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THE STEPS OF CREATING AN EXPERIMENTAL SYSTEM FOR ACCUMULATION AND STORAGEOF ELECTRICAL ENERGY

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ABSTRACT

The basic questions of the integrated environmental safety and energy conservation issues in the transport sector of Russia and the world as a whole are viewed in this scientific article. The usefulness of hybrid and electric vehicles is shown. Modern types of accumulator cells used in hybrid and electric vehicles were examined. The main stages of development, manufacturing and testing of complex accumulation and energy storage system for the driverless electric vehicle of FSUE NAMI were analyzed. The main aspects of operation of the electric vehicles at low ambient temperatures were considered. The results of the laboratory tests for the accumulation and energy storage system with thermostatic system were shown.

Keywords: vehicle, electric vehicle, energy efficiency, control system, accumulation, energy storage system, thermoelectric element.

1. INTRODUCTION

Currently, most of the world's automotive countries are trying to find the solution of the integrated environmental safety and energy efficiency issues by emission regulation of CO_2, as well as by the implementation of vehicles with alternative energy (vehicles with hybrid power generation systems, electric cars, vehicles, fuel cell and a lot others).

Directions of the development of electric vehicles, vehicles with the hybrid power generation systems and their components are the most optimal from the point of view of solving of the big cities' environmental issues (population is over 5 million people), megaregions (resort zone) and tunnels with heavy traffic flows, taking into account more and more increasing requirements on emission of the harmful substances and CO_2 greenhouse gas reduction.

2. RESEARCH METHODS

The study used the research methods of system analysis including methods of decomposition and optimization of technical solutions. This method is based on the use of thermoelectric module on the basis of Peltier effect.

3. MAIN PART

The development of vehicles on electricity is one of the most promising directions in the alternative energy sector. Their use allows reducing fossil fuel consumption and diminishing the harmful effects of transport on the environment. Energy storage devices for electric traction in vehicles are typically the electrochemical batteries. At the current stage of the development, even modern lithium-ion batteries have limited energy intensity per unit of weight that makes it impossible to provide the autonomous run of the electric vehicle equal to the autonomous run of conventional vehicle with internal combustion engine while using a consumer battery of an adequate size.

The selection of the type of electrical energy storage has a particular significance in the design of an electric vehicle. Modern batteries have better specific characteristics compared to other battery chemistries (Table-1). However, electric cars are trailed traditional vehicles in the ratio of the total mass and the transported actual load [1,7,10,11].

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Table-1. Performance characteristics of various battery chemistries.

Theoretical				Practical		
Battery type	V_{max}	**Charge capacity Ah/g**	**Energy density Wh/kg**	V_{nom}	**Energy density Wh/kg**	**Energy density Wh/L**
Lead-acid	2.1	0.12	252	2.0	35	100
NiCd	1.35	0.181	244	1.2	40	90
Ni-MH	1.35	0.178	240	1.2	80	220
Li-NiCo	4.1	0.109	448	3.8	200	420
IMR	3.5	0.122	426	3.0	150	400
LiFePo4	3.65	0.111	405	3.4	115	255
LiTiO	2.8	0.09	252	2.5	75	150
Li-S	2.5	0.341	950	2.15	400	365
Sodium metal chloride	2.6	0.22	572	2.5	120	190
Zinc-air	1.6	0.82	1312	1.2	400	900
Magnesium-air	3.1	2.2	6820	1.4	800	1390
Lithium-air	3.4	3.68	13124	2.7	2500	3750

In electric vehicles, a traction battery functions as a fuel tank. At the same time it is a "trouble spot" of this kind of alternative transport. Batteries of which the accumulator unit consists of, even a modern lithium-ion one, have relatively low rates of specific power and specific energy consumption. For autonomous run of the electric vehicle on a single charge, comparable with the run of the traditional vehicle with an internal combustion engine (ICE), a battery of high energy consumption and, consequently, of a large mass is required.

Usually in electric vehicles the rechargeable batteries with specific energy of the order of 110 ÷ 150 W·h/kg are used. At assembly the traction battery of them, power consumption will decrease because of the additional elements – jar, cooling system, monitoring system. It will take not more than 120 Wh/kg taking into account the efficiency coefficient of performance (COP) of the electric motor drive (85% on average). Energy density of gasoline (at the lower calorific value of a combustible) is 12.000 Wh/kg. With the coefficient of efficiency of the thermal engine which is in the range of 10 ... 36%, the energy it generates from 1 kg of fuel is 1220 ... 4400 Wh/kg, which is 8 ... 28 times much than the energy stored in the traction battery. Thus, for autonomous run of the traditional vehicle fuel tank having a volume of 40-45 L, the electric vehicle shall have a mass of about 1000 kg which is not acceptable neither technically nor economically [9, 12-15]. The solution of this problem by increasing the battery capacity leads to higher cost and increase of vehicle weight, which in turn increases the energy consumption for overcoming the movement resistance forces. In addition, the large traction battery has a prolonged period of 8 hours charge on average.

All this gets more complicated if the electric car is used in adverse climatic conditions, in the countries where the winter air temperature is negative from 0°C to -30°C.

The climatic conditions of the Russian Federation are among the toughest in the world. For example, in Moscow winter temperature can be -30^{0}C, and in Irkutsk -50^{0}C. At the same time the Russian Federation has a vast territory and long distances between cities. The lithium-ion battery systems can be operated in a quite wide range of temperatures, but there are extremes we should remember all the time, especially in countries with a cold climate and variety of time zones such as Russia. The inherent disadvantages of the electric car multiplied by climatic features of the countries with a cold climate exacerbate the problems hindering the popularization of electric transport.

Negative characteristic of the lithium batteries is that they are very poorly adapted to the freezing temperatures. Typically, they admit discharging at temperatures below -10 ... -20°C (with decreasing capacity and current output) and charging at temperatures above zero only.

Batteries suffer from the cold for the reason that the electricity liquid which is a conductive substance of the electric accumulator providing the electric power between the positive and negative pole, thickens in cold weather, so the electrochemical processes become slower in the battery. The bad conductivity of the electricity liquid increases the internal resistance of the battery system which provides much less energy at the output [6,8].

The lithium-ion batteries are being charged quite well at low temperatures above zero, but they also can be plug in for fast charging at the temperature range of 5-45°C. Charging and discharging processes are being well

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at high permissible temperatures (till 45°C), but it decreases the battery lifetime.

At temperatures below +5°C it is necessary to reduce the charging current. The charging is not allowed at temperatures below 0°C. In this case the external changes are not observed but the chemical processes needed for the correct battery operation will be broken, which may result in permanent damage to the battery. During charging at this temperature, the lithium metal particles may reach the anode. This coat is not lost at the charging/discharging cycles [2-5]. The batteries with this coat are less breakage-proof and can lose their efficiency at vibrations.

Currently, the experimental model of driverless electric vehicle was designed, developed and tested at the Central Scientific Research Automobile and Automotive Engines Institute, abbreviated as NAMI (Figure-1).

Figure-1. Driverless electric vehicle.

The energy accumulation experimental system was developed for this vehicle. It designed for checking and studying of the developed technical solutions in providing electric energy for the traction module. The developed energy accumulation experimental system consists of three battery modules and eight sub-modules of 12 accumulator cells each.

The energy accumulation experimental system includes an environment monitoring board and a board of active balancing that works on the principle of flyback transmission accumulated in the primary side of the balancing torque converter.

The monitoring system provides:

- Tracking set parameters of accumulators and accumulator battery (for example, voltages, currents, temperatures values). Specific necessary parameters are determined by the accumulator battery developer and with regard to the customer's requirements when it targets to a particular customer.

- The defined algorithm for the accumulator battery operation for the purpose of its safe exploitation and improving its performance (for example, emergency stop of AB accumulators from charging or discharging external circuits at excessive currents; reconnection at the installation of acceptable levels).

- Transferring information to the user (visually or via the communication interface) about the values of the monitored parameters.

- The possibility to adjust the parameter settings by user.

- Other AB functions performing controlled by the developer to provide the optimal modes of charging, discharging and consumer characteristics.

The data are transmitted via the CAN channel providing galvanic isolation of metering and balancing circuits up to a voltage of 600 V.

The experimental electric power storage system includes 96 accumulator cells such as AMP20M1HD-A type. Rated voltage is 316.8 V, the energy intensity is 27 kW/h, and the total internal resistance is 57.6 milliohms. The physical form of the experimental electric power storage system is shown in Figure 2.

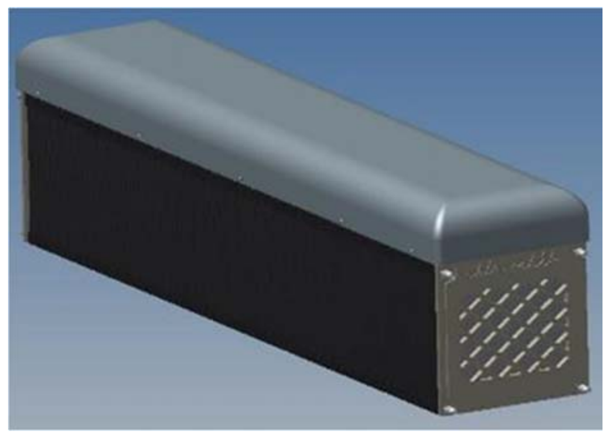

Figure-2. 3D model of energy storage system.

When designing the power storage system based on the lithium cells, their temperature change was taken into account, depending on the performance modes and ambient temperatures.

To solve this issue the thermostatic system was developed using the Peltier thermoelectric elements. Also, the method of calculation of heat transfer has been developed which allows calculating the necessary parameters of these elements.

For studying the operating temperatures of the accumulator modules in the designed thermally insulated tankages, the preanalysis of heat loss at different ambient temperatures and at thermostatic temperature of $+10^{0}$C was conducted. The characteristic curves obtained by using foamed polyethylene (curve 1) and airgel of Cryogel Z type (curve 2) are shown in Figure-3. The tests carried out in a climatic chamber showed that the convergence with the calculated data is not worse than 4%.

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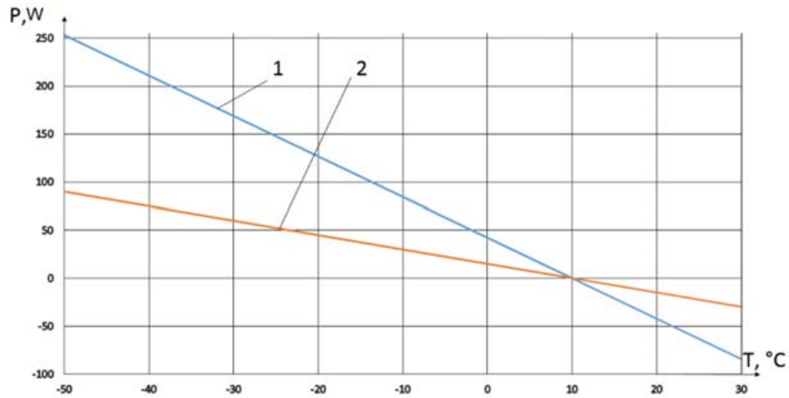

Figure-3. Capacity of thermal losses at low temperatures.

For further calculations, considering the real low capacity of heat transmission, we assume that the heat exchange of the internal environment of the developed tankages with the external environment is small at positive ambient temperature, so we can neglect it. This assumption will lead to a slight error in the calculations but this will not have a significant impact on the final results of the calculations.

The thermal efficiency calculation was performed based on the movement while the driving cycle according to UNECE Regulation No 83. For this case, the discharging and charging characteristics of the accumulator battery are shown in Figure-4.

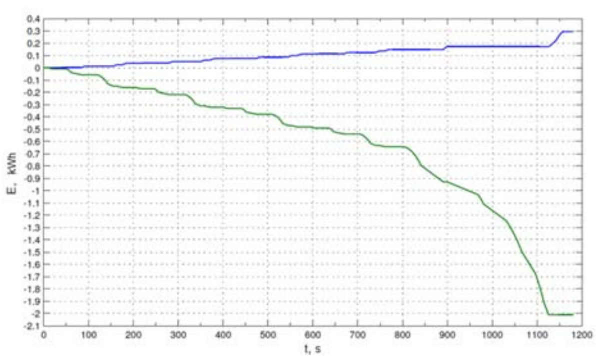

Figure-4. Results of the computational research of input and output streams in energy storage battery of the developed vehicle.

The result of the research shows that the total energy received and given by the accumulator battery is $W_{AB} = 2.3$ kWh.

The calculated average efficiency coefficient of the integrated accumulator battery in these conditions is $\eta = 0.95$. Then the total thermal power released in the accumulator battery is 115 Wh, or the afterheat output is 116 watts taking into account the duration of the cycle for a single accumulator battery.

The Peltier thermoelectric module of TB-127-2.0-1.15 type is suitable for thermal efficiency compensation of such a level. The module provides the required temperature in the accumulator tankage at temperature of the heat-absorbent surface of +30°C. Table-2 shows the main characteristics of this module.

Table-2. Specification of thermoelectric module TB-127-2.0-1.15.

Thermoelectrical parameters	**Unit**	**Value**
I_{max}	Amps	16.1
U_{max}	Volts	15.7
ΔT_{max}	K	69
Q_{max}	Watts	156
R_{ac}(at 295 K)	Ohm	0.75
Tolerance	%	±10
All parameters except R_{ac} are given at T_h=300K		
Assembly parameters	Unit	Value
Wires	HB – 0.35 4 600	
Cross section	mm^2	0.35
Metallization	Not	
Sealing	Not	
Internal solder	^{0}C	139
Brazing solder	^{0}C	not
Operational parameters	Unit	Value
Working temperature range	^{0}C	-50 ÷ +80
Max. processing temperature	^{0}C	130
ROHS compliance		YES

The utilization of this module allows to provide thermostatic process of the accumulator battery in the considered performance mode at the level of 10-15°C.

Let us view the thermal efficiency mode at charging from the vehicle-borne charger. The vehicle-borne charger provides current charging current of 12 A. The charging lasts for about 8 hours. The average battery voltage is 250 V. The calculated average integrated effectiveness of the accumulator battery of the viewed mode is $\eta = 0.98$. The total thermal power released in the

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accumulator battery is W_{TP} = 480 Wh, or W_{TP1} = 576 kJ taking into account the duration of the cycle for a single accumulator battery module.

The power of the Peltier selected element at the cooling mode at temperature of +30°C in accordance with its characteristic curves is 130 watts. 8 hours of temperature compensation energy will make W_{TC} = 3744 kJ.

It is evident that the required cooling is taking place. At this time the thermostatic system shall have the on-off operation at about 10°C.

Let us consider the actual maximum rating of the accumulator battery. This is a car drive mode on the level road at speed of 130 km/h for 60 minutes. In this mode the traction motor operation with an output of 25 kW is required. In view of effectiveness of the electric motor, its the most favorable mode equals to 0.95 and the power consumption for 60 minutes will be 26.3 kWh.

Thus, the energy of the battery discharging will be 26.3 kWh or 94680 kJ. In this case, the amount of energy consumed in the accumulator battery for heating is 4734 kJ, and respectively 1.580 kJ for one accumulator module.

As noted above, the output of the Peltier selected element in the cooler mode at temperature of the heat-absorbent surface +30°C is 130 watts in accordance with its performance characteristic curve. Temperature compensation energy for 60 minutes will be 1400 kJ.

Obviously, the absorbed heat of the Peltier element is not sufficient to provide the desired temperature compensation. However, an excess of thermal energy which will be spent on heating the accumulator module is only 180 kilojoules in one accumulator module. Given that the lithium battery heat capacity is 1.1 kJ/kg^{0}C and the mass of the accumulators in the module is equal to 96 kg, the total increase in temperature does not exceed 1.7^{0}C. It is quite acceptable.

Operation of electric vehicles and vehicles with hybrid power generation systems in Russia has significant features. This is due to severe winter conditions in central and, especially in the northern regions and Siberia where winter temperatures go to -30^{0}°C and below.

The lithium-ion batteries cannot take charge at low temperatures. The attempts to charge them lead to a substantial acceleration of degradation. Discharging the accumulators in these conditions aside from reducing the actual capacity also leads to an acceleration of the degradation process. It should be bear in mind that the cost of accumulator batteries has a significant share of the total cost of electric vehicles and vehicles with hybrid power generation systems. This particularly applies to electric vehicles. Certainly, it is advisable to ensure the parking of these vehicles in the heated space. But often this is not possible. In addition, when driving this type of a car to the workplace of the owner, the vehicle can be on the parking for a long time, up to 9 hours or more. And the accumulator battery temperature can decrease substantially.

Thus, it is extremely important to ensure the operational circumstances for the accumulator batteries in comfort conditions for them.

Let us assume that in the adverse conditions of storage the temperature of the accumulator battery, investigated in this paper, drops to -40°C. For heating from -40°C to +10°C of the accumulator module of 96 kg with specific thermal capacity of 1.1 kJ/kg°C, it is necessary to consume energy equals to 5280 kJ.

The laboratory experiment with the developed accumulator module was conducted. It was found that at temperature -40°C of the single accumulators it is required heating power of about 140 watts to maintain the temperature in the module +55°C. This low required power is due to the relatively small heat-absorbent surface of the single accumulators. Raise of the heating temperature can lead to local overheating in the accumulator cell and release of lithium metal on the overheated electrode elements that is not acceptable. It turns out that the time required to power compensation in 5280 kJ at a heating power of 140 watts will be 10.5 hours.

Certainly, taking into account the thermo-insulated state of the accumulator module, it can be argued that the accumulator cooling process will be quite slow. But if a car is to be stored at very low temperature for several days, then the cooling of the accumulators will be significant.

The proposed solution to this problem is following. It was found in this experiment that at ambient temperature of -40°C, it is enough to have internal heating at 90 watts in order to maintain the temperature in the accumulator module of +10°C. Thus, to provide temperature control of the accumulator module at a predetermined level it is necessary to include the built-in Peltier element in the heating mode.

The maximum temperature difference for the Peltier element will be 65°C which is almost the limit of providing heat exchange for the selected element type. However, a resistive heat is released on its "warm" side which is forming while the passage of current. The magnitude of this heat release will be 160 W, i.e. the amount of the released heat is even in excess. But the thermostatic system operates in on-off mode, thereby maintaining the desired temperature in the accumulator module will be provided.

4. RESULTS

The developed accumulation and energy storage system is designed to provide power for electric traction drive, as well as for accumulating and storing energy produced by regenerative braking.

The use of the control system of the electric vehicle accumulator batteries in the developed accumulation and energy storage system allows to provide:

- integration of the accumulator battery modules (AB) into a single storage device, capable of operating as part of electric vehicle with the required reliability;

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- protection of AB accumulators from overheating caused by the work of batteries with high currents in charging or discharging modes;
- adequation of stress of the individual AB battery cells with minimum loss in balancing energy;
- thermostatic control of the AB battery cells providing their work in the most favorable conditions not related to the environment;
- an increase in the AB resource by reducing the load on the individual accumulator cells having a capacity less than the average for the battery;
- providing electric vehicle components for the correct information about AB state for more energy-efficient operation.

The developed accumulation and energy storage system provides: voltage not less than 300 V; energy intensity not less than 27 kW/hour; maximum charging current not less than 90A; maximum charging current not less than 270A.

The developed accumulation and energy storage system is intended for the electric vehicles operating in harsh climatic conditions of the Russian Federation.

The application of the developed thermostatic principle allows to provide accumulator battery operation in the most favorable temperature range, which in turn provides an increase in battery service life of not less than 10 ÷ 20%. The developed thermostatic system will provide operating temperatures in the range of -40...+50°C and the power consumption no more than 150W with the selected type of insulation material.

5. CONCLUSIONS

a) The modern mass-produced electric vehicles do not meet the requirements of their use at low ambient temperatures according to their performance characteristics.
b) As a result of the study confirmed by the experiments, the technical requirements for thermostatic system of the accumulator batteries based on the lithium batteries for operation at low temperatures were formed.
c) The developed thermostatic system has demonstrated its efficiency, and it ensures the quality performance of the accumulator batteries of electric vehicles in a wide temperature range typical for the Russian Federation territory.

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