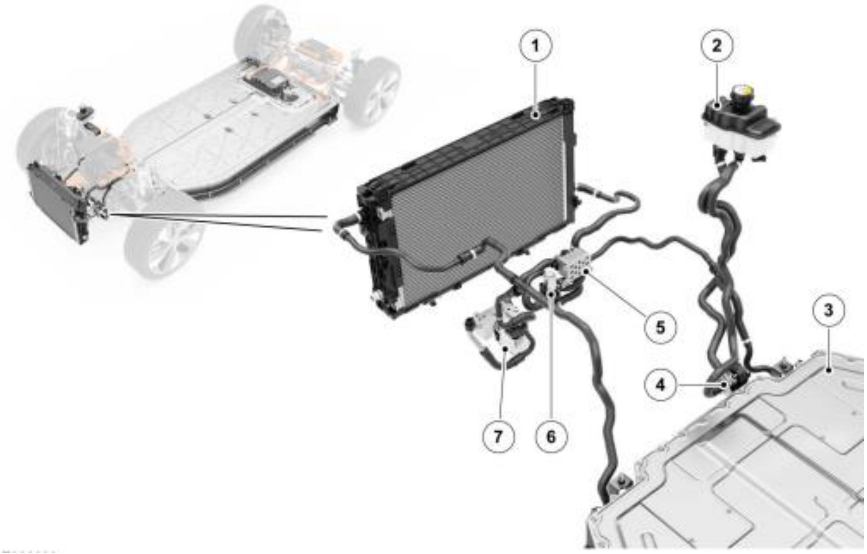
An electric pump (Pic 12) allows you to provide the necessary coolant flows.



Pic. 12. Electric liquid pump: 1 - flange; 2 - bearings; 3 - cooling fan of the pump electric motor; 4 - stator; 5 - rotor; 6 - rotor shaft; 7 - pump motor housing; 8 - shaft seal; 9 - pump housing

The electric pump is controlled by a control unit that contains data on the temperatures of the heating and cooling cycles in the parametric characteristics memory.

The cooling system diagram of a high-voltage battery (Pic 13) is necessary to ensure optimal temperature conditions for its operation.



Pic. 13. Schematic diagram of the high-voltage battery cooling system:

1 - high-voltage battery radiator; 2 - coolant expansion tank; 3 - high-voltage battery; 4 - electric coolant pump; 5 - high-voltage battery heat exchanger; 6 - solenoid valve; 7 - high-voltage battery cooler.

Maintaining the battery's optimum operating temperature at 20-25°C ensures that the battery operates at optimum efficiency and delivers the required power under all conditions. To achieve this goal, the battery temperature control system provides cooling and heating of the coolant. The high-voltage battery cooling circuit is controlled by the battery power control unit. This unit receives temperature data from the high-voltage battery to control its temperature. Two temperature sensors are used to monitor the coolant temperature at the inlet and outlet of the battery cooling circuit. The power control unit regulates the internal temperature of the high-voltage battery by monitoring this data and regulating the flow of coolant through the circuit.

The coolant flow is controlled by a 12-volt electric coolant pump 4. If necessary, the coolant is removed through the radiator 1 or the high-voltage battery cooler 7 to reduce its temperature.

If the temperature in the high-voltage battery coolant circuit is below 14 °C, the control unit switches on the electric battery coolant pump 4. In this case, the coolant in the high-voltage battery circuit flows to the solenoid valve 6 and the high-voltage heater.

When receiving a signal from the battery sensors about its overheating, the solenoid valve 6 directs the cold coolant from the high-voltage battery to the battery coolant heat exchanger 5 and removes the heat. When the temperature in the high-voltage battery coolant circuit reaches 17 °C, the active heating is switched off.

If the high-voltage battery temperature is >33°C and the ambient temperature is >25°C, the control unit switches on the electric battery coolant pump 4. In this case, the hot coolant from the high-voltage battery circuit flows to the solenoid valve 6 and is cooled in the high-voltage battery cooler 7. When this cooled coolant enters the HV battery coolant circuit, heat is transferred from the HV battery packs to the coolant and the cycle repeats.

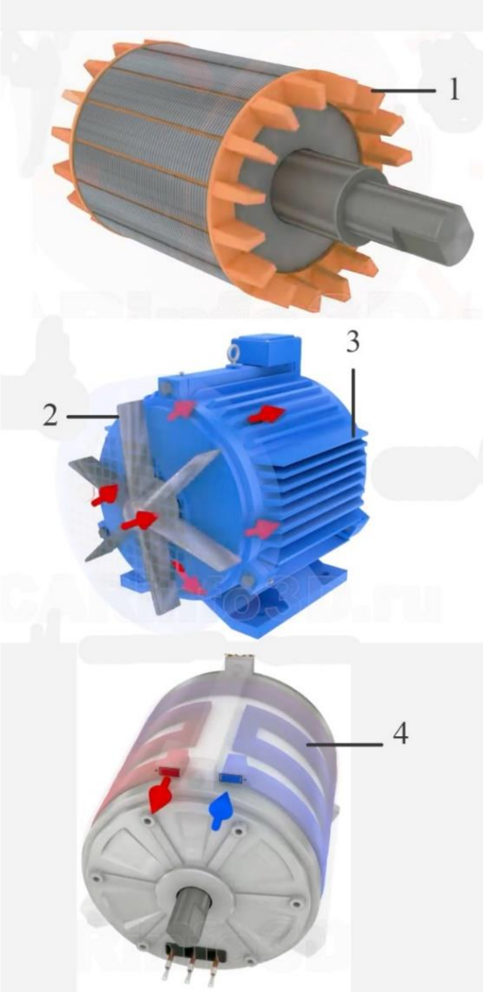
Preconditioning of an electric vehicle. Preconditioning of an electric vehicle includes battery preconditioning and interior preconditioning. Preconditioning of an electric vehicle is only performed when a vehicle departure event is detected by the driver. Battery preconditioning ensures that the high-voltage battery is at an optimal temperature and state of charge when you start driving to ensure maximum range and performance. Battery preconditioning only occurs when the vehicle is connected to a charger and a vehicle departure event is set. If the vehicle is not connected, the high-voltage battery temperature is not regulated.

If preconditioning is not performed, the EV will use its own high-voltage battery to heat or cool it and/or the interior, rather than an external power source, which will reduce range and performance.

During charging, the temperature of the high-voltage battery will rise to approximately 45 °C to ensure optimal charging speed. This temperature depends on many variables and the rate at which the battery is being charged. After charging, the battery is quickly cooled to approximately 26 °C to ensure long life and performance.

Battery preconditioning begins at the time calculated by the battery power management unit. Battery preconditioning occurs approximately 4.5 hours before the scheduled departure event. This process can take anywhere from 30 minutes to 4 hours, depending on battery temperature, power source, and environmental conditions. Once battery preconditioning is complete, the cabin is preconditioned for 30 minutes prior to departure, and battery temperature is not adjusted thereafter.

Electric motor cooling. Electric motor cooling can be done in various ways, the main ones (Pic. 14): using ventilation blades, fans and fins, liquid cooling and a combination of these types of cooling.

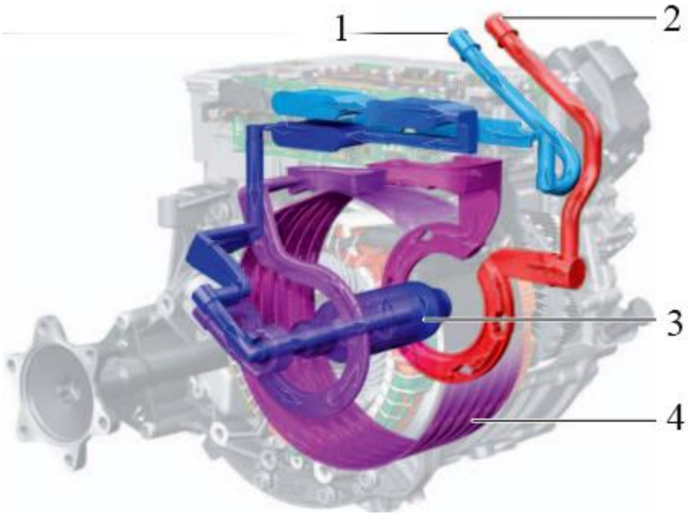


Pic. 14. Methods of cooling an electric motor:

1 - ventilation blades; 2 - fan; 3 - fins; 4 - liquid cooling.

The most effective system for electric motors in electric vehicles is liquid cooling. As an example, let's take the cooling of the electric motors in the Volkswagen electric car. The traction motors of the electric drive of the front and rear axles are cooled by a liquid circulating in a low-temperature circuit. Both the stator and the rotor are washed with coolant. The additional internal rotor cooling has brought significant benefits in terms of extending the service life and the frequency of using maximum power. To simplify maintenance and repair work, all coolant pipes are routed to the traction motor.

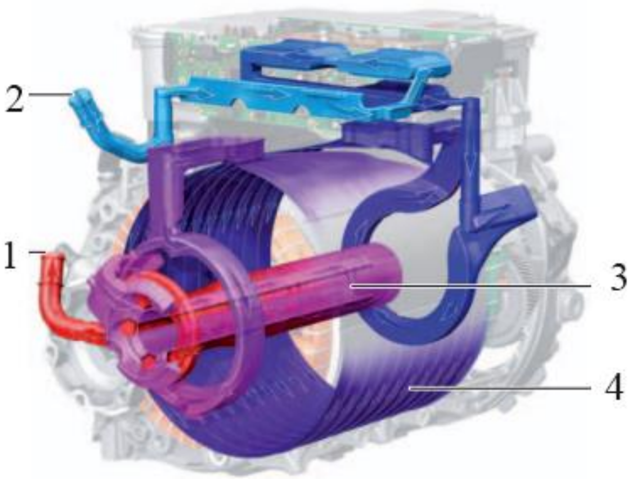
Front axle. The power electronics and the electrically driven traction motor are connected to the cooling system in series (Figure 15). The coolant first flows through the power and control electronics, then through the rotor cooling nozzle to the front axle. The coolant then flows through the stator cooling channels and returns to the cooling system circuit.



Pic. 15. Power electronics of the front axle electric drive and traction motor cooling system:

1 - coolant inlet; 2 - coolant outlet; 3 - internal rotor cooling; 4 - stator cooling jacket.

Rear axle. In the rear axle, the coolant first flows through the power and control electronics (Figure 16). After that, it enters the stator cooling channels. And only from there does it flow through the sprayer to the rotor and then returns to the circulation circuit.



Pic 16. Cooling system for power electronics and rear axle stator:

1 - coolant outlet; 2 - coolant inlet; 3 - internal rotor cooling; 4 - stator cooling network.

Temperature sensors. Each electric motor of an EV has a temperature sensor. For example, a Volkswagen electric car is equipped with two temperature sensors (Figure 17). In a front-wheel drive engine, these are the three-phase AC front-wheel drive coolant temperature sensor G1110 and the front-wheel drive motor temperature sensor G1093. The three-phase AC front-wheel drive coolant temperature sensor G1110 monitors the incoming coolant temperature. The front-wheel drive motor temperature sensor G1093 measures the stator temperature. For greater measurement accuracy, this sensor is mounted on the stator winding and is duplicated, i.e. two sensors are mounted on the stator winding, although only one is needed. If one stator temperature sensor fails, the other performs the temperature monitoring function. If only both sensors fail, the electric drive motor must be replaced. If one of the two sensors fails, the event is not recorded in the recorder. Only the front-wheel drive motor temperature sensor G1093 is displayed in the measured values.

The design on the rear axle is similar. The temperature sensor for the rear traction motor G1096 is mounted on the stator. The coolant temperature is measured by the three-phase AC coolant temperature sensor for the rear electric drive G1111.

Pic. 17. Temperature sensors:

1 - electric drive coolant temperature sensor; 2 - electric motor coolant temperature sensor.

Mechanical seal. Due to the high power, electric drive traction motors require internal rotor cooling, which is provided by a coolant flow through the rotor shaft. To prevent fluid from the electric motor from entering the stator, the rotating rotor shaft is fixed to the stationary housing using mechanical fasteners. These seals are provided by fixed teeth and, unlike conventional radial lip seals, are designed for high rotational speeds. The Volkswagen electric car uses one mechanical seal on the front traction motor and two on the rear.

As part of the service, the fluid must be drained from the front reservoir every 30,000 km or every two years.

The leaking coolant is collected in a receiver tank attached to the electric motor. The front axle has a recess in the resolution cover where the coolant collects. There is also a threaded drain plug.

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