О НЕКОТОРЫХ ВАРИАНТАХ УЛУЧШЕНИЯ ПАРАМЕТРОВ ТЕРМОЭЛЕКТРИЧЕСКИХ ПРЕОБРАЗОВАТЕЛЕЙ

Исследована зависимость чувствительности термопреобразователя от взаимного расположения его конструктивных элементов. Подтверждена важность оптимального согласования сопротивления термопары с сопротивлением нагревателя для каждого конкретного применения термопреобразователя и целесообразность оптимизации элементов его конструкции. Библ. 4,Рис. 2, табл. 1.

.**Ключевые слова**: термоэлектрический преобразователь, термопара, нагреватель, чувствительность.

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ON THE POSSIBILITY OF USING THERMOELECTRIC GENERATORS FOR HIGH-POWER TRANSPORT STARTING PRE-HEATERS

The main reasons for the complicated start-up of vehicles at low ambient temperatures are analyzed. The advantages and disadvantages of using pre-heating to improve engine start-up are identified. The principle of operation and design features of general-purpose pre-heaters and pre-heaters for armored vehicles are given. The rationality of using thermoelectric generators for the operation of such equipment is substantiated. The results of studies on the thermodynamic features of preheating systems for an internal combustion engine, in which the sources of electricity are thermoelectric generators, are presented. The physical schemes of the "pre-heater-thermogenerator" systems are considered and their energy characteristics are evaluated. The most effective applications of thermoelectric sources of electricity for engine start training for operation are determined. Bibl. 32, Fig. 3, Tabl. 1.
Key words: starting pre-heater, thermoelectric generator, physical model, efficiency.

Introduction

To overcome the difficulties associated with operating cars at low temperatures, various means of thermal pre-training of internal combustion engines (ICE) are increasingly used [1, 2]. The most effective of these are starting pre-heaters, namely flame sources of heat that run on the fuel of cars and heat the engine coolant. To overcome the difficulties associated with the operation of automobiles at low temperatures, various means of thermal pre-training of internal combustion engines (ICE) are increasingly used [1, 2]. The most effective among such means are starting pre-heaters, namely flame heat sources that run on automobile fuel and carry out heating of the engine coolant. In addition to a reliable start of the internal combustion engine, the use of starting pre-heaters creates conditions for saving on average about 90-150 liters of fuel per season, reduces the toxicity of exhaust gases during engine warming up to 5 times and allows increasing engine life by 200-300 km per start when heated from temperature (-20 ÷ -30) ° C [3, 4].

Pre-heating of the engine is also important for large-size equipment, including that of military purpose. The main reasons that make it difficult to start armored vehicles at low ambient temperatures are:

1. Increasing the viscosity of engine oil on the parts of connecting rod and piston group of an internal combustion engine (ICE).

2. Lubricant viscosity increase in transmission units.

3. Freezing of fuel in fuel lines, fuel filter and other parts of the fuel system.

4. Deterioration of fuel ignition conditions in engine cylinders, which is associated with a decrease in its volatility and low temperatures of air entering the internal combustion engine cylinders from the environment.

5. Freezing of heat carrier in the engine cooling system.

6. Decrease in the power of starter generator due to the reduced capacity of the batteries.

7. The excessive consumption of fuel during the cold start of the internal combustion engine, which is not always available in the places of military operations.

The influence of these factors at low temperatures is manifested simultaneously, which leads to a reduction in engine life and premature failure of combat armored vehicles. This significantly increases the likelihood of sudden violations and failures in the operation of the equipment.

The determining factor limiting the possibility of mass use of starting pre-heaters is the discharge of the battery during operation of the pre-heat equipment [5].

One of the promising methods for solving the problem of battery discharge during thermal preparation of vehicle engines for launch is the use of thermoelectric generators as sources of electric energy for starting pre-heaters [6 - 12]. This idea is the basis of research pursued at the Institute of Thermoelectricity, aimed at creating thermoelectric pre-heat sources for engines of passenger cars [13 – 16]. As a result of the research, an experimental sample of a thermoelectric diesel engine pre-heater with a thermal power of 3 kW was developed for pre-heating of internal combustion engines up to 4 liters. The heater contains a thermoelectric generator with an electric power of 80 - 100 W, which operates from the heat of the starting pre-heater and provides power to its components. In addition, the excess electric energy of the thermogenerator can be used to recharge the car battery, which was confirmed by experimental tests of the heater in bench conditions [17].

The purpose of this work is to analyze the feasibility of using thermoelectric generators for high-power transport starting pre-heaters, in particular for armored vehicles and to select the most efficient physical scheme for creating such generators.

Brief description of high-power heaters

Modern starting pre-heaters with a thermal power from 15 kWfor diesel engines are presented in Table 1. The leading companies in this direction are Webasto and Eberspächer (Germany), Teplostar and Shardrinsk Automotive Components Plant (Russian Federation), PROHEAT (Canada) [18-31].

Company Webasto (Germany) produces starting pre-heaters with a thermal power up to 35 kW [18, 19]. The electric energy consumption of such heaters is 90-170 W without regard to the power of circulation pump. In so doing, the electric power of recommended circulation pumps of the type U 4814 is 104 W, of the type U 4851 – 209 W. Therefore, total electric energy consumption of starting pre-heaters from Webasto with a thermal power 16 - 35 kW is from 194 to 379 W.

Table 1

Starting pre-heaters with a thermal power from 15 kW for diesel engines

Manufacturer	Model	Output thermal power, kW	Electric power consumption, W	Fuel consumption, l/h
Webasto (Germany)	DBW 160	16	90*	2.3

continuation of table

	DBW 230	23.3	110*	3.0
	DBW 300	30	130*	4.0
	DBW 350	35	170*	4.4
	* - without circulation pump (electric power consumption of recommended circulation pumps of the type *U* 4814 – 104 Вт, *U* 4851 – 209 W)			
Eberspächer (Germany)	Hydronic L 16	16	60**	2
	Hydronic L 24	24	80**	2.9
	Hydronic L 30	30	105**	3.7
	Hydronic L 35	35	120**	4.2
	** - without circulation pump (electric power consumption of recommended circulation pumps of the type Flowtronic 5000 – 104 W, Flowtronic 6000 SC – 210 W)			
Teplostar (RF)	14 ТС-10	15	132	2
	20 ТС-Д38	20	200	2.5
	АПЖ – 30Д-24	30	336	3.7
JSC “Shadrinsk Automotive Components Plant” (RF)	ПЖД24Б	24	170	3.8
	ПЖД30	30	340	5
	ПЖД30Г	30	340	5
	ПЖД30Е	30	340	5
	ПЖД30Л	30	340	5
	ПЖД30М	30	340	5
	ОЖД30.8106010	30	140	3.8
	ПЖД44Ш	37	340	8.5
	ПЖД600	58	490	11.4
PROHEAT (Canada)	M50 12V	15	114***	1.8
	M50 24V	15	125***	1.8
	M80 12V	23	102***	3
	M80 24V	23	125***	3
	M90 24V	26	125***	3.1
	M105 24V	31	228***	4
	M125 24V	37	228***	4.2
	*** - without circulation pump			

Company Eberspächer (Germany) produces *L*-series starting pre-heaters with a thermal power of 16 to 35 kW [20, 21]. The consumed electric power of such heaters is 60-120 W, without regard to the power of the circulation pump.

Hydronic *L* heaters are the most powerful liquid heaters from Eberspächer. Designed for installation on vehicles with large engine displacement and large interior, Hydronic *L* 30 / 35kW are available with both spaced and compact version with integrated components: water pump, fuel filter, which saves time on installation. The heater is capable of operating both on diesel fuel and on fuel oil.

The electric power of the recommended circulation pumps: type Flowtronic 5000 - 104 W, Flowtronic 6000 SC - 210 W. Thus, the total energy consumption of the Eberspächer Hydronic *L* Series Pre-Heater is from 164 to 330 watts.

The Russian company Teplostar produces three models of starting pre-heaters with thermal power from 15 to 30 kW - 14TS-10, 20 TS-D38, АПЖ - 30Д-24 [22-24]. The electric power consumption of such heaters is 132-336 watts.

Shadrinsk Automotive Components Plant (RF) produces starting pre-heaters with thermal power up to 58 kW [25-29]. The electric power consumption of heaters with thermal power from 24 to 58 kW is 170-490 W.

Company PROHEAT (Canada) produces starting pre-heaters of M-series with thermal power from 15 to 37 kW [30]. The electric power consumption of such pre-heaters is 114 - 128 W without taking into account the power of circulation pump.

Thus, up to 500 W of electrical energy is required to operate starting pre-heaters shown in Table 1.

Starting pre-heater in armored vehicles is used to heat the coolant in the cooling system and the oil in the circulation tank before starting the engine [31]. It is installed in the fighting compartment of the tank and consists of a boiler and mechanisms for supplying and burning fuel (fuel pump, fan, nozzle, glow plug), a water pump and gearbox with manual and electric drives.

The boiler is a cylindrical heater, all-welded stainless steel construction, consisting of a body, a flame tube and a coil box.

The boiler body and the flame tube have double cylindrical walls between which internal cavities are formed, filled with coolant (boiler water space). The internal cavities of the body and the flame tube are interconnected by four tubes.

The inner front part of the boiler body together with the conical cover forms the boiler furnace, and the rear part forms the gas chamber. An exhaust pipe is welded from below to the boiler body, which discharges combustion products through an opening in the tank bottom to the outside. A box is welded on top of the body, which contains a coil for heating the fuel. The heated liquid enters from the boiler body into the coil box through an opening located in the upper part of the body.

The pump assembly of the heater includes a water pump; fan, fuel pump and gearbox with manual and electric actuators. This whole assembly is mounted in a common crankcase.

The centrifugal type water pump is used for forced circulation if the coolant in the heating system. A centrifugal fan delivers the air necessary for the combustion of fuel in the boiler furnace. The plunger type fuel pump delivers fuel to the nozzles of the heater. The control of the pumping unit can be carried out mechanically using a manual drive and electrically from an electric motor.

The centrifugal heater nozzle is designed to spray fuel in the furnace of the boiler, which is ignited by the spark plug. The spark plug is powered by a 24V battery. In the event of a spark plug failure, the fuel can be ignited by a torch through the upper right hole of the cone, which is closed by a plug.

To disconnect the heater from the cooling system (for the summer period of operation of the tank), a heater shut-off valve is installed.

During the operation of the heater, the coolant under the action of the water pump of the heater is fed through the pipeline and branched into four parallel streams.

The first flow passes through the engine, heats the cylinder heads and blocks and returns to the heater through the water pump.

The second flow passes through the pipeline into the coil of the circulating oil tank, heats the oil in the circulation tank and returns to the heater boiler through the housing of the intake oil pipeline.

The third flow passes through the water radiator through the water pump of the engine and by the pipeline returns to the boiler of the heater.

The fourth flow passes from the discharge pipe of the heater through the pipe into the cavity of the oil pump. From the pump, the liquid enters the casing of the intake pipe of the pump and then into the boiler of the heater. In the boiler, the liquid is heated and circulated again through the above flows.

Thus, in comparison with the pre-heater for traditional vehicles, the nozzle tank pre-heater has a number of design and functional differences, which makes it more reliable and efficient.

Such and improved nozzle starting pre-heaters with a thermal power of 30-70 kW are installed on many tanks developed by the former USSR - T-55, T-64, T-64A, T-72, etc. [32].

In modern armored personnel carriers, starting pre-heaters are installed, which are also used for other civilian vehicles - trucks, buses and special equipment with a liquid cooling system.

Since electric energy is needed to power the main functional components of starting liquid pre-heaters, its source is the battery of an armored vehicle. At low temperatures (-20 ÷ -40 ° C), the battery capacity decreases by 2 to 3 times, which creates problems in providing electric energy to both starting pre-heaters and other equipment that should work when the engine is not running. This situation creates risks when starting armored vehicles, so in practice it often becomes necessary to warm up engines without using starting pre-heaters - blowtorches, hot water, tank stoves, etc. In combat conditions, this creates significant problems in the operation of armored vehicles. Therefore, despite the advantages in the use of liquid starting pre-heaters, consisting, in particular, in increasing the engine life and saving fuel when starting it, the use of heaters still remains problematic due to their non-autonomous operation.

Some time ago, there were attempts to solve the problem of non-autonomous operation of starting pre-heaters by using a gas turbine internal combustion engine in combination with a dynamo, which is used to power the battery during start pre-heating. However, the main disadvantage of such a system is the increased noise level and high temperatures of the combustion products, which is an unmasking factor in the conditions of military operations.

To overcome this problem, it is promising to use thermoelectric sources of heat and electricity, which, in addition to pre-heating, supply the functional components of the heaters. Therefore, they do not need battery power to power them.

To use such sources of heat and electricity in order to improve the operational capabilities of armored military equipment, the electric power of the thermal generator 300-500 watts is necessary. Such thermoelectric devices have a high service life, are reliable and resistant to mechanical loads and meet the requirements for their use in military equipment.

In 1958-1969, works on the creation of a tank heater with a thermoelectric generator were carried out at VNII-100 [32]. The work was carried out jointly with the Institute of Semiconductors of the USSR Academy of Sciences and the Kalinin LPI. The TEG was supposed to provide an electrical power of approximately 500 watts, which would allow the tank crew to maintain the machine in standby mode, heat the living compartment, heat the batteries and spend some of the electricity on recharging the batteries or for running the radio station without starting the main engine. The heater had a thermal power of about 72 kW and an electrical power of 340 watts. Work on the improvement of TEG in the USSR lasted until the mid-1980's.

Physical schemes of starting pre-heaters and their analysis

Fig. 1 shows a physical model of system for start heating of engines that comprises liquid starting pre-heater and thermoelectric generator heat supply to which is carried out individually with the use of separate heat sources.

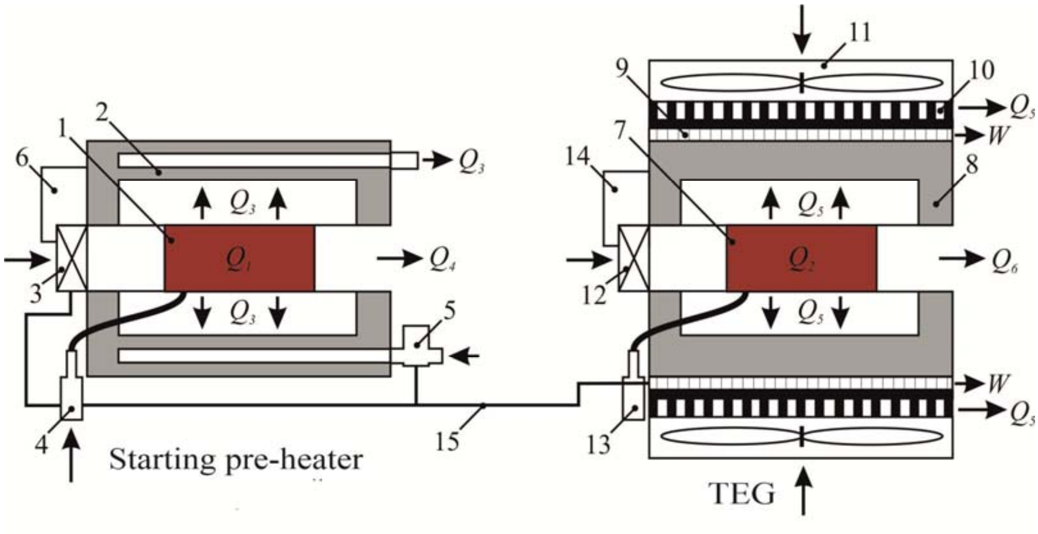

Fig. 1. Physical model of "staring pre-heater—thermoelectric generator" system with individual heat sources : 1 –starting pre-heater burner; 2 – heat exchanger; 3 – starting pre-heater air fan; 4 – starting pre-heater fuel pump; 5 – circulation pump; 6 – starting pre-heater electronic unit; 7 – thermogenerator burner; 8 –hot heat exchanger; 9 –thermopile; 10 – air radiator; 11 – fan for heat removal; 12 – thermogenerator air fan; 3 – thermogenerator fuel pump; 14 – thermogenerator electronic unit; 15 – electric connection means.

Liquid starting pre-heater is composed of heat source 1 which is in the internal volume of heat exchanger 2. As a heat source, a flame burner was used, air and fuel to which are supplied by a fan 3 and a pump 4.

In the heat exchanger of the heater, channels are made in which the heat carrier is heated, following which, by pumping with the circulation pump 5, it enters the car engine. Starting and controlling the operation of starting pre-heater components (air fan, fuel pump, circulation pump) is carried out by the electronic unit 6.

The thermoelectric generator contains an individual flame burner 7, a hot heat exchanger 8 for supplying heat to the thermopile 9 and a heat removal system, which consists of air radiators 10 and fans 11. The fuel and air are supplied to the heat source of the heat generator by the fan 12 and the fuel pump 13. To stabilize the output voltage of the thermogenerator and control its operation, an electronic unit 14 is provided in the TEG model.

The thermoelectric generator operates as follows. The thermal energy resulting from the combustion of fuel heats the hot heat exchanger, passes through the thermopile and is discharged into the environment. Due to the temperature difference between the hot and cold sides of the thermopile, an electric current is generated to power the pre-heater.

Thus, the system under consideration provides the starting pre-heater with the necessary electric energy, practically without using a battery. However, such a system can also perform additional functions, in particular, a thermogenerator can be used as an auxiliary source of electrical energy. This energy can be employed, if necessary, to charge the battery or other energy supply needs, for example, to power various additional electrical devices.

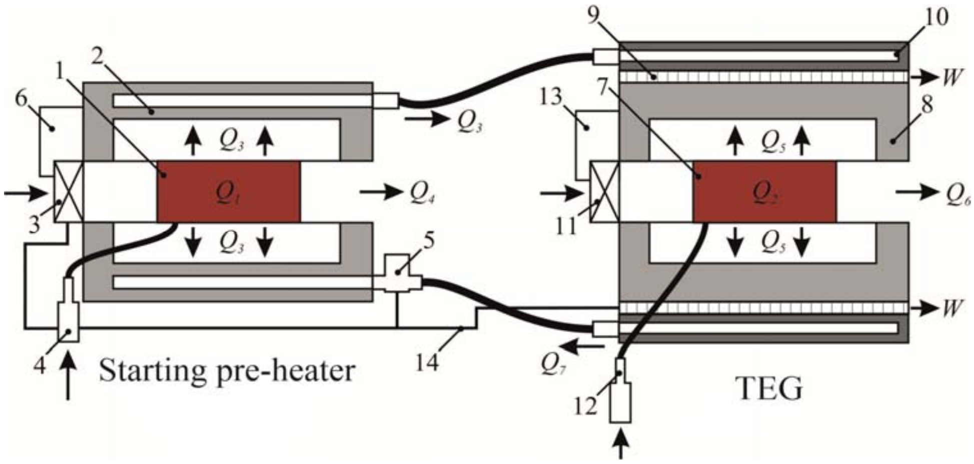

Fig. 2. Physical model of "starting pre-heater-thermoelectric generator" system with individual heat sources and a joint hydraulic circuit: 1 – starting pre-heater burner; 2 – heat exchanger; 3 – starting pre-heater air fan; 4 – staring pre-heater fuel pump; 5 – circulation pump; 6 – starting pre-heater electronic unit; 7 – thermogenerator burner; 8 – hot heat exchanger; 9 – thermopile; 10 – cold liquid heat exchanger; 11 – thermogenerator air fan; 12 –thermogenerator fuel pump; 13 –thermogenerator electronic unit; 14 – electric connection means.

Fig. 2 shows a diagram of the "pre-heater-thermoelectric generator" system, which combines the pre-heater and thermoelectric generator with a single hydraulic circuit. In this regard, in the cooling system of the thermogenerator, the air radiators and fans for removing heat from the thermopile are replaced by liquid heat exchangers 10 in which the heat carrier circulates.

Since the heat flux Q7, removed from the thermopile, is expended for heating the heat carrier, this system allows the engine to be preheated both with a starting pre-heater and using a thermoelectric generator.

The physical model of the system (Fig. 3) with a joint heat source comprises a hot heat exchanger 1, the internal volume of which accommodates a burner 2. Fuel and air delivery to the burner is realized by fan 3 and fuel pump 4. On the external surface of the hot heat exchanger there is a thermopile 5, the heat from which is removed by heating liquid circulating in the cold heat exchangers 6 by pumping with liquid pump 7. The start and control of the heater is carried out by the electronic unit 8.

Thus, in the above system, the thermoelectric generator and the pre-heater are combined in a single design, which allows you to obtain electric energy and heat the engine with one heat flow Q. In this case, part of the heat Q_1 is carried by the combustion products into the environment, and heat Q_2, in the form of heat Q_3 , and electric W power, is used to warm the engine and power the heater components, and, if necessary, to recharge the battery during preheating.

The highest values of efficiency are characterized by "thermoelectric generator-starting pre-heater" system with a joint source of heat and a system in which the starting pre-heater and TEG are combined by a hydraulic circuit. Obviously, a system with a joint heat source is cheaper, which makes it more efficient to use. At the same time, a system with a single hydraulic circuit can be more versatile. As a thermoelectric generator for such a case, a separate thermoelectric pre-heater of low thermal power can be used, the electric output power of which is enough to power the main pre-heater. Such a heater can be installed separately, in an accessible place of an armored vehicle, which makes its implementation easier.

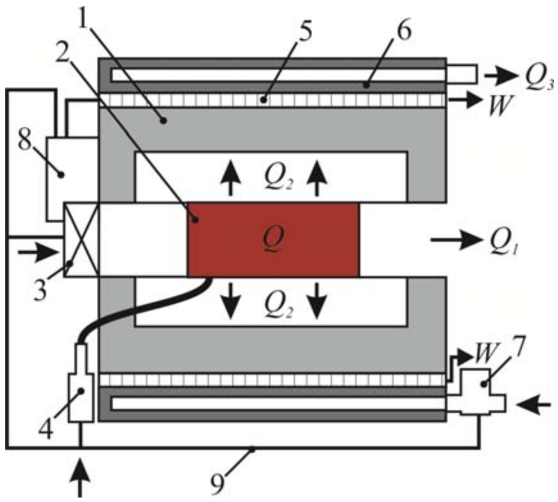

Fig. 3. Physical model of "starting pre-heater –thermoelectric generator" system with a joint heat source: 1 – starting pre-heater burner; 2 – hot heat exchanger; 3 – starting pre-heater air fan; 4 – starting pre-heater fuel pump; 5 –thermopile; 6 – cold liquid heat exchanger; 7 – starting pre-heater circulation pump; 8 – electronic unit; 9 – electric connection means.

Conclusions

1. The design features of general-purpose starting pre-heaters and high-power starting pre-heaters are considered. The possibility of using thermoelectric generators for the operation of such equipment is justified. The necessary electric power of such generators is determined – up to 500 W.
2. Physical schemes of starting pre-heaters with thermoelectric sources of electricity are considered. The most rational for start heating of internal combustion engines is "starting pre-heater-thermoelectric generator" system with a joint heat source and a system that combines starting pre-heater and thermogenerator with one hydraulic circuit.

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ПРО МОЖЛИВІСТЬ ВИКОРИСТАННЯ ТЕРМОЕЛЕКТРИЧНИХ ГЕНЕРАТОРІВ ДЛЯ ТРАНСПОРТНИХ ПЕРЕДПУСКОВИХ НАГРІВАЧІВ ВЕЛИКИХ ПОТУЖНОСТЕЙ

Проаналізовано основні причини ускладненого запуску транспортних засобів за понижених температур навколишнього середовища. Визначено переваги та недоліки в застосуванні передпускового підігріву для покращення запуску двигуна автомобілів. Наведено принцип роботи та особливості конструкції передпускових нагрівачів загального використання та передпускових нагрівачів для бронетехніки. Обґрунтовано раціональність використання термоелектричних генераторів для роботи такого обладнання. Наведено результати досліджень термодинамічних особливостей систем передпускового розігріву двигуна внутрішнього згорання, в яких джерелами електричної енергії є термоелектричні генератори. Розглянуто фізичні схеми систем «передпусковий нагрівник–термогенератор» та проведено оцінку їхніх енергетичних характеристик. Визначено найефективніші варіанти застосування термоелектричних джерел електрики для передпускової підготовки двигунів транспортних засобів до експлуатації. Бібл. 32, рис. 3, табл. 1.
Ключові слова: передпусковий нагрівник, термоелектричний генератор, фізична модель, ефективність.

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О ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ ТЕРМОЭЛЕКТРИЧЕСКИХ ГЕНЕРАТОРОВ ДЛЯ ТРАНСПОРТНЫХ ПРЕДПУСКОВЫХ НАГРЕВАТЕЛЕЙ БОЛЬШОЙ МОЩНОСТИ

Проанализированы основные причины осложненного запуска транспортных средств по пониженных температур окружающей среды. Определены преимущества и недостатки в применении предпускового подогрева для улучшения запуска двигателя автомобилей. Приведены принцип работы и особенности конструкции предпусковых нагревателей общего пользования и предпусковых нагревателей для бронетехники. Обоснованно рациональность использования термоэлектрических генераторов для работы такого оборудования. Приведены результаты исследования термодинамических особенностей систем предпускового разогрева двигателя внутреннего сгорания, в которых источниками электроэнергии являются термоэлектрические генераторы. Рассмотрены физические схемы систем «предпусковой отопитель - термогенератор» и проведена оценка их энергетических характеристик. Определены наиболее эффективные варианты применения термоэлектрических источников электричества для предпусковой подготовки двигателей транспортных средств к эксплуатации. Библ. 32, рис. 3, табл. 1.

Ключевые слова: предпусковой отопитель, термоэлектрический генератор, физическая модель, эффективность.

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