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DESIGN OF THERMOELECTRIC GENERATOR FOR TRANSPORT HIGH-POWER STARTING PREHEATER

A physical model of an autonomous system for pre-start heating of vehicles is considered, in which a preheater and a thermoelectric generator providing the system with electric energy are combined by one hydraulic circuit. The results of evaluating the energy characteristics of thermoelectric generators for such systems and the expected values of the efficiency and total thermal power of systems for various serial heaters with a thermal power of more than 15 kW are given. Bibl. 29, Fig. 1, Table 1.
Key words: пstarting preheater, thermoelectric generator, physical model, efficiency.

Introduction

To overcome the difficulties related to the operation of vehicles at low temperatures, starting preheaters are increasingly used - flame heat sources operating from vehicle fuel and heating the engine coolant [1, 2]. At the same time, an effective method for solving the problem of discharging the storage battery of vehicles during the operation of starting preheaters is the use of a thermoelectric generator operating from the heat of the heater and providing autonomous power supply to its components [3 – 8]. In addition, the excess electrical energy from the thermogenerator can be used to recharge the battery and power other equipment.

At the Institute of Thermoelectricity, an experimental model of a thermoelectric starting preheater with a thermal power of 3.5 kW and a maximum electrical power of 100 W has been created for heating vehicles with an engine capacity of up to 4 liters [9 – 11]. Experimental studies of the heater at low temperatures have confirmed the efficiency of the design and proved its effectiveness as a pre-start source of heat for the engine and a source of electricity for heater components. [12]

A preliminary analysis [13] indicates the prospects for such applications to improve the operational capabilities of high-power vehicles, including armoured vehicles.

The purpose of this work is to assess the energy characteristics of the "thermoelectric generator – preheater" system for high-power vehicles and to determine the necessary parameters of thermoelectric generators that make it possible to make such a system autonomous and prevent the discharge of vehicle batteries.

Physical model of “thermoelectric generator-starting preheater” system

The most attractive in terms of efficiency and ease of operation is "thermoelectric generator-preheater" system, in which the preheater and TEG are combined by a single hydraulic circuit. As a thermoelectric generator for this case, a separate thermoelectric preheater of lower thermal power can be used, the electric power of which is sufficient to power the main preheater. Such a heater can be installed separately, in an accessible place of the vehicle, which makes it easier to implement. Fig. 1 shows a physical model of such system for preheating of engines.

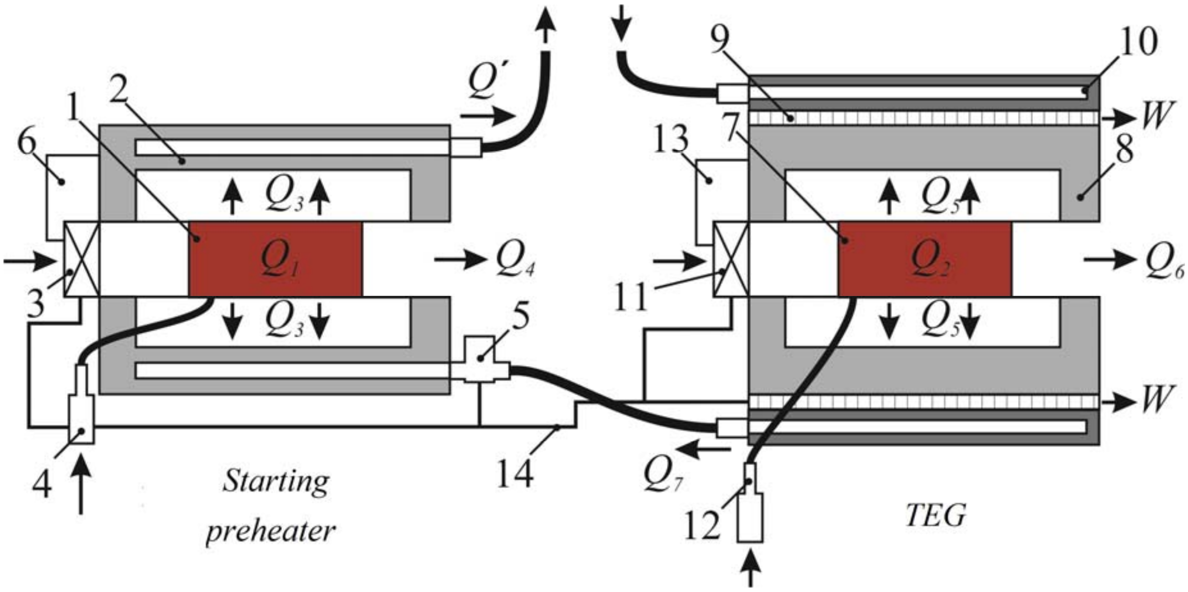

Fig. 1. Physical model of "starting preheater—thermoelectric generator" system :
1 –starting preheater burner; 2 – heat exchanger;
3 – starting preheater air fan; 4 – starting preheater fuel pump;
5 – circulation pump; 6 – starting preheater electronic unit;
7 – thermogenerator burner; 8 –hot heat exchanger;
9 –thermopile; 10 – cold liquid heat exchanger;
11 – thermogenerator air fan; 12 –thermogenerator fuel pump;
13 – thermogenerator electronic unit; 14 – electric connection means.

Liquid starting preheater 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 preheater 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, a fan 11 and a heat removal system composed by liquid heat exchangers 10 in which heat carrier is circulating.

Fuel and air delivery to the heat source of thermogenerator is performed by fan 12 and fuel pump 13. An electronic unit 13 is provided in the model of TEG for stabilization of thermogenerator output voltage and control of its work.

The thermoelectric generator in such a system operates as follows. The thermal energy resulting from the combustion of fuel heats the hot heat exchanger, passes through the thermopile and is removed through liquid heat exchangers where heat carrier is circulating, to the hydraulic circuit common with starting preheater. Due to the temperature difference between the hot and cold sides of the thermopile, an electric current is generated to power the preheater, as well as all electrical elements of the generator itself.

Thus, the system under consideration provides the starting preheater with the necessary electric energy, practically without using a battery. However, such a system can also perform additional functions, e.g. a thermogenerator can be used as an auxiliary source of electrical energy in a vehicle.

Results of calculation of the energy characteristics of thermoelectric generator for high-power autonomous pre-start heating system

The efficiency η for the "preheater-thermoelectric generator" system can be introduced as the ratio of the received useful energy to the consumed thermal energy Q. Useful energy will be considered the received thermal energy Q', which is directly used for preheating the engine, and electrical energy W, which is required for the operation of the system:

$$\eta = \frac{Q' + \sum_i W_i}{Q}, \tag{1}$$

where W_i are powers of electric energy system consumers.

The consumed thermal energy of the system will be equal to the total thermal energy of the burners of the preheater and the thermoelectric generator (TEG):

$$Q = Q_1 + Q_2, \tag{2}$$

where Q_1 and Q_2 are thermal energies of the burners of the preheater and thermal generator that can be expressed by the following relations:

$$Q_1 = \eta_{A1} \cdot A \cdot m_1 \tag{3}$$

$$Q_2 = \eta_{A2} \cdot A \cdot m_2 \tag{4}$$

where η_{A1}, η_{A2} is efficiency of burners of the preheater and TEG; A is calorific value of fuel used to operate the system; m_1, m_2 is fuel consumption of the preheater and heat generator, respectively.

Part of the heat Q_1 is used to heat the circulating fluid Q_3, the other part Q_4 is carried by the combustion products into the environment. A similar heat distribution takes place in the thermoelectric generator, namely, part of the heat Q_5 from the burner 7 through the thermopiles 9 is transferred to the liquid heat sinks 10 and discharged into the general heating circuit of the circulating fluid Q_7. The rest of the heat Q_6 is removed from the heat generator by combustion products.

So, expression (1) for system efficiency will be re-written as follows:

$$\eta = \frac{Q_3 + Q_7 + W}{Q_1 + Q_2}, \tag{5}$$

where useful heat Q_7 can be found from heat balance equation:

$$Q_2 = W + Q_7 + Q_6 \tag{6}$$

To assess the efficiency of the system shown in Fig. 1, the characteristics of serial preheaters of different companies, given on their websites and in the operating instructions [14 - 27], were used.

For instance, starting preheater DBW 350 of company Webasto (diesel version, A = 43 MJ/kg) has thermal power Q_3 = 35 kW and power consumption m_1 = 4.4 l/hour [15].

The output electric power of thermal generator is W = 394 W: 170 W – for powering the components of starting preheater, 209 W – for powering the circulation pump and 15 W for power supply to the components of TEG.

The value of thermal energy Q_2 can be estimated by the following ratio:

$$\eta_{TEG} = \frac{W}{Q_2}, \tag{7}$$

where η_{TEG} is the efficiency of thermoelectric generator.

Since the thermal energy Q_2 is used to heat the circulating fluid in the common hydraulic circuit, the efficiency of the system will not depend on the efficiency of the thermoelectric generator, and, consequently, on the efficiency of the thermoelectric modules used in the generator. This opens up the possibility to reduce the cost of the generator by using cheaper modules with lower efficiency, which is an important difference of the thermoelectric generator for the transport preheater from the generators for other applications.

To estimate the efficiency of the system, we can take into account that the efficiency of modern TEGs, where single-stage modules based on bismuth telluride are used, is ~ 3.5% [28]. Therefore, to provide the specified output electric power, it is necessary to spend approximately Q_2 = 11.3 kW of heat. Given that the amount of heat Q_6 lost with the combustion products in the designs of thermoelectric generators is on average 25% of the thermal power Q_2 [29], we find the amount of thermal energy Q_7 (Q_7 = 8.4 kW) consumed to heat the heat carrier and the approximate efficiency of this system (η ~ 80%). Results of calculations for this and other variants of starting preheaters are given in Table.

<u>*Table*</u>

Results of calculations of the energy characteristics of “thermoelectric generator – starting preheater” system

Specifications of high-power serial starting preheaters [13 –26]				Calculation results		
Model of starting preheater	Output thermal power of the heater, kW	Electric power consumption of the heater, W	Fuel flow rate of the heater, l/hour	Output thermal power of TEG, kW	Total thermal power of “TEG-heater” system, kW	Efficiency of “TEG-heater” system, %
Webasto (Germany) DBW 160	16	194*	2.3	4.5	20.5	71.9
Webasto (Germany) DBW 230	23.3	214*	3.0	4.9	28.2	78.4
Webasto	30	339**	4.0	7.6	37.6	76.2

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(Germany) DBW 300						
Webasto (Germany) DBW 350	35	379**	4.4	8.4	43.4	79.9
Eberspächer (Germany) Hydronic L 16	16	164***	2	3.8	19.8	80.2
Eberspächer (Germany) Hydronic L 24	24	184***	2.9	4.3	28.3	82.7
Eberspächer (Germany) Hydronic L 30	30	315****	3.7	7.1	37.1	81.1
Eberspächer (Germany) Hydronic L 35	35	330****	4.2	7.4	42.4	83.0
Teplostar (RF) 14 TC-10	15	132	2	3.2	18.2	76.1
Teplostar (RF) 20 TC-D38	20	200	2.5	4.6	24.6	80.3
Teplostar (RF) APZh – 30D-24	30	336	3.7	7.5	37.5	81.1
SHAAZ (RF) PZhD24B	24	170	3.8	4.0	28.0	65.5
SHAAZ (RF) PZhD 30	30	340	5	7.6	37.6	63.6
SHAAZ (RF) PZhD30G	30	340	5	7.6	37.6	63.6
SHAAZ (RF) PZhD30E	30	340	5	7.6	37.6	63.6
SHAAZ (RF) PZhD30L	30	340	5	7.6	37.6	63.6
SHAAZ (RF) PZhD30M	30	340	5	7.6	37.6	63.6
SHAAZ (RF)	30	140	3.8	3.3	33.3	79.5

Specifications of high-power serial starting preheaters [13 –26]				Calculation results		
Model of starting preheater	Output thermal power of the heater, kW	Electric power consumption of the heater, W	Fuel flow rate of the heater, l/hour	Output thermal power of TEG, kW	Total thermal power of "TEG-heater" system, kW	Efficiency of "TEG-heater" system, %
OZhD30.8106010						
SHAAZ (RF) PZhD44Sh	37	340	8.5	7.6	44.6	47.6
SHAAZ (RF) PZhD600	58	490	11.4	10.8	68.8	54,4
PROHEAT (Canada) M50 12V	15	218*	1.8	5.0	20.0	82.5
PROHEAT (Canada) M50 24V	15	229*	1.8	5.2	20.2	82.5
PROHEAT (Canada) M80 12V	23	206*	3	4.7	27.7	77.5
PROHEAT (Canada) M80 24V	23	229[1]	3	5.2	28.2	77.6
PROHEAT (Canada) M90 24V	26	229*	3.1	5.2	31.2	83.5
PROHEAT (Canada) M105 24V	31	437**	4	9.7	40.7	78.3
PROHEAT (Canada) M125 24V	37	437**	4.2	9.7	46.7	86.4

* – with regard to electric power consumption (104 W) of circulation pump U 4814;
** – with regard to electric power consumption (209 W) of circulation pump U 4851;
*** – with regard to electric power consumption (104 W) of circulation pump Flowtronic 5000;
**** – with regard to electric power consumption (210 W) of circulation pump Flowtronic 6000 SC.

As can be seen from Table 1, the efficiency of "thermoelectric generator - preheater" system for most variants of heaters is at the level of 75-80%. In this case, taking into account the thermal power produced by the heat generator, more powerful modifications of heaters can be replaced by an autonomous system consisting of a less powerful heater and a thermoelectric generator that provides the entire system with electricity. For example, instead of a preheater Hydronic L 35 with a thermal power of 35 kW, an autonomous system can be used, which consists of a Hydronic L 30 heater with a thermal power of 30 kW and a thermoelectric generator with a thermal power of 7 kW and an electric one of about 350 W, which is enough to power such a system. For the most powerful starting preheater PZhD600 among those listed in the table with a thermal power of 58 kW, the thermoelectric generator must have a useful thermal power of 11 kW and an electric one - 0.5 kW (with the efficiency of the thermoelectric generator ~ 3.5%). The total thermal power of such a system will be about 70 kW, which is sufficient for use in armoured vehicles.

The above estimates of energy characteristics of thermoelectric generators are the basis for designing such a generator for a specific variant of the preheater.

Conclusions

1. The energy characteristics of thermoelectric generators for autonomous preheating systems of high-power vehicles are evaluated. The expected values of efficiency and total thermal power of the "thermoelectric generator – preheater" systems for serial heaters with a thermal power over 15 kW are determined.
2. It is established that the efficiency of the "thermoelectric generator - preheater" system for most variants of heaters is at the level of 75-80%. In this case, taking into account the heat output produced by the heat generator, more powerful modifications of heaters can be replaced by an autonomous system consisting of a less powerful heater and a thermoelectric generator that provides the entire system with electricity.
3. It is obtained that a preheater with a thermal power of 58 kW (for example, type PZhD600) can be used to provide the vehicle with thermal energy up to 70 kW, combined into one hydraulic circuit with a thermoelectric generator with a thermal power of 11 kW. In this case, the electricity consumed by the system (0.5 kW) will be fully provided by the heat generator.

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ПРО ПРОЕКТУВАННЯ ТЕРМОЕЛЕКТРИЧНОГО ГЕНЕРАТОРА ДЛЯ ТРАНСПОРТНОГО ПЕРЕДПУСКОВОГО НАГРІВАЧА ВЕЛИКОЇ ПОТУЖНОСТІ

Розглянуто фізичну модель автономної системи для передпускового розігріву транспортних засобів, у якій передпусковий нагрівник і термоелектричний генератор, що забезпечує систему електричною енергією, об'єднані одним гідравлічним контуром. Наведено результати оцінки енергетичних характеристик термоелектричних генераторів для таких систем та очікувані значення ККД та загальної теплової потужності систем для різних серійних нагрівників тепловою потужністю понад 15кВт. Бібл. 29, рис. 1, табл. 1.
Ключові слова: передпусковий нагрівник, термоелектричний генератор, фізична модель, ефективність.

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О ПРОЕКТИРОВАНИЕ ТЕРМОЭЛЕКТРИЧЕСКОГО ГЕНЕРАТОРА ДЛЯ ТРАНСПОРТНОГО ПЕРЕДПУСКОВОГО НАГРЕВАТЕЛЯ БОЛЬШОЙ МОЩНОСТИ

Рассмотрена физическая модель автономной системы для предпускового разогрева транспортных средств, в которой предпусковой отопитель и термоэлектрический генератор, обеспечивающий систему электрической энергией, объединенные одним гидравлическим контуром. Приведены результаты оценки энергетических характеристик термоэлектрических генераторов для таких систем и ожидаемые значения КПД и общей тепловой мощности систем для различных серийных нагревателей тепловой мощностью более 15кВт. Библ. 29, рис. 1, табл. 1.
Ключевые слова: предпусковой отопитель, термоэлектрический генератор, физическая модель, эффективность.

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