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Standalone heater on hydrocarbon fuel with built-in thermoelectric power generator and operating time independent of the battery capacity

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The Northern boundaries of the areas of operation in cold severe climatic conditions of internal combustion engines are expanding from year to year. Start up of the engine at cold climatic low temperatures requires preheating with autonomous air heaters for cabin and liquid heaters of the internal combustion engine. These heaters are working on liquid carbon fuel. The definition of "autonomous" is conditional, since the electric power of the heater equipment (fuel pump, coolant pump, ignition system and control of operation) is carried out from the engine battery.

At sub-zero temperatures, the battery capacity is reduced by several times and after preliminary work on the heater, the battery may not have enough energy to start the engine. The installation of an additional battery (or the battery with higher capacity) solves the problem only partly and not in all cases.

By solving the problem of the battery life of the heater increasing without discharging becomes possible:

- To maintain the engine and interior temperature for a long time when the engine is stopped with a muffled engine. The operating time in this mode to maintain the heat will be several times more than when the engine is idle;
- To reduce fuel consumption at stops several times;
- To reduce environmental pollution;
- To save the lifetime of the engine and the battery;
- To ensure that the battery of the engine would be charged during parking.

Comparison of fuel consumption of KAMAZ-740.31-240 engine at idle mode with domestic liquid heater 14TS-10-24-C (installed On KAMAZ-740.31-240 engine) and Planar–44D–24 air heater are presented in the table 1.

Table 1. Comparison of fuel consumption in liter per hour (l/h).

Kamaz-740.31-240 engine, l/h	Liquid heater 14TC-10-24-C, l/h	Air heater Planar–44D–24, l/h
4.5	from 0,5 to 2	from 0,1 to 0.5

The method of electric energy generation for autonomy mode was chosen basing on the following criteria:

- the built-in generator should not significantly increase the dimensions;
- prevalence and reproducibility of energy conversion technology;
- reliability (lifetime) would not be lower than the reliability of existing heaters;
- no additional maintenance required;
- comparable cost of the new heater with the existing models.

These criteria are most satisfied by the system of thermoelectric power generation, which directly converts part of the heat flow generated during the combustion of fuel in the heater into electricity based on the Seebeck effect. Autonomous electric power sources (AEPS) based on this effect have been used in various industries for over 70 years.

The conducted patent analysis showed that actually working designs of the Autonomous source of electric power supply (AEPS) of the heater are not produced by industrial enterprises according to the current patents.

For testing the design of the AEPS a liquid heater type 14TC-10-24-C was selected (link). This heater is mass-mounted on trucks with diesel engine on the conveyor of trucks assembling factories.

The length of the layout with built-in AEPS, compared with the serial sample, is increased by a third. Width and height have not changed. Estimated time of nominal output generation mode is 8 min, with an estimated nominal capacity of 100 watts.

The cost of one AEPS in the production of batches of 1000 items compared to the price chosen as the base heater 14TC-10-24-WITH is about 100%. This can provide a competitive advantage comparing with popular heaters such as Eberspacher, Webasto, etc.

The design of the AEPS provides a temperature mode of thermoelectric generating modules (TGM), close to the maximum allowable. This ensured the maximum efficiency of thermoelectric conversion and allowed to achieve relatively small dimensions and weight.

The calculations allowed choosing the optimal types of TGM for experiments. Currently, the industry produces a number of standard thermoelectric generator modules with different thermal resistance and allowing creating AEPS with different methods of heat transfer to the environment. The most common are liquid and air cooling. In the first case, a pump is required for moving working fluid through the engine or through an external radiator for cabin heating. In the case of air cooling, heat is removed to the environment by blowing a fan.

The design uses heat removal with the help of liquid as the most promising in terms of efficiency.

The domestic industry produces a wide range of TGMs with different overall dimensions and number of thermoelectric pairs inside. Historically and due to technological features the most widespread were TGMs with dimensions of 40x40mm. From TGMs with such dimensions was selected the generator module TGM-199-1,4-0,8.

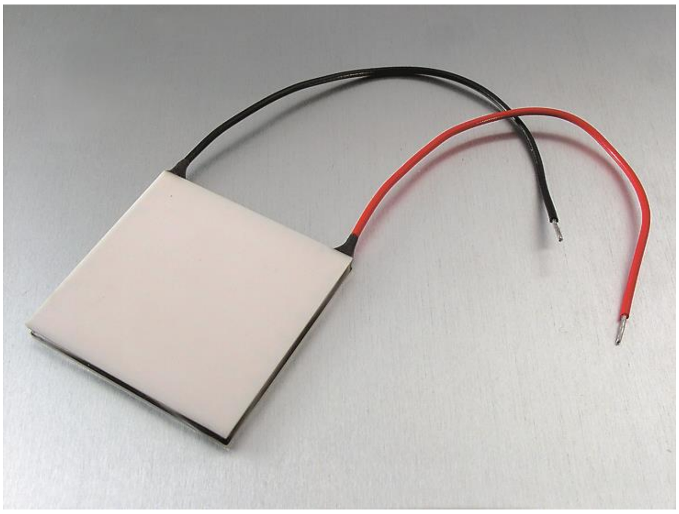

Fig.1. Appearance of thermoelectric module TGM-199-1,4-0,8

The distinctive features of the selected module are:

- extremely low thermal resistance of TGM Rt=0.57 K/W provides integration of the AEPS into the heater design without significant changes;
- big number of thermocouples provides a greater value of thermal EMF;

As the calculated operating temperature of the hot side of the generating module, the maximum operating temperature of 200 ° C for this type of modules was chosen.

The most important thermoelectric parameters of the module are shown in Table 2.

Table. 2. Thermoelectric parameters of the applied TGM.

Thermoelectric parameters	***Unit of measure***	***Value***
Generated power, P* (at T_h=200°C and T_c=30°C)	**W**	**11,4**
I_{load}*	**A**	**2,80**
U_{load}*	**V**	**4,10**
R_{ac} (at *200°C*), ±10 %	**Ohm**	**1,46**
Rt*	**K/W**	**0,57**

were:

R_{ac} - internal electrical resistance (at AC) of TGM at working temperature;

R_{load} is the electrical load resistance;

R_t - thermal resistance of TGM.

* Values are given for electrical load resistance R_{load}=R_{ac}

The current-voltage characteristic of the selected module is shown in Fig. 2

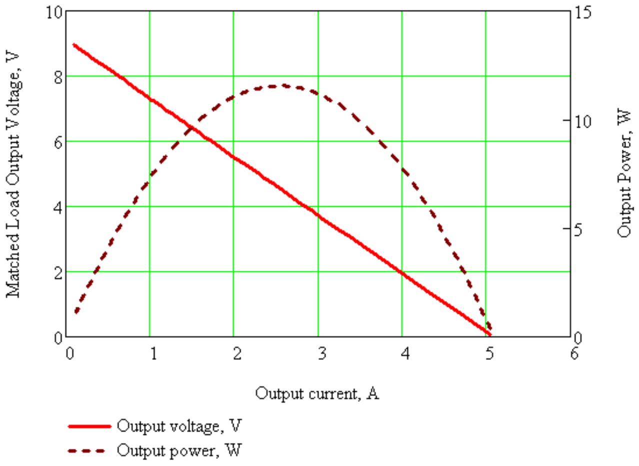

Fig. 2. The current-voltage characteristic of the selected module

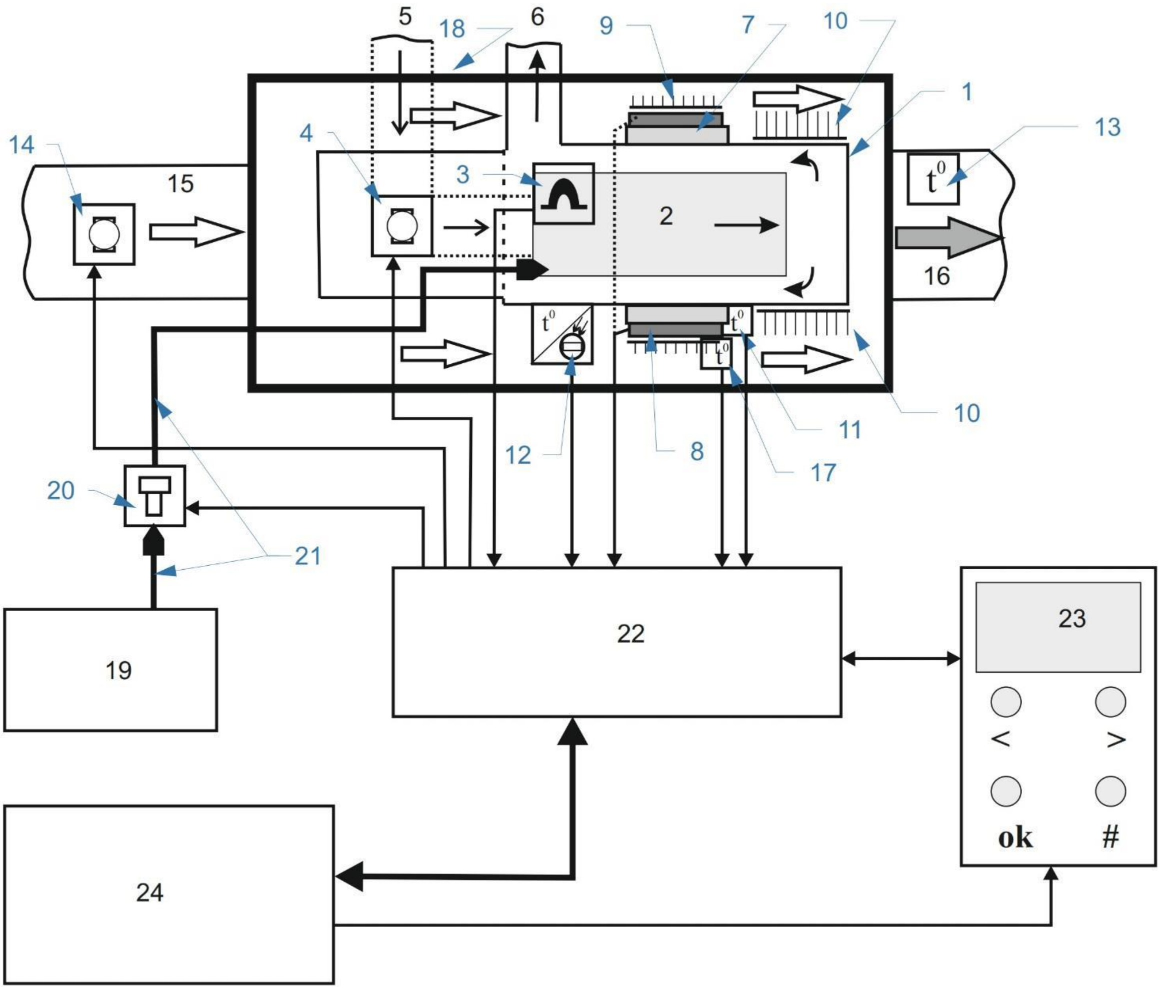

Fig. 3. Block diagram of the auxiliary heater.

Block diagram of the auxiliary heater is shown in figure 3. It contains a heat exchanger 1, inside of which is a combustion chamber 2 with a spark plug (or glow plug) 3, an air blower 4, a suction pipe 5 and an exhaust pipe 6. On the surface of the cylindrical heat exchanger 1, the heat-distributing sectors 7 are placed, with thermoelectric generating modules (TGM) 8. On the opposite surface of TGM 8, cooling radiators 9 are installed. On the free surface of the heat exchanger 1 regular heat exchange radiators 10 are presented. The heat-distributing sectors 7 are equipped with temperature sensors 11. Combustion chamber 2 is equipped with a combustion sensor 12. The temperature of the heated coolant is controlled by a temperature sensor 13. For liquid heater-electric pump 14 (for air heater - electric fan) is applied. Cooling radiators 9 are equipped with temperature sensors 17. The device is enclosed in a housing 18. Fuel from the fuel tank 19 is fed to the combustion chamber 2 by means of the fuel pump 20 along the fuel line 21. Spark plug (or glow plug) 3, outputs of temperature sensors 11, 13, 17, combustion sensor 12 are connected to the electronic control unit 22, which controls the entire process with the help of the control panel displaying current mode of heater operation. Charging the battery 24 is also carried out by the control unit 22.

Each TGM 8 is uniformly pressed by the cooling radiator 9 to the heat-distributing sector 7, forming a sector whose tightening force is set by a Belleville spring.

The use of two temperature sensors on the hot and cold side of the TGM does not allow its overheating, provides long-term trouble-free operation of the AEPS, maintains the optimum temperature of the heated and cooled sides of the TGM, maintaining its maximum efficiency.

The auxiliary heater operates as follows. The device is switched on and brought to the operating mode in the same way as in the known devices, due to the electricity of the battery 24 controlled by the electronic unit 22 through the control panel 23. First, the air blower 4 is started (in the case of a liquid heater – a coolant pump, and for an air heater - an electric fan 14), then the fuel pump 20 is switched on, which supplies fuel from the fuel tank 19 along the fuel line 21 to the combustion chamber 2, where the initial fuel ignition is carried out by means of a spark plug (glow plug) 3. Switching off the glow plug 3 (ignition) is carried out by command from the electronic control unit 22 after establishing a stable combustion in the combustion chamber 2, which is determined by the combustion sensor 12. Adjustment of the required temperature of the coolant and the temperature of the heat exchanger ensuring optimal operation of the TGMs 8 is carried out using an electronic control unit 22 on the basis of a control panel 23. Temperature is regulated according temperature sensors 13 output signal by changing the amount of fuel supplied to the combustion chamber 2, the amount of injected air by the air blower 4, the rate of flow of the coolant through the heat exchanger 1 based on the readings of the temperature sensors 11. The temperature sensor 17 controls the degree of heating of the heat-distributing sectors 7 and the cooling radiators 9 of TGMs 8.

Operation of the auxiliary heater is controlled by the control unit. The appearance of the control panel and housing is shown in figure 4. The control panel is compatible with the standard on-board electronic control network bus LIN 5.6 and CAN 4. Two heaters at the same time could be controlled (for example, liquid heater internal combustion engine 7 and cabin air heater 8).

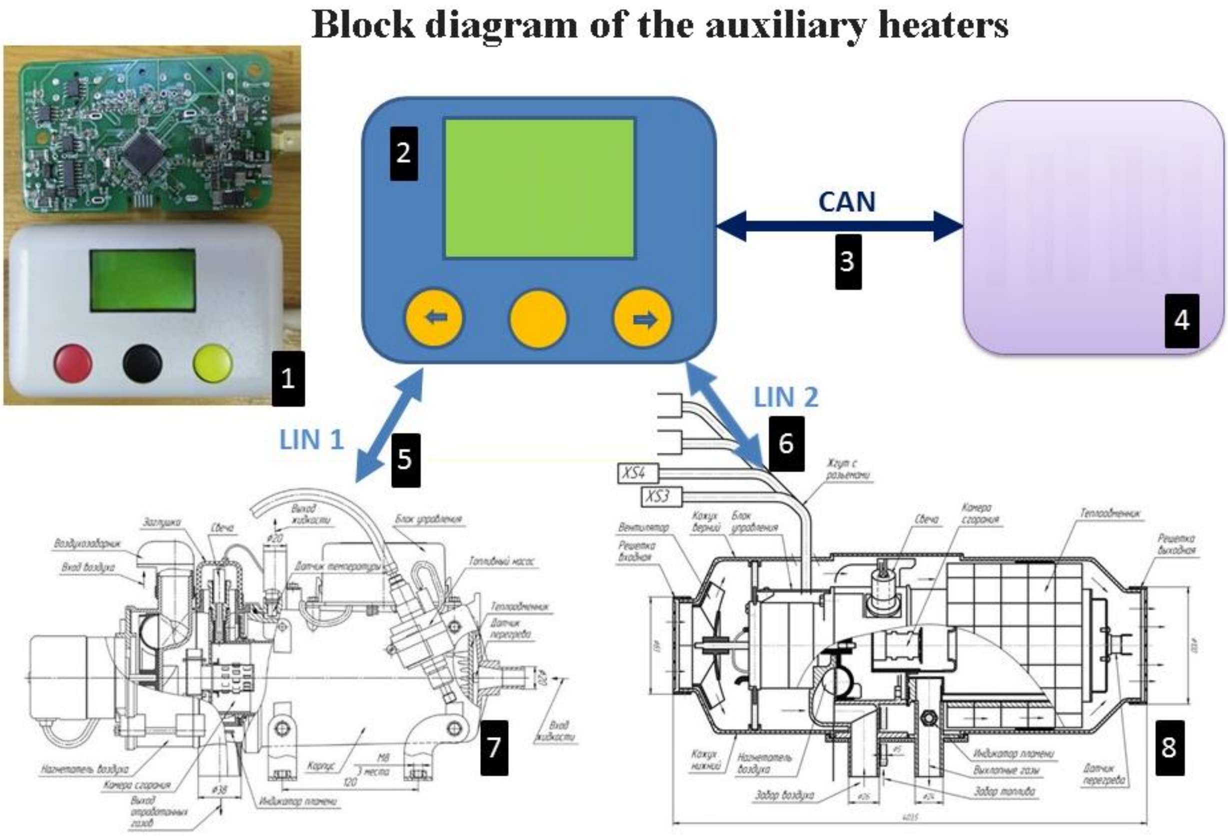

Fig. 4. Block diagram of the auxiliary heaters.

The temperature of the hot side of the TGM for different modes (ambient temperature, heat power of the burner, coolant temperature, etc.) is supported by the control system and provides it in the range of 200+ / -5 ° C.

For the above design, the efficiency of thermoelectric conversion is about 5%. TGM stand in the way of heat to the working fluid and have low thermal resistance (table. 2). Up to 5% of the heat flow passing through the TGM is converted into electrical energy, the remaining 95% is transferred to heat the coolant, thus, the total efficiency of the AEPS in this design is 100%. By this any other system of autonomous power supply could not boast.

During implementation, a test stand, test method was developed and applied. Various modifications of the auxiliary heater have been tested. The design of the AEPS has been optimized and resource tests have been carried out. As the basic model liquid auxiliary heater 14TC-10-24 with a nominal voltage of 24V and diesel fuel was chosen. The heater was equipped with AEPS with two arrays of TGM. Each array consists of 8 pieces of TGM-199-1.4-0.8 in serial with total internal resistance of 15 Ohms for each array.

To measure the temperature on the hot side of the TGM, a thermocouple was installed at the hottest point of the heat exchanger.

Qualification tests were carried out in normal climatic conditions:

- water was used as a coolant;
- the ambient temperature near the test stand 25 ° C.

The test results are shown in table 3.

Table 3. The results of the tests of the AEPS

Parameter	Time from startup, min		
	5	8	10
Electric current in first TGMs chain, A	1.97	2.01	2.05
First TGMs chain output voltage, V	29.38	29.78	30.25
Electric power in load, W	57.9	59.9	62.0
Electric current in second TGMs chain, A	1.50	1.59	1.73
Second TGMs chain output voltage, V	24.80	24.89	25.41
Electric power in load, W	37.2	39.6	44.0
Total generated electric power, W	95.1	99.5	**106.0**
Coolant temperature inlet, ^{o}C	30	40	44
Coolant temperature outlet, ^{o}C	180	190	205

During the tests different temperature modes were worked out, on-off cycles were applied. The total duration of the test was 125 hours.

Further tests were carried out with the autonomous heater 14TC10-24-C connected as an electric load, relevant power consuming devices description is provided in table 4.

Table 4. Power consumption of standalone heater units.

	Power consumption in different modes, W		
	Low	Medium	Full
Coolant pump, W	28	28	28
Fuel pump, W	4	7	14
Air blower, W	45	55	80
Total:	77	90	122

Start-up powering was provided by external power source. After 5 minutes the AEPS reached specified mode. Power supply source was turned off and the heater continued to operate in standalone mode.

Testing processing video is available by following link:
http://cirit.ru/joomla/index.php/news/30-ispytaniya-avtonomnogo-podogrevatelya

Summary

The tests confirmed correctness of the choice of the concept of fully autonomous heater design for the internal combustion engine. R&D tasks were performed. The optimized design of the auxiliary heater on hydrocarbon fuel with built-in power generator and operating time independent of the battery capacity is developed and implemented. The model samples were produced and tested on the customized stand. Patent issue request received a positive decision.

The product is ready to go through the prototype stage before starting the series production. Stakeholders are welcomed.