M.F. Dmytrychenko, *Dr. of Technical Sciences*
Yu.F. Gutarevych, *Dr. of Technical Sciences*
D.M. Trifonov, *Cand. of Technical Sciences*
O.V. Syrota, *Cand. of Technical Sciences*

National Transport University1,
M.Omelianovycha-Pavlenka Str., Kyiv, 01010, Ukraine,
e-mail: d.trifonov@ntu.edu.ua

THE USE OF THERMOELECTRIC ENERGY CONVERTERS TO REDUCE THE INFLUENCE OF NATURAL AND CLIMATIC FACTORS ON THE TECHNICAL READINESS OF A VEHICLE

The article discusses the problem associated with the operation of a vehicle at low ambient temperatures, substantiates the need for special measures to maintain the optimal thermal regime of the battery. The analysis of the factors influencing the start of a cold engine is carried out. The effect of low temperature of the storage battery on the energy performance of the electrical starting system is shown. Computational studies of the proposed system for compensating the heat losses of the storage battery during the maintenance of a vehicle at low temperatures by the method of thermostating with the use of thermoelectric energy converters are carried out. Bibl. 14, Fig. 4, Tabl. 3.
Key words: technical readiness, storage battery, thermoelectric generator, phase transition thermal accumulator, electric heating elements.

Introduction

The car has become an integral part of modern life. However, its use raises a number of problems primarily related to environmental pollution and low energy efficiency. Since the creation of the car, there has been a problem associated with ensuring a reliable and trouble-free start of the cold internal combustion engine (ICE) at low ambient temperatures. This problem is still relevant today.

The purpose of the work is to carry out computational studies of the system to ensure compensating the heat losses of the storage battery by the method of thermoelectric stabilization of its optimal temperature when a vehicle is kept out of the garage at low ambient temperatures.

Analysis of previous research

Review and analysis of literary sources related to the impact of natural and climatic factors on a vehicle during operation, primarily in urban conditions, characterized by long periods of inactivity, small movements, frequent and short stops and garage-free maintenance during the inter-shift period allows one to determine precisely the ambient air temperature as the main factor that affects the technical readiness of a vehicle.

Low temperatures complicate the start of a cold engine and lead to deterioration of its operating conditions, which generally reduces the technical readiness and use of the vehicle for its intended purpose.

The technical readiness of a vehicle at low ambient temperatures is mainly determined by the reliable start of a cold engine and the recovery time of its thermal regime. It is largely complicated as a result of a decrease in the discharge characteristics of storage battery in the mode of starting the engine due to an increase in the viscosity and resistance of the electrolyte, an increase in resistance to cranking of the engine crankshaft and deterioration of the conditions for the formation of the fuel-air mixture.

Mixing deteriorates due to a decrease in the intake temperature below the optimum, which leads to a deterioration in fuel evaporation and a decrease in the temperature of the working fluid at the end of the compression stroke. With a decrease in the ambient air temperature from 20 ° C to minus 30 ° C, the temperature at the end of the compression stroke decreases by 100 ... 210 ° C, while in diesel engines there is a delay in the autoignition of fuel two to three times in time, which leads to a deterioration of burning process. The viscosity of winter diesel fuel with a decrease in inlet air temperature from +20 ° C to minus 30 ° C increases 15 times. The viscosity of gasoline when the inlet temperature decreases from 0 ° C to minus 30 ° C is one and half times higher, and evaporation is 50 percent lower.

As the temperature decreases, the viscosity of the oil in the engine lubrication system increases. This leads to an increase in friction power losses in the conjugate parts of the cylinder-piston group and as a consequence to a decrease in the cranking speed of the engine crankshaft.

The reliability of starting the internal combustion engine at low ambient temperatures is largely determined by the performance of the battery. The battery performance is understood as the maximum possible number of crankshaft rotations with a duration of 15 seconds each [1].

The decrease in the temperature of the electrolyte is accompanied by an increase in its viscosity and internal resistance, which leads to a significant decrease in voltage at the terminals of the battery, which reduces the power developed by the starter in the cold engine start mode. With a decrease in the temperature of the electrolyte from + 30 ° C to minus 40 ° C, its resistivity increases 8 times [2]. According to the Research Institute of Starter Batteries, at a temperature of 0 ° C, the current efficiency of batteries is 90%, and at minus 40 ° C - 20%. At an electrolyte temperature below minus 20 ° C, an intensive deterioration in the efficiency of charging batteries from the on-board network was established. When charging the battery from a stationary device, the battery electrolyte is actively boiling at a constant density. Because the energy supplied is almost completely spent on water hydrolysis, batteries are practically inoperable at minus 30 ... 35 ° C [3].

A decrease in the battery capacity in the starting mode leads to a decrease in the starting crankshaft rotation speed, and a decrease in voltage leads to a decrease in the torque developed by the starter. Achieving the required starting speed of the crankshaft at low temperatures is difficult due to an increase in the cranking resistance torque of the engine crankshaft. In the process of starting the engine at low temperatures, the determining factor is the ratio of the moment of resistance of the engine crankshaft and the torque developed by the starter.

In this connection, the main concern of ensuring the operability of the battery and, as a consequence, of the technical readiness of a vehicle as a whole, should be the maintenance of the optimal temperature of the battery. The easiest way to solve this problem is to slow down the electrolyte cooling. For example, according to the Research Institute Avtoprilad uninsulated battery 6ST-132 is cooled from + 25 ° C to minus 30 ° C at a rate of 6.6 °C for one hour; and insulated – 1.4 ° C for one hour.

In practice, there are many ways to ensure the technical readiness of a vehicle at low temperatures. However, most of them require the solution of complex design and technical problems and, under operating conditions, turn out to be ineffective or quite energy consuming. Therefore, the proposed work considers those that are based on the methods of storage battery thermal control through use of secondary energy resources of the internal combustion engine, which arise in large quantities during its operation.

Research results

With the rapid growth in the number of vehicles over the past decades, combined with the tightening of standards for fuel consumption and emissions of harmful substances, the utilization of thermal energy of exhaust gases as part of the secondary energy resources of a transport engine is becoming a promising direction for solving the above problem. This allows the implementation of energy-efficient technologies for road transport. Exhaust gases have a high thermal potential, take about 30% of the fuel energy into the environment, not only wasting primary energy resources, but also increasing the heat load on the environment.

Application of heat accumulators using phase transition heat-accumulating materials is an effective and promising way of storing heat energy on board a vehicle. This method makes it possible to provide a high density of accumulated energy with an isothermal nature of the accumulation process and makes it possible to store accumulated thermal energy on board a vehicle for quite a long time.

In this regard, it seems promising to develop systems that would have the ability to convert the thermal energy accumulated in phase transition heat accumulator into electrical energy. To solve this problem, according to the authors, thermoelectric energy converters can be effectively used [4]. The advantages of the latter are the absence of moving parts, silent operation, environmental friendliness, versatility in terms of methods of supply and removal of thermal energy, potentially high reliability [5, 6].

This article presents the results of computational studies of the thermoelectric system proposed in [7,8], which provides the optimal thermal regime of the starter battery at the end of the operation of the internal combustion engine during the maintenance of the vehicle at low ambient temperatures.

Thermoelectric generators (TEG), as autonomous direct current sources, received intensive development after semiconductor thermopiles were taken as the basis for their design. Over the past decades, there has been a constant improvement of semiconductor thermoelectric materials, which is aimed primarily at increasing their thermoelectric figure of merit in order to increase the electricity they produce and improve the efficiency [9].

Significant disadvantages of semiconductor TEGs are their fragility, high cost and complexity of the design of an automobile thermoelectric generator (ATEG) to ensure efficient operation, due to the need for an external source of cooling, which makes it possible to obtain the necessary (stable) temperature gradient and the presence of an electronic converter, which allows maintaining the necessary output voltage. The need for such a scheme is explained by the fact that the electromotive force generated by ATEG is not constant, since the temperature difference constantly changes its value in different operating modes of the transport ICE.

In the conditions of real operation of the vehicle, the ATEG, from the point of view of the efficiency and stability of its thermoelectric properties, must have the necessary mechanical strength and chemical resistance under the conditions of prolonged vibration and shock loads, with sharp drops in the temperature, pressure, and humidity.

Thus, it is fair to assume that in order to obtain electrical energy sufficient to power low-power devices under conditions of a small temperature gradient, metal conductors are more suitable for the manufacture of ATEG.

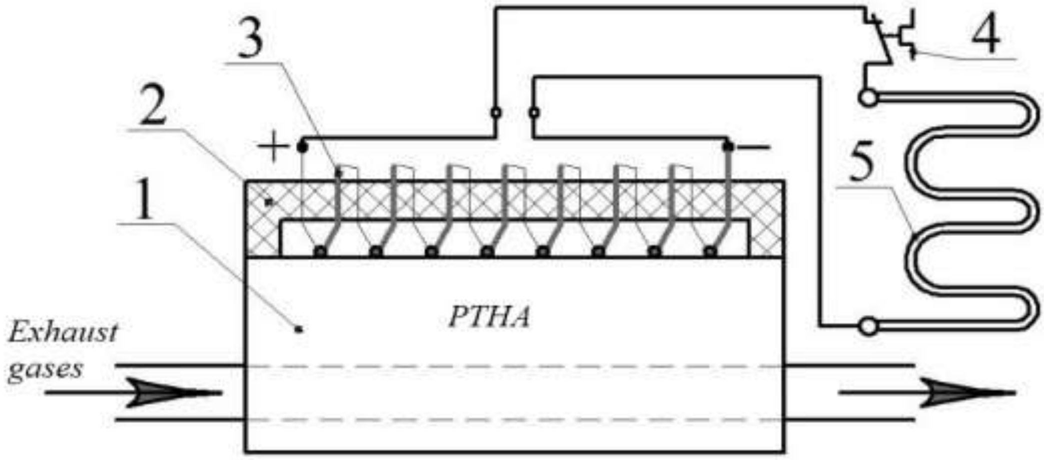


Fig. 1. Thermoelectric system for utilization of thermal energy of exhaust gases with phase transition heat accumulator:
1 – phase transition heat accumulator,
2 – layer of heat-resistant compound,
3 – thermoelectric generator,
4 – heat regulator, 5 – heating element.

Taking into account the above, the authors proposed a method for increasing the thermal readiness of a vehicle, in particular, the electrical starting system, under low temperatures. The implementation of this method and, as a consequence, the provision of the optimal thermal mode of the storage battery, is possible due to the use of a device for compensating heat losses of storage battery by thermostating with heating elements.

The heat capacity of the battery is quite high, so when you install it in a container with insulated walls (thermocase), the rate of drop of the electrolyte temperature will be quite low. Heating elements are added inside the thermocase. The built-in temperature regulator turns off heating on reaching + 25 ° C and turns it on again at + 15 ° C.

The operating principle of the proposed system is as follows (Fig. 2): after stopping the internal combustion engine the storage battery naturally cools down (section I), upon reaching the storage battery temperature 15 °C, electric heating elements are connected to ATEG to heat the storage battery to 25 °C (section II), following which the heating elements are turned off. After reducing the temperature of the storage battery to 15 °C (section III) – the process is repeated. Responsible for the switching of electrical circuits is the electronic control unit that receives information from the temperature sensor of the storage battery (the temperature sensor is installed on the negative terminal of the storage battery).

The proposed technical solution makes it possible to generate electrical energy without any additional energy transmitted to the system both the internal combustion engine is in operation and when the vehicle is kept in open areas under low temperatures. Based on the results of previous experimental studies, the possibility of using metal TEGs for generating electrical energy for quite a long time after the end of the ICE operating cycle was confirmed [7].

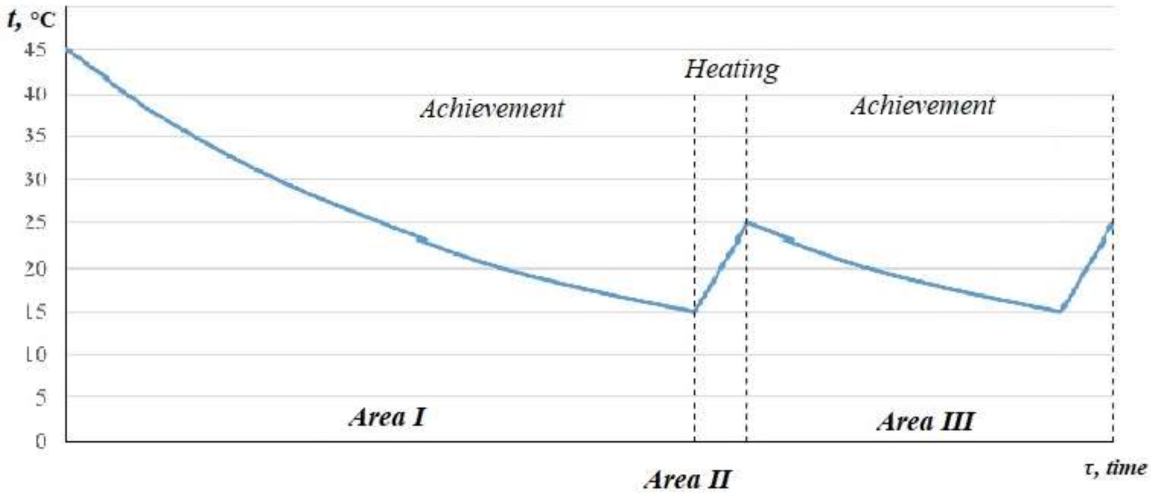


Fig. 2. Operating principle of a device for compensating heat losses of storage battery

Computational studies

Calculation of the amount of energy required for thermal stabilization of the 6CT-44A battery of ZAZ Tavria class cars with a capacity of 44 A·h in the temperature range 15...25 °C.

The mass of the specified battery is 13.6 kg, of which the mass of the electrolyte is 3.6 kg. To simplify the calculation, we assume that another mass – 10.0 kg falls on lead (the mass of the body of the storage battery and separators is neglected). Some design parameters of the 6CT-44A battery are shown in Table 1 [10].

Table 1

Some design parameters of the 6CT-44A storage battery

Overall dimensions, mm			Mass, kg	
length	width	height	without electrolyte	with electrolyte
207	175	175	10	13,6

The amount of heat required to heat the battery (Q_b) is defined as the sum of the amount of heat for heating the lead (Q_{Pb}) and the amount of heat for heating the electrolyte (Q_{El}):

$$Q_{АБ} = Q_{Pb} + Q_{Ел} \quad (1)$$

The amount of heat is defined by the formula:

$$Q = m \cdot c_p \cdot \Delta t, \quad (2)$$

where m is mass of heated substance, kg;

c_p is specific heat, J/kg·K;
Δt is temperature difference, K.
The values of specific heats of storage battery components are given in Table 2.

Table 2

The values of specific heats of storage battery components

Storage battery components	c_p, J/(kg·K)
Water H_2O	4182
Sulphuric acid (100%) H_2SO_4	1380
Lead *Pb*	128

The heat capacity of electrolyte with a density of 1.28 g/cm^3 was determined using the data given in Table 3 [11].

Table 3

The amount of distilled water and acid, required
to prepare 1 l of electrolyte with a density of 1.28 g/cm^3 (at 25 °C)

The required electrolyte density, g/cm^3	The amount of water, l	The amount of sulphuric acid with a density of 1.83 g/cm*	
		l	kg
1.28	0.781	0.285	0.523

Using the data in Table 1 and 3, we received the required amount of sulfuric acid with a density of 1.83 g / cm^3 - 1.88 kg; distilled water - 2.81 kg. Based on the obtained values and data of

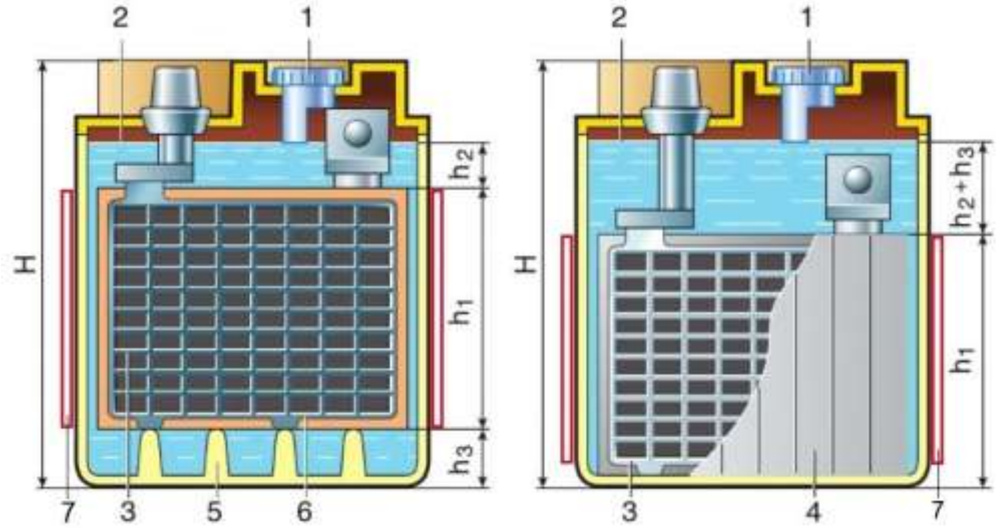
Table 2 we calculated the specific heat of the electrolyte with a density of 1.28 g/cm^3 - 1.15 kJ/(kg·K).

Based on the obtained values and formulae 1, 2, we calculated the amount of heat required to heat the 6ST-44A battery from 15 ° C to 25 ° C:

$$Q_b = 10 \cdot 10.0 \cdot 128 + 10 \cdot 3.6 \cdot 1150 \approx 54 \text{ (kJ)}$$

If the calculated thermal energy is converted into consumed electrical power, then we get about 15 W · h.

In practice, it is impossible to achieve the full use of storage battery active materials involved in current-forming process. Moreover, the electrolyte (height h_3), which is located in the mud space between prisms 5 and the electrolyte reserve (height h_2 in a battery with a sheet separator and height h_2+h_3 in a battery with an envelope separator), does not take part in current-generating process during electrical starting of the internal combustion engine. In this connection, the paper proposes to limit the heating area of storage battery (side and end surfaces with height h_1) by the height of the electrode to reduce the power of the electric heating element 7 (Fig. 3).



a *b*

Fig. 3. Schematic of storage battery: [12]
a – conventional battery; b – battery with unattended envelope separators;
1 - plug; 2 – electrolyte level in a battery; 3 - electrode; 4 – envelope separator;
5 – mud space prisms; 6 – card separator;7 – electric heating element;
H – battery height; h_1 – electrode height; h_2 – electrolyte reserve in a battery with a sheet separator; h_3 – height of prisms; h_2 + h_3 – electrolyte reserve in a battery with an envelope separator

Therefore, the value of the required electric power of the electric heating element can be much lower than the calculated and with regard to the volume of electrolyte that does not participate in the current-generating process it can be reduced by 40… 60%, which will make up to 9 W · h.

Calculation of thermoelectric generator.

Based on the analysis of possible electric heating materials for heating storage battery, the use of carbon fiber material as an external electric heater of storage battery is proposed (Fig. 4).

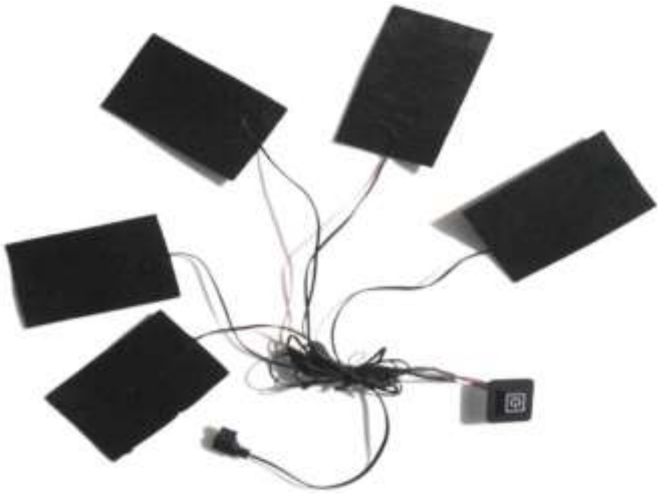


Fig. 4. Electric heating elements based on carbon fiber materials

The use of carbon fiber materials as heating elements helps provide:
• larger area with a uniform temperature distribution on the surface;
• high heat transfer rates;
• reliable operation for a long time;
• low cost of electricity consumption compared to counterparts about 30%;
• heating in 3s after power supply and the same fast cooling.
The technical characteristics of the proposed heating element are as follows:
• thickness: about 0.3 mm
• substrate size: about 110 * 70 mm
• heating temperature: 50…55 °C
• voltage: 3.7 ... 5.0 V
• current: 1.85 ± 0.05 A
• power output: 8.5 ± 0.2 W
• resistance: 3 Ohm

Based on the technical characteristics of the heating element, we calculated a thermoelectric generator based on chromel-copel (L) thermocouples to power an external electric heater of 6CT-44A storage battery. As a heat source, a phase transition thermal accumulator was used, assuming its average temperature in the zone of contact with TEG (t_h) = 78.5 °C, the temperature of the cold junction (t_c) = 0 °C. The calculations used the method proposed in [13].

The purpose of the calculation is to determine the required number of series-connected *L* type thermocouples to ensure the operation of the external electric heater of storage battery.

The required number K of thermocouples in TEG, each of which having internal resistance *r* and thermoEMF e_t, was calculated by the formula (3):

$$K = \frac{U}{e_t - Ir} \qquad (3)$$

where U is voltage on the load, V;
e_t is thermoEMF developed by thermocouple, V;
I is current flowing in the thermocouple circuit, A

r is internal resistance of thermocouple, Ohm.

Current flowing in the thermocouple circuit was calculated by the formula (4):

$$I = \frac{e_t}{r + R} \tag{4}$$

where R is load resistance, Ohm.

The internal resistance of thermocouple was calculated by the formula (5):

$$r = \frac{\rho_1 l}{s_1} + \frac{\rho_2 l}{s_2} \tag{5}$$

where ρ_1, ρ_2 are the resistivities of materials of which thermocouples are made, Ohm·mm^2/m;
l is the length of thermocouple conductor (assumed to be equal for both conductors), m;
s_1, s_2 are cross-sectional areas of thermocouple conductors, mm^2.

According to [14], the thermoEMF developed by thermocouple of L type is on the average 4.1 mV. According to [14], the resistivity of chromel metal alloy was assumed to be 0.038 Ohm•mm^2/m and the resistivity of copel alloy – 0.027 Ohm•mm^2/m, with the wire diameter 0.7 mm and the length of both thermocouple conductors assumed to be 0.02 m.

Based on the results of calculating the cross-sectional area of the thermocouple conductors, we obtained 0.38 mm^2.

According to formula (5), the resistance of thermocouple was determined as r = 0.0034 Ohm. Formula (4) was used to calculate current flowing in thermocouple circuit, I = 0.0014 A, formula (3) – to determine the required number of thermocouples in TEG, K ≈ 1200 pcs.

Conclusions

1. Based on the results of the studies, a system was proposed for compensating the heat losses of the battery during the maintenance of the vehicle at low temperatures by the thermostating method using thermoelectric energy converters.
2. The proposed technical solution makes it possible to generate electrical energy, both when the internal combustion engine is operating and when the vehicle is kept in open areas at low temperatures, using a phase transition heat accumulator as a heat exchanger, which accumulates the thermal energy of exhaust gases.
3. To power the external electric heater of a car battery, it is proposed to use a thermoelectric generator on chromel-copel (L) thermocouples.
4. According to the calculation results, to ensure thermoelectric stabilization of the optimal temperature of the 6ST-44A automobile battery, the required number of series-connected L type thermocouples was determined, to ensure the operation of an external electric heater with a total power of up to 9 W - about 1200 pieces.

References

1. Krokhta G.M., Usatykh N.A., Guskov Yu.A., Voronin D.M. (2016). Osobennosti raboty starternykh akkumuliatornykh batarei pri samoprogreve dvigatelia v zimnii period [Operating peculiarities of starter storage batteries during self-heating of the engine in winter]. *Dostizheniia nauki i tekhniki APK – Achievements of Science and Technology of Agro-Industrial Complex*, 30

(12), 94-97 [in Russian].

2. Timinskii V.I. (1985). *Spravochnik po elektrooborudovaniiu avtomobilei, traktorov, kombainov [Handbook of the electrical equipment of cars, tractors, combines].* Minsk: Uradzhai [in Russian].
3. Pankratov N.I. (1985). Ekspluatatsiia akkumuliatornykh batarei pri nizkikh temperaturakh [Operation of storage batteries at low temperatures]. *Avtomobilnyi Transport*, 2, 16–19 [in Russian].
4. Kajikawa T., Funahashi R. (2016). Recent activity on thermoelectric power generation technology in Japan. *J. Thermoelectricity*, 1, 5-15.
5. Anatychuk L.I., Prybyla A.V. (2016). Comparative analysis of thermoelectric and compression heat pumps for individual air-conditioners. *J.Thermoelectricity*, 2, 31-39.
6. Anatychuk L.I., Lysko V.V. (2019). On the possibility of using thermoelectric generators for high-power transport starting pre-heaters. *J.Thermoelectricity*, 3, 80-92.
7. Dmytrychenko M.F., Gutarevych Y.F., Trifonov D.M., Syrota O.V., Shuba E.V. (2018). On the prospects of using thermoelectric generators with the cold start system of an internal combustion engine with a thermal battery. *J.Thermoelectricity*, 4, 49-54.
8. *Patent of Ukraine №136638* (2019). Dmytrychenko M.F., Gutarevych Yu.F., Trifonov D.M., Syrota O.V., Shuba S.V. Thermoelectric system of thermal energy utilization with thermal accumulator of phase transition [in Ukrainian].
9. Zu-Guo Shen, Lin-Li Tian, Xun Liu. (2019). Automotive exhaust thermoelectric generators: Current status, challenges and future prospects. *Energy Conversion and Management*, 195, 1138-1173.
10. Bykov K.P., Shlenchik T.A. (2006). *Avtomobili "Tavria", "Slavuta" ZAZ-1102, ZAZ-1103, ZAZ-1105 i ikh modifikatsii. Ustroistvo, ekspluatatsiia, remont, posobiie po remontu. [Automobiles "Tavriia", "Slavuta" ZAZ-1102, ZAZ 1103, ZAZ 11-05 and their modifications. Design, operation, repair, repair manual].* T.A.Shlenchik (Ed.). Chernigiv: PKF "Ranok" [in Russian].
11. Kashtanov V.P., Titov V.V., Uskov A.F. (1983). *Svintsovyie starternyie akkumuliatornyie batarei. Rukovodstvo [Lead starter batteries. Manual].* Moscow [in Russian].
12. Kurzukov N.I., Yagniatinskii V.M. (2008). *Akkumuliatornyie batarei. Kratkii spravochnik. [Storage batteries. Quick reference book].* Moscow: LLC "Book publishing house "Za rulem" [in Russian].
13. Bernshtein A.S. (1956). *Termoelektricheskiie generatory. Massovaia radio biblioteka. Vypusk 252 [Thermoelectric generators. Mass radio library. Issue 252].* Moscow; Leningrad; Gosenergoizdat [in Russian].
14. *State Standards Committee of the USSR*. Wire made of chromel, alumel, kopel and constantan alloys for thermoelectrodes of thermoelectric converters. Technical Specifications. GOST 1790-77.

Submitted 20.07.2020

Дмитриченко М.Ф. *доктор техн. наук*
Гутаревич Ю.Ф. *доктор техн. наук*
Тріфонов Д.М. *канд. техн. наук*
Сирота О.В. *канд. техн. наук*

Національний транспортний університет
вул. М. Омеляновича-Павленка, 1, м. Київ,
01010, Україна, *e-mail: d.trifonov@ntu.edu.ua*

ЗАСТОСУВАННЯ ТЕРМОЕЛЕКТРИЧНИХ ПЕРЕТВОРЮВАЧІВ ЕНЕРГІЇ ДЛЯ ЗМЕНШЕННЯ ВПЛИВУ ПРИРОДНО-КЛІМАТИЧНИХ ФАКТОРІВ НА ТЕХНІЧНУ ГОТОВНІСТЬ ТРАНСПОРТНОГО ЗАСОБУ

У статті розглядається проблема, пов'язана з експлуатацією транспортного засобу в умовах низьких температур оточуючого повітря, обґрунтовується необхідність прийняття спеціальних заходів для підтримки оптимального теплового режиму акумуляторної батареї. Проведено аналіз факторів, що впливають на пуск холодного двигуна. Показано вплив низької температури акумуляторної батареї на енергетичні показники електростартерної системи пуску. Проведені розрахункові дослідження запропонованої системи для компенсації теплових втрат акумуляторної батареї під час утримання транспортного засобу в умовах низьких температур методом термостатування з застосуванням термоелектричних перетворювачів енергії. Бібл.14, рис.4, табл. 3.

Ключові слова: технічна готовність, акумуляторна батарея, термоелектричний генератор, тепловий акумулятор фазового переходу, електронагрівальні елементи.

Дмитриченко М.Ф., *доктор техн. наук*
Гутаревич Ю.Ф., *доктор техн. наук*
Трифонов Д.Н., *канд. техн. наук*
Сирота А.В., *канд. техн. наук*

Национальный транспортный университет
ул. М. Емельяновича-Павленко, 1, г. Киев, 01010, Украина,
e-mail: d.trifonov@ntu.edu.ua

ПРИМЕНЕНИЕ ТЕРМОЭЛЕКТРИЧЕСКОГО ПРЕОБРАЗОВАТЕЛЯ ЭНЕРГИИ ДЛЯ УМЕНЬШЕНИЯ ВЛИЯНИЯ ПРИРОДНО-КЛИМАТИЧЕСКИХ ФАКТОРОВ НА ТЕХНИЧЕСКУЮ ГОТОВНОСТЬ ТРАНСПОРТНОГО СРЕДСТВА

В статье рассматривается проблема, связанная с эксплуатацией транспортного средства в условиях низких температур окружающего воздуха, обосновывается необходимость принятия специальных мер для поддержания оптимального теплового режима аккумуляторной батареи. Проведен анализ факторов, влияющих на пуск холодного двигателя. Показано влияние низкой температуры аккумуляторной батареи на энергетические показатели электростартерной системы пуска. Проведены расчетные исследования предложенной системы для компенсации тепловых потерь аккумуляторной батареи во время содержания транспортного средства в условиях низких температур методом термостатирования с применением термоэлектрических преобразователей энергии. Библ.14, рис.4, табл. 3.

Ключевые слова: техническая готовность, аккумуляторная батарея, термоэлектрический генератор, тепловой аккумулятор фазового перехода, электронагревательные элементы.

References

1. Krokhta G.M., Usatykh N.A., Guskov Yu.A., Voronin D.M. (2016). Osobennosti raboty starternykh akkumuliatornykh batarei pri samoprogreve dvigatelia v zimnii period [Operating peculiarities of starter storage batteries during self-heating of the engine in winter]. *Dostizheniia nauki i tekhniki APK – Achievements of Science and Technology of Agro-Industrial Complex,* 30 (12), 94-97 [in Russian].
2. Timinskii V.I. (1985). *Spravochnik po elektrooborudovaniiu avtomobilei, traktorov, kombainov [Handbook of the electrical equipment of cars, tractors, combines].* Minsk: Uradzhai [in Russian].
3. Pankratov N.I. (1985). Ekspluatatsiia akkumuliatornykh batarei pri nizkikh temperaturakh [Operation of storage batteries at low temperatures]. *Avtomobilnyi Transport*, 2, 16–19 [in Russian].
4. Kajikawa T., Funahashi R. (2016). Recent activity on thermoelectric power generation technology in Japan. *J. Thermoelectricity*, 1, 5-15.
5. Anatychuk L.I., Prybyla A.V. (2016). Comparative analysis of thermoelectric and compression heat pumps for individual air-conditioners. *J.Thermoelectricity*, 2, 31-39.
6. Anatychuk L.I., Lysko V.V. (2019). On the possibility of using thermoelectric generators for high-power transport starting pre-heaters. *J.Thermoelectricity*, 3, 80-92.
7. Dmytrychenko M.F., Gutarevych Y.F., Trifonov D.M., Syrota O.V., Shuba E.V. (2018). On the prospects of using thermoelectric generators with the cold start system of an internal combustion engine with a thermal battery. *J.Thermoelectricity,* 4, 49-54.
8. *Patent of Ukraine №136638* (2019). Dmytrychenko M.F., Gutarevych Yu.F., Trifonov D.M., Syrota O.V., Shuba S.V. Thermoelectric system of thermal energy utilization with thermal accumulator of phase transition [in Ukrainian].
9. Zu-Guo Shen, Lin-Li Tian, Xun Liu. (2019). Automotive exhaust thermoelectric generators: Current status, challenges and future prospects. *Energy Conversion and Management*, 195, 1138-1173.
10. Bykov K.P., Shlenchik T.A. (2006). *Avtomobili "Tavria", "Slavuta" ZAZ-1102, ZAZ-1103, ZAZ-*

1105 i ikh modifikatsii. Ustroistvo, ekspluatatsiia, remont, posobiie po remontu. [Automobiles "Tavriia", "Slavuta" ZAZ-1102, ZAZ 1103, ZAZ 11-05 and their modifications. Design, operation, repair, repair manual]. T.A.Shlenchik (Ed.). Chernigiv: PKF "Ranok" [in Russian].

11. Kashtanov V.P., Titov V.V., Uskov A.F. (1983). *Svintsovyie starternyie akkumuliatornyie batarei. Rukovodstvo [Lead starter batteries. Manual].* Moscow [in Russian].
12. Kurzukov N.I., Yagniatinskii V.M. (2008). *Akkumuliatornyie batarei. Kratkii spravochnik. [Storage batteries. Quick reference book].* Moscow: LLC "Book publishing house "Za rulem" [in Russian].
13. Bernshtein A.S. (1956). *Termoelektricheskiie generatory. Massovaia radio biblioteka. Vypusk 252 [Thermoelectric generators. Mass radio library. Issue 252].* Moscow; Leningrad; Gosenergoizdat [in Russian].
14. *State Standards Committee of the USSR*. Wire made of chromel, alumel, kopel and constantan alloys for thermoelectrodes of thermoelectric converters. Technical Specifications. GOST 1790-77.

Submitted 20.07.2020