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ELECTRONIC CONTROL UNIT FOR THERMOELECTRIC AUTOMOBILE STARTING PRE-HEATER

Design and operation algorithm of electronic control unit for thermoelectric automobile starting pre-heater is presented. The main functional units of the device are described. The results of experimental research on the work of electronic unit with the heater components are given.

Key words: processor module, analog-to-digital converter, thermoelectric converter, flame indicator.

Introduction

Modern means for preheating of vehicle engines under low ambient temperatures must meet a number of requirements. Thus, alongside with high heat productivity, low fuel consumption and reasonable dimensions, starting pre-heaters must start reliably and operate without failure. That is why apart from creation of new heat-efficient designs, producers of starting equipment place great emphasis on development of electronic control units, namely systems of automatic control of heater components, i.e. fuel and circulation pumps, air supply fan, burner filament pin.

The basic functions of such electronic unit are as follows [1]:

– temperature control of engine cooling liquid and depending on its value establishment of corresponding heating conditions;

– diagnostics of components when starting the heater and during its operation;

– the heater switch on and off on command from control panel;

– the heater switch off in case of emergency (failure of components, heat carrier overheat, absence of flame, voltage difference, short circuit, etc.).

For the autonomous thermoelectric starting pre-heater developed in the Institute of Thermoelectricity [2 – 8] the task of creation of electronic unit is significantly complicated, since alongside with traditional components, the heater design employs a thermoelectric converter which is used for electric energy supply to components themselves, as well as to automobile battery. So, apart from the above functions the electronic unit must provide constant and simultaneous temperature control of the hot and cold sides of thermal converter. Otherwise, thermopile overheat will not only cause quick failure of all heater components, but will also cause malfunction of other automobile equipment. It is important to choose rational operation algorithm of the heater that would not only assure maximum efficiency of thermoelectric conversion, but also would create conditions for a reliable start-up and stable operation of the device.

The purpose of this work is to create electronic control unit for thermoelectric automobile starting pre-heater and examine it for compliance with the above functional requirements.

Design and operating principle

Block-diagram of electronic control unit for thermoelectric automobile starting pre-heater is shown in Fig. 1.

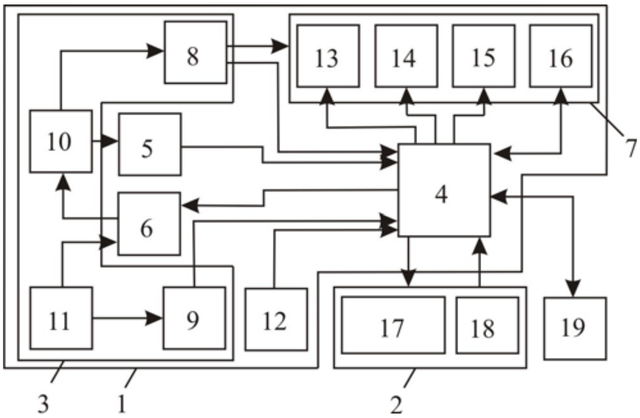


Fig. 1. Block-diagram of electronic control unit [8]: 1 – monitor control unit; 2 – regulating and indicating unit; 3 – signal processing unit; 4 – processor module; 5 – voltage converter; 6 – battery charge control unit; 7 – external actuator control unit; 8 – input circuit of battery v oltage meter; 9 – input circuit of thermopile voltage meter; 10, 11 – terminals; 12 – digital thermal sensor unit; 13 – power switching unit of filament pin; 14 – power switching unit of fuel pump; 15 – power switching unit of circulation pump; 16 – fan power supply and speed control; 17 – optical indication unit; 18 – temperature control unit; 19 – software communication unit.

Electronic control unit consists of two building blocks: 1 – monitor control unit of thermoelectric starting pre-heater and 2 – regulating and indicating unit.

Monitor control unit comprises signal processing unit 3, processor module 4 powered from voltage converter 5, battery charge control unit 6 and external actuator control unit 7.

Sensor signal processing units consist of input circuits 8 and 9 of battery and thermopile voltage meter which are connected through terminals 10 and 11 to processor module, digital thermal sensor unit 12 and analog-to-digital converter (ADC) of processor module (not shown in the figure).

External actuator control unit comprises power switching units 13, 14, 15 of filament pin, fuel pump and liquid pump, respectively, as well as unit 16 for power supply and speed control of a fan for air supply to combustion chamber.

Regulating and indicating unit (control panel) consists of optical indication unit 17 and cold heat carrier temperature control unit 18 (Fig. 2).

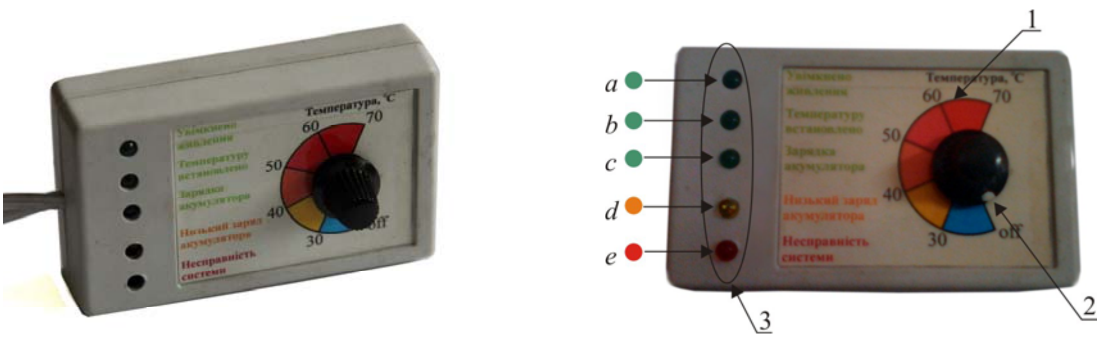


Fig. 2. Control panel of thermoelectric starting pre-heater: 1 – cold heat carrier temperature scale; 2 – cold heat carrier temperature control; 3 – optical indication scale. a – "Components power supply on" indicator; b – "Heat carrier temperature set" indicator; c – "Battery charging" indicator; d – "Low batter charge" indicator; e – "System malfunction" indicator.

It should be noted that in case of malfunctions in the work of the heater “System malfunction” indicator informs of error type by corresponding number of flashes.

For heater testing and keeping track of its components operation the electronic unit can be connected to specialized software (Fig. 3) by means of communication unit 19 and additional converter of data interface (is not part of the system).

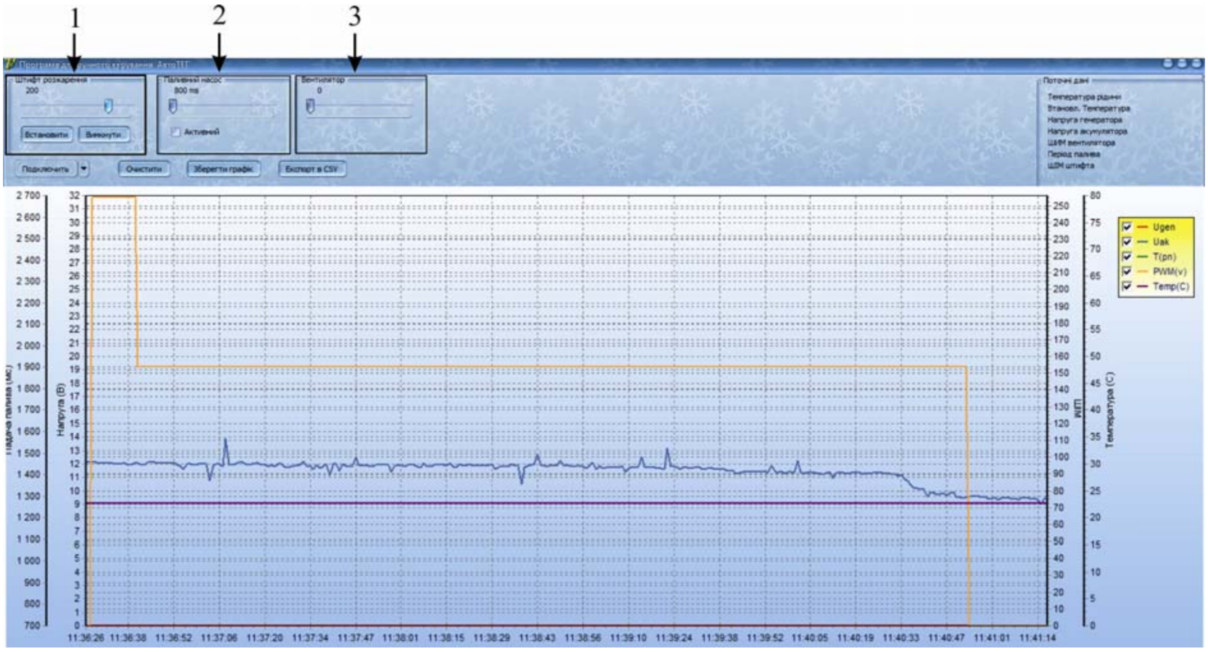


Fig. 3. Program window for heater testing and keeping track of its components operation:
1 – filament pin power manual control window; 2 – fuel pump pulse period manual control window;
3 – fan rpm manual control window; Ugen – electric voltage output of thermoelectric heater;
U_{bat} – electric voltage of automobile battery; T (pn) –fuel pump pulse period;
PWM (v) –fan speed; Temp(C) – cold heat carrier temperature.

Connection to personal computer enables monitoring of the state of control signals from control units of peripheral devices, reflection of signals from sensors for measuring voltage, fan speed and voltage values on battery and generator terminals, as well as a list of device operation algorithm events is accessible.

The system also involves possibility of switching to manual control. In this mode, control signal of filament pin power, fan power, fuel supply period and heat carrier pump on and off can be assigned manually.

Control unit works as follows.

When the battery is connected to terminals 10, there is shutdown of all peripheral actuators and examination of the set temperature on control 7. At the set temperature below 30 ºC (“off” zone) the device goes to standby mode. At the set temperature above 30 ºC switching of the device and initialization of the burner take place by the following algorithm.

Units 15 and 16 switch on the pump and the fan using control signal from central processor 1.

In 10 seconds an inspection of fan speed takes place. If there are no pulses from fan speed control sensor 16, an emergency shutdown of the heater occurs, i.e. all peripheral devices are switched off and a corresponding error signal is displayed on optical indicator unit 7. If the pulses arrive, the initialization algorithm continues, i.e. fan power is reduced and filament pin is smoothly switched on by power switching unit of filament pin 13 by means of control signal from central processor unit 1.

In 40 seconds with the help of power switching unit of fuel pump 14 and control signal from central processor unit 1 the supply of fuel by fuel pump begins. In the process, the voltage is checked on the terminals of thermoelectric generator 11. Through the input circuit of thermoelectric generator voltage meter 9 the signal comes to the input of ADC unit of central processor 1. If in 5 minutes there is no voltage increase on the generator terminals, the heater switches off accidentally. If in 40 seconds there is voltage increase, the burner is lit, filament pin is switched off and the period of fuel supply is gradually reduced from 2.5 to 1 s.

Following that, the system exits initialization mode and enters stabilization mode.

In stabilization mode, constant monitoring of heat carrier temperature is realized by means of digital thermal sensor unit 12.

If heat carrier temperature is less than the set temperature, the period of fuel supply is smoothly reduced to 1 s. If this temperature corresponds to the set value, current period of fuel supply is maintained and a signal of temperature stabilization is displayed on optical indicator unit 6. If heat carrier temperature is higher than the set temperature, the period of fuel supply is gradually increased to 2.5 s.

During operation of the device there is constant voltage control on battery terminals 10 through input circuit of battery voltage meter 8. In conformity with the voltage on battery terminals and period of fuel supply the necessary fan power is set by battery power switching unit 6 and control signal from central processor unit 1. In so doing, battery charge control is done by means of battery charge switching unit 6 and control signal from central processor unit 1.

Moreover, the system exerts constant control over the presence of flame by measuring the voltage on terminals 11 of thermoelectric generator. If voltage drop within 15 seconds is greater than 0.4 V, the system initiates flame disappearance, the burner is restarted, and if the burner could not be restarted, an error message is displayed on optical indicator unit 6.

In 2 hours of operation in the absence of manual disconnection of the heater – it is switched off automatically – the fan power increases to maximum and fuel delivery stops (“blowdown” mode).

In 10 minutes the device goes to standby mode, and the heater can be re-started by turning the knob of thermal controller 7 to position below 30 ºC and re-setting of the necessary temperature.

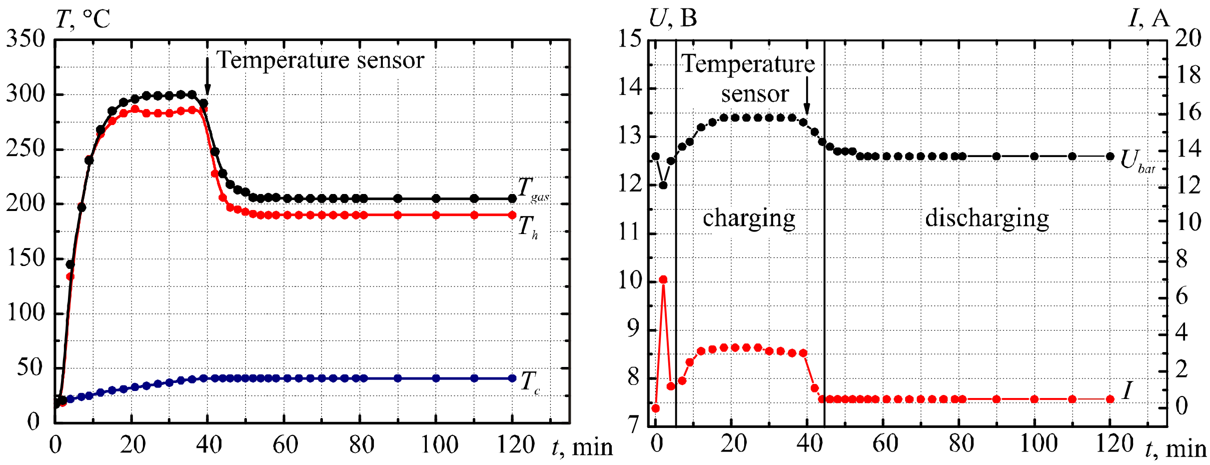
Thus, operation algorithm of the heater is based on smooth increment of heat source thermal power and gradual increase of electric power consumption by the heater components.

Such automatic alternate transition from the moment of components initiation to the mode of maximum power through a series of intermediate modes [5] provides reliable starting and stable operation of device.

Research results

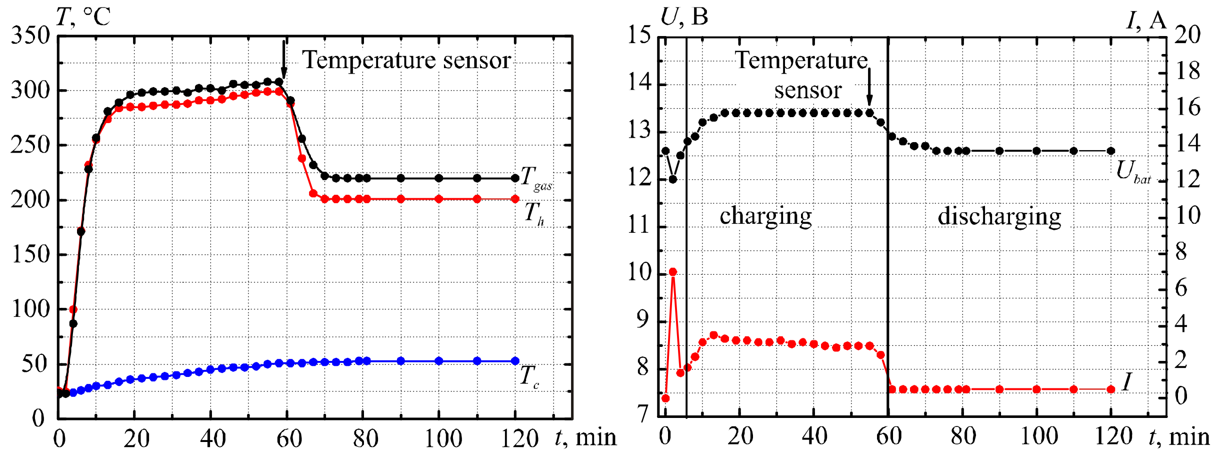
The operation algorithm of electronic unit paired with components of thermoelectric automobile heater is illustrated by the results of bench tests (Fig. 4 – 7).

The evidence presented suggests that the behaviour of both temperature and electrical dependences is practically identical. After switching on the device and up to the moment of reaching the assigned heat carrier temperature the electronic unit in conformity with the algorithm in microprocessor gradually increases thermal power of heat source to maximum. In so doing, accordingly, there is increase in temperature characteristics T_c, T_h, T_{gas} and transfer from the battery mode of components power supply to autonomous mode. With increasing electric power output of the generator, the electronic unit directs excess electric energy to battery recharging.



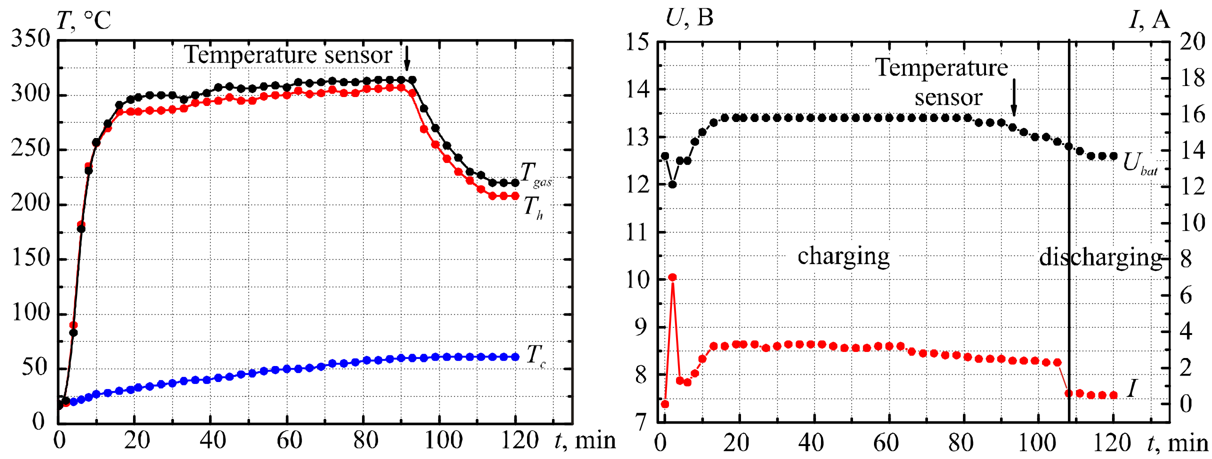
a) *b)*

Fig. 4. Results of research on thermoelectric automobile heater with electronic control unit:
T_{gas} – outlet gas temperature; T_h – hot heat exchanger temperature;
T_c – cold heat exchanger temperature; U_{bat} – battery voltage;
I – current in "heater"-"battery" circuit. Heat carrier temperature is set at 40 °C.



a) *b)*

Fig. 5. Results of research on thermoelectric automobile heater with electronic control unit.
Heat carrier temperature is set at 50°C. The notation is similar to Fig. 4.



a) *b)*

Fig. 6. Results of research on thermoelectric automobile heater with electronic control unit.
Heat carrier temperature is set at 60°C. The notation is similar to Fig. 4.

When the set temperature of heat carrier is reached, the electronic unit in conformity with the output signal of digital thermal sensor, which is on one of the liquid heat exchangers of the heater, increases the period of fuel delivery to the burner and the heater starts working in the mode of set temperature support. In so doing, the temperature on the hot heat exchanger and the temperature of gases drop, and the temperature on the cold heat exchangers is stabilized. Note that in this mode the power generated by thermoelectric modules is insufficient for battery recharging, so the electronic unit by reversing current in "heater"-"battery" circuit switches power supply of components from the modules back to the battery. As can be seen from Fig. 4 – 6, under these conditions battery discharge current is as low as ~ 0.2 A, which as compared its capacity is certainly a very low value (for instance, discharge current in operation of staring pre-heater "Webasto Thermo Top C" is an order of magnitude higher – 3 – 5 A). Therefore, it can be stated that in heat carrier temperature support mode the heater actually works without the use of battery energy.

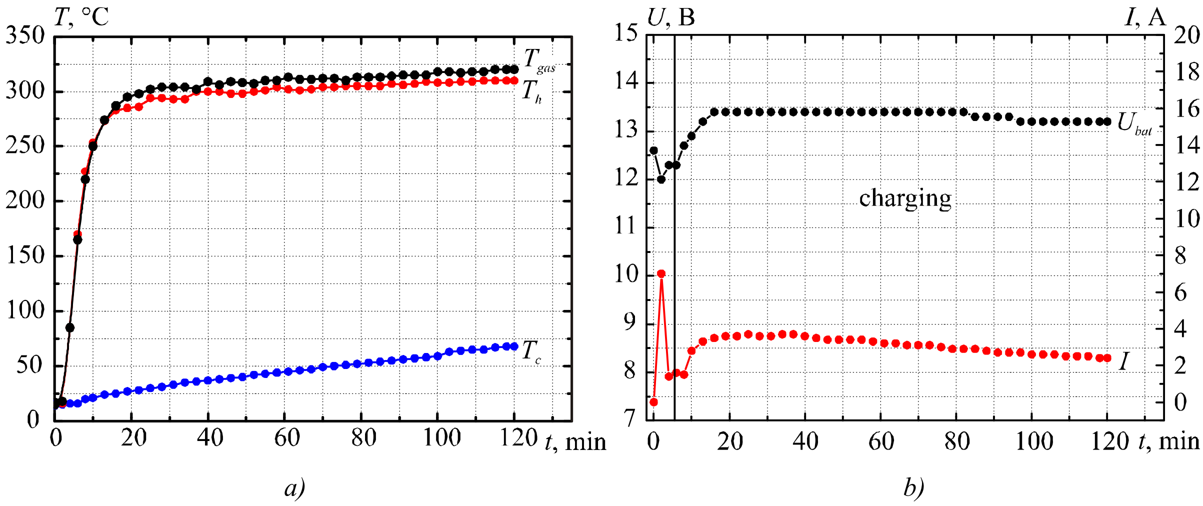


Fig. 7. Results of research on thermoelectric automobile heater with electronic control unit. Heat carrier temperature is set at 70 °C. The notation is similar to Fig. 4.

With heat carrier temperature set at 70 °C (Fig. 7) digital thermal sensor does not work, since heat carrier is heated to given temperature practically at the moment of switching off the heater. However, there are special advantages in this, since automobile battery is constantly charging.

It is also noteworthy that in the course of investigations an emergence situation was artificially created in operation of the heater by alternative disconnection from power supply of a fuel pump, a fan, a circulation pump. The results confirm the rationality of chosen algorithm for system protection from overheats and other dangerous situations, namely the electronic unit initializes an error in the operation of the heater (disappearance of flame in combustion chamber, overheat of the cold side of modules, etc.) and stops its work – the heater switches to "blowdown" mode. In so doing, as noted earlier, a signal of respective error type is displayed on control panel.

Conclusions

1. A fundamentally new design of electronic control unit for thermoelectric starting pre-heater was created where thermoelectric converter is used as a flame sensor, and thermoelectric modules of the converter – for self-energizing of the system and battery recharging.
2. It was shown that heater control is carried out by an intelligent control algorithm of flame, air and fuel delivery and battery charge, which assures stable operation of device and creates a reliable

protection system in case of emergency.

3. As a result of experimental tests, the rationality of chosen electronic unit design and of the algorithm of heater operation employed was confirmed.

References

1. V.S. Naiman, *All about Starting Pre-Heaters* (Moscow: ACT, 2007), p. 213.
2. V.Ya. Mykhailovsky, M.V. Maksimuk, 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 (2015).
3. V.Ya. Mykhailovsky, M.V. Maksimuk, Rational Powers of Thermal Generators for Starting Pre-Heaters of Vehicles, *J.Thermoelectricity* 4, 69 – 77 (2015).
4. V.Ya. Mykhailovsky, M.V. Maksimuk, Computer Design of Thermoelectric Automobile Starting Pre-Heater Operated with Diesel Fuel, *J.Thermoelectricity* 1, 52 – 65 (2016)
5. L.I. Anatychuk, V.Ya. Mykhailovsky, M.V. Maksimuk, I.S. Andrusiak, Experimental Research on Thermoelectric Automobile Starting Pre-Heater Operated with Diesel Fuel, *J.Thermoelectricity* №4, 81 – 90 (2016).
6. Patent (UA) № 72304 InCl: F01N 5/00; H01L35/00 Automobile Heater with Thermoelectric Power Supply / L.I.Anatychuk, V.Ya.Mykhailovsky. – Publ. 10.08.2012, Bul. № 15, Appl. u2012 02055 of 23.02.2012.
7. Patent (UA) № 102303 InCl F01N 5/00 H01L 35/00 Thermoelectric Power Supply for Automobile / L.I. Anatychuk, V.Ya. Mykhailovsky. – Publ. 25.06.2013, Bul. № 12, Appl u2011 13957 of 28.11.2011.
8. Patent (UA) № 90764 InCl F02N 19/00 Control System of Liquid Starting Pre-Heater for Internal Combustion Engines / V.Ya. Mykhailovsky, P.V. Zvozdetskyi, M.V. Maksimuk. – Publ. 10.06.2014, Bil № 11, Appl.u2013 15422 of 30.12.2013.

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