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EXPERIMENTAL BENCH STUDIES OF THERMOELECTRIC SOURCE OF HEAT AND ELECTRICITY FOR HEAVY DUTY VEHICLES

The design of a thermoelectric generator with an electrical power of up to 350 W for supplying electrical energy and ensuring autonomous operation of pre-start sources of heat and electricity with a thermal power of up to 40 kW for high duty vehicles is considered. A description of the bench for studying the characteristics of the developed thermoelectric generator and the results of experimental investigations of the generator model sample are presented. Bibl. 8, Fig. 4, Table 1.

Key words: starting pre-heater, thermoelectric generator, bench studies.

Introduction

The operation of vehicles in conditions of low ambient temperatures requires the use of methods for preliminary thermal preparation of engines for start-up. To do this, starting pre-heaters are increasingly used, powered by the fuel of vehicles and using the heating of the engine coolant [1, 2].

Preheating of the engine is also important for large-scale civil and military equipment. The main reasons that make it difficult to start such equipment at low ambient temperatures are: increasing the viscosity of the engine oil on the parts of the connecting rod-piston group of the internal combustion engine (ICE); increasing the viscosity of the lubricant in the transmission units; solidification of fuel in fuel lines, fuel filter and other parts of the fuel system; deterioration of fuel ignition conditions in the engine cylinders, which is due to the reduction of its evaporation and low temperatures of the air entering the cylinders of the internal combustion engine from the environment; freezing of the coolant in the engine cooling system; reduction of power of the starter-generator due to reduction of capacity of rechargeable batteries; overuse of fuel at cold

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

The determining factor limiting the possibility of mass use of starting pre-heaters is the discharge of the battery during the operation of pre-start equipment [3]. An effective method of solving this problem is the use of a thermoelectric generator, which works from the heat of the heater and provides autonomous power to its components [4 – 6]. In addition, the excess electricity of the heat generator can be used to recharge the battery and power other equipment.

In [7, 8] the possibility of using thermoelectric sources of heat and electricity to improve the performance of high-power vehicles is shown and the results of development and optimization of thermoelectric generator design for such sources are presented.

The purpose of this work is to conduct experimental studies of the developed model sample of a thermoelectric generator to confirm its expected characteristics.

Description of the thermoelectric generator design

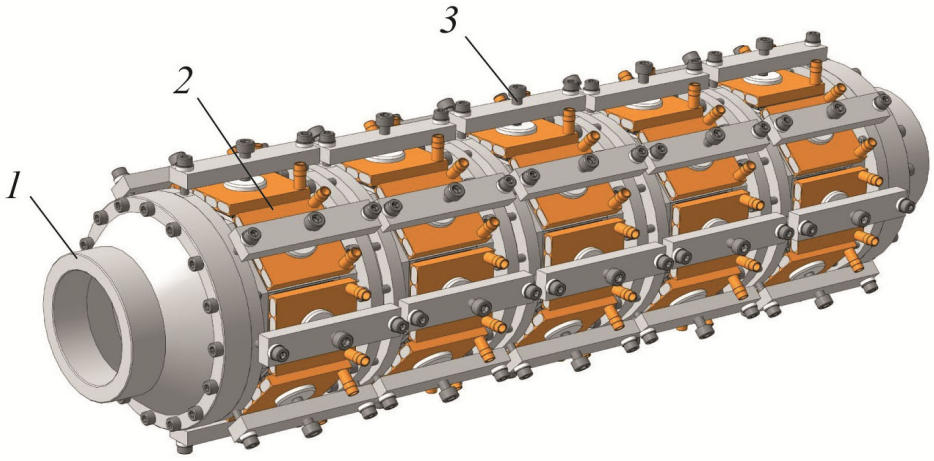
The main unit of the pre-start source of heat and electricity for high duty vehicles, which provides autonomous operation of the system without discharging the vehicle battery is a thermoelectric generator, the general design and appearance of which is shown in Fig. 1. The computer-aided design [8] made it possible to optimize the design of such a generator.

The thermoelectric generator contains a five-section system of hot heat exchangers, which is supplied with hot air from a heat source by a fan, which together with the fuel pump is part of the heat source (not shown).

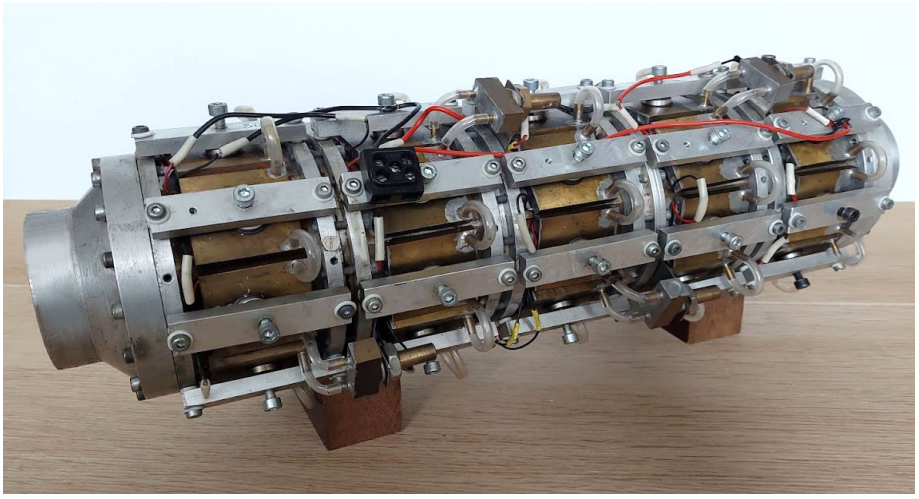
On the outer surface of the heat exchangers are thermoelectric modules, the heat from which is removed by a system of liquid heat exchangers. Thermal contact between thermoelectric modules and heat exchangers is provided by clamping devices. The free space between hot and cold heat exchangers is filled with thermal insulation.

The design of hot heat exchangers (Fig. 2) of each section (diameter and number of channels) is selected so as to ensure optimal operation of thermoelectric modules. The thermoelectric module 10 is clamped between the seat 9 on the hot heat exchanger and the cold heat exchanger 11 by means of a clamp. The clamp consists of a clamping bar 4, a clamping screw 5 and a disk 6 and is attached to the hot heat exchanger by means of screws 7 with fluoroplastic washers 3. Between the surface of the module and the hot heat exchanger is an electrical insulator - mica gasket 8.

Cold heat exchangers consist of a housing made of a material with high thermal conductivity (copper), in which through channels are made, connected in series with a system of plugs. All cold heat exchangers are connected in series in two parallel circuits and are connected to the hydraulic circuit of the vehicle's engine cooling system. The circulation of the liquid heat carrier in the "heater-motor" circuit is carried out by a pump. An overheating sensor is located on one of the cold heat exchangers to control the temperature of the heat carrier.



a)



b)

Fig. 1. Design (a) and appearance (b) of thermoelectric generator for pre-start source of heat and electricity for high duty vehicles:
1– system of hot heat exchangers;
2– system of cold heat exchangers; 3 – clamping devices

The generator contains 40 Altec-1061 generator modules, which are best suited for use in pre-start heat sources. The modules are electrically connected. Interconnect of the modules is selected so that the output voltage of the heater corresponds to the voltage on the vehicle battery.

The thermoelectric generator system has an electric power of up to 350 W, which will be enough to power the preheaters type PROHEAT M90 24V (with a useful thermal power of 26 kW and electric power consumption up to 230 W) or OZhD30.8106010 (with a useful thermal power of 30 kW and electric power consumption up to 140 W). Such a system, taking into account the thermal energy of a thermoelectric generator (about 10 kW), will be equivalent in terms of thermal power – 36 - 40 kW (but autonomous) and will allow replacing the PZhD-44Sh type pre-heater (with a useful thermal output of 37 kW and a consumed electric power of up to 340 V), which is widely used in heavy duty civil and military equipment.

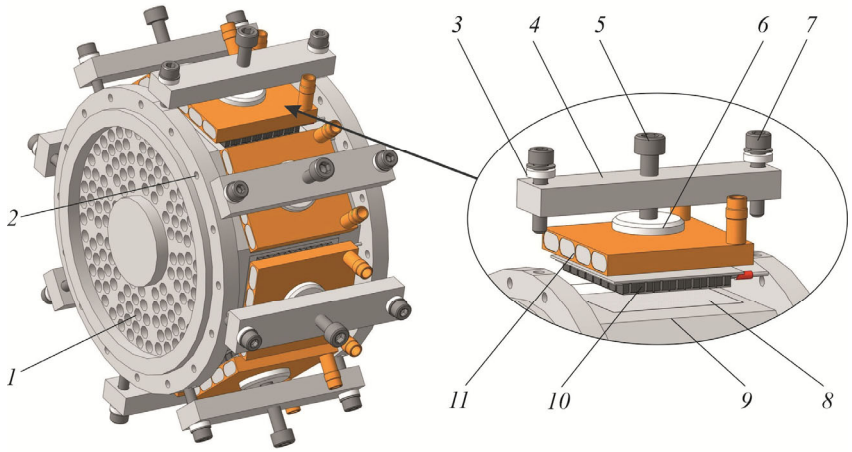


Fig. 2. Design of the hot heat exchanger of thermoelectric generator:1– channels for passing hot gas; 2 – holes for fastening the sections of the hot heat exchanger to each other; 3 – fluoroplastic washers; 4 – clamping bar; 5 – clamping screw; 6 – clamping disc; 7 – screws for attaching the clamp to the heat exchanger; 8 – mica plate; 9 – the seat of thermoelectric module; 10 – thermoelectric module; 11 – cold heat exchanger

Description of a bench for studying characteristics of the developed thermoelectric generator and the results of experimental studies

The layout of the bench for experimental studies of a model sample of a thermoelectric generator is shown in Fig. 3. The thermoelectric generator 1 is connected to the heat source 7 on diesel fuel. In the system of liquid cold heat exchangers 3 by means of the pump 4 the heat carrier was pumped, the flow rate of which was measured by the flow meter 9. The liquid circuit also contained a radiator 8 to transfer heat from the generator to the environment and maintain the desired temperature of the coolant.

The temperatures of hot heat exchangers T_1 – T_5 of sections 1-5 of the thermoelectric generator, as well as the temperature of the coolant at the inlet T_6 and outlet T_7 from the cold heat exchanger system were measured using chromel-alumel thermocouples, the cold junctions of which were immersed in Dewar vessel 6.

As a result of experimental studies (Table 1) of the developed model sample of the thermoelectric generator of heat and electricity for high duty vehicles, it was found that at full power of the heat source the developed generator has an electric power of about 350 watts.

In Table 1: T_1 – T_5 are the temperatures of the hot heat exchangers of sections 1-5 of thermoelectric generator, respectively; T_6 is coolant temperature at the inlet to the system of cold heat exchangers; T_7 is coolant temperature at the outlet of the system of cold heat exchangers; $G_т$ is coolant consumption in the system of cold heat exchangers; E is the EMF of thermoelectric generator; U is the voltage of thermoelectric generator in the mode of matched load; I is the current of thermoelectric generator in the mode of matched load; W is the electrical power of thermoelectric generator in the mode of matched load.

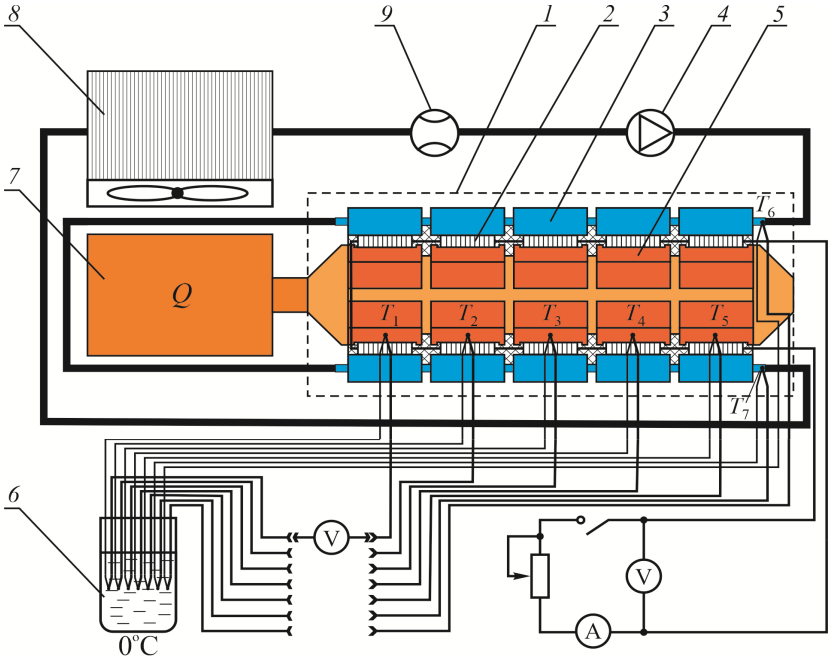


Fig. 3. Layout of the bench for experimental studies of characteristics of the developed model sample of thermoelectric generator: 1 –thermoelectric generator; 2 – thermoelectric modules;3 – cold heat exchangers; 4 – circulation pump; 5 – hot heat exchangers; 6 – Dewar vessel; 7 – heat source on diesel fuel; 8 – radiator

Table 1.

Results of bench studies of thermoelectric generator

T_1, °C	T_2, °C	T_3, °C	T_4, °C	T_5, °C	T_6, °C	T_7, °C	$G_т$, m^3/h	E, V	U, V	I, A	W, W
Thermal power of the heat source ~ 5 kW											
183.2	181.3	175.8	170.0	164.2	19.8	25.5	0.7	20.77	10.39	13.75	142.8
Thermal power of the heat source ~ 10 kW											
294.9	293.8	284.8	275.3	263.3	20.1	30.9	0.7	35.06	17.53	20.07	351.8

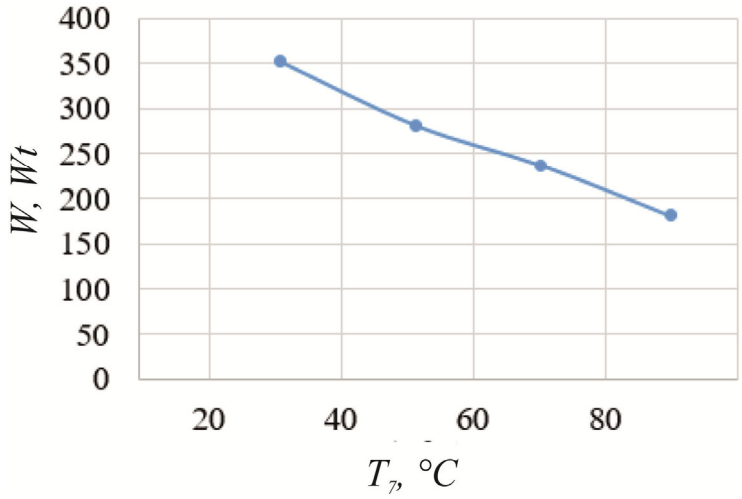


Fig. 4. Dependence of generator power W on coolant temperature T_7 in the system of liquid heat exchangers

The dependence of generator power W on coolant temperature T_7 in the system of liquid heat exchangers (heat removal from thermoelectric modules) is presented in Fig. 4. As is seen from the figure, with a rise in coolant temperature (T_7 – from 30 to 90 °C), the generator power is reduced from 350 W to 180 W.

The results obtained, taking into account possible experimental errors, correspond to the expected results of computer design.

Conclusions

1. The design of a thermoelectric generator with electric power up to 350 W and heat power up to 10 kW is described. In combination with a pre-heater with a thermal power of 25-30 kW, the generator will form an autonomous preheating system with a thermal power of up to 40 kW.
2. A bench was set up to study the characteristics of the developed thermoelectric generator for the pre-start source of heat and electricity for high duty vehicles.
3. Bench experimental studies of the model sample of the developed thermoelectric generator were carried out. It has been established that at a coolant temperature in the thermoelectric generator cooling system in the range from 30 to 90 °C, the power of the thermoelectric generator is from 180 to 350 W, which fully corresponds to the expected values.

References

1. Reznik L.G., Romalis G.M., Charkov S.T. (1989). *Effektivnost ispolzovaniia avtomobilei v razlichnykh usloviiakh ekspluatatsii [The efficiency of using cars under different operating conditions].* Moscow: Transport [in Russian].
2. Kuznetsov E.S., Boldin A.P., Vlasov V.M., et al. (2001). *Tekhnicheskaia ekspluatatsiia avtomobilei:Uchebnik dlia vuzov. 4 izdaniie, pererab. i dopoln.[Technical operation of cars: Textbook for universities. 4th ed. revised and enlarged].* Moscow: Nauka [in Russian].

3. Mykhailovsky V.Ya., Maksumuk M.V. (2014). Automobile operating conditions at low temperatures. The necessity of applying heaters and the rationality of using thermal generators for their work. J.*Thermoelectricity,* 3, 20-31.
4. *Patent of Ukraine № 102303* F01N 5/00 H01L 35/00 (2013). L.I.Anatychuk, V.Ya.Mykhailovsky. Thermoelectric power supply for automobile [in Ukrainian].
5. *Patent of Ukraine №72304* F01N 5/00; H01L35/00 (2012). L.I.Anatychuk, V.Ya.Mykhailovsky. Automobile heater with thermoelectric power supply [in Ukrainian].
6. *Patent of Ukraine №124999* F02N 19/10; H01L35/00. Maksymuk M.V. Automobile heater with thermoelectric power supply [in Ukrainian].
7. 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.
8. Anatichuk L. I., Lysko V. V. Computer design of a thermoelectric generator for a source of heat and electricity for high-power vehicles // *J.Thermoelectricity*. – 2021, 2. – P. 74 - 79.

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СТЕНДОВІ ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ТЕРМОЕЛЕКТРИЧНОГО ДЖЕРЕЛА ТЕПЛА ТА ЕЛЕКТРИКИ ДЛЯ ТРАНСПОРТНИХ ЗАСОБІВ ВЕЛИКОЇ ПОТУЖНОСТІ

Розглянуто конструкцію термоелектричного генератора електричною потужністю до 350 Вт для живлення електричною енергією та забезпечення автономної роботи передпускових джерел тепла та електрики з тепловою потужністю до 40 кВт для транспортних засобів великої потужності. Наведено опис стенду для дослідження характеристик розробленого термоелектричного генератора та результати експериментальних досліджень макетного зразка генератора. Бібл. 8, рис. 4, табл. 1.

Ключові слова: передпусковий нагрівник, термоелектричний генератор, стендові дослідження.

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СТЕНДОВЫЕ ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ТЕРМОЭЛЕКТРИЧЕСКОГО ИСТОЧНИКА ТЕПЛА И ЭЛЕКТРИКИ ДЛЯ ТРАНСПОРТНЫХ СРЕДСТВ БОЛЬШОЙ МОЩНОСТИ

Рассмотрена конструкция термоэлектрического генератора электрической мощностью до 350 Вт для питания электрической энергией и автономной работы предпусковых источников тепла и электричества с тепловой мощностью до 40 кВт для транспортных средств большой мощности. Представлено описание стенда для исследования характеристик разработанного термоэлектрического генератора и результаты экспериментальных исследований макетного образца генератора. Библ. 8, рис. 4, табл. 1.

Ключевые слова: предпусковой отопитель, термоэлектрический генератор, стендовые исследования.

References

1. Reznik L.G., Romalis G.M., Charkov S.T. (1989). *Effektivnost ispolzovaniia avtomobilei v razlichnykh usloviiakh ekspluatatsii [The efficiency of using cars under different operating conditions].* Moscow: Transport [in Russian].
2. Kuznetsov E.S., Boldin A.P., Vlasov V.M., et al. (2001). *Tekhnicheskaia ekspluatatsiia avtomobilei:Uchebnik dlia vuzov. 4 izdaniie, pererab. i dopoln.[Technical operation of cars: Textbook for universities. 4th ed. revised and enlarged].* Moscow: Nauka [in Russian].
3. Mykhailovsky V.Ya., Maksumuk M.V. (2014). Automobile operating conditions at low temperatures. The necessity of applying heaters and the rationality of using thermal generators for their work. J.*Thermoelectricity,* 3, 20-31.
4. *Patent of Ukraine № 102303* F01N 5/00 H01L 35/00 (2013). L.I.Anatychuk, V.Ya.Mykhailovsky. Thermoelectric power supply for automobile [in Ukrainian].
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7. 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.
8. Anatichuk L. I., Lysko V. V. Computer design of a thermoelectric generator for a source of heat and electricity for high-power vehicles // *J.Thermoelectricity*. – 2021, 2. – P. 74 - 79.

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