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AUTOMOBILE OPERATING CONDITIONS AT LOW TEMPERATURES. THE NECESSITY OF APPLYING HEATERS AND THE RATIONALITY OF USING THERMAL GENERATORS FOR THEIR WORK

The main reasons for a complicated startup of transport means at low ambient temperatures are analyzed. The benefits and drawbacks of using start heating for a better startup of automobile engine are determined. The operating principle and structural features of starting pre-heaters are described. The rationality of using thermoelectric generators for the operation of such equipment is substantiated.

Key words: engine, start heating, compartment heater, thermoelectric generator.

Introduction

To date, startup of internal combustion engine at low ambient temperatures remains a relevant problem for any and every kind of transport means [1 – 6]. It is primarily due to a negative effect of low temperatures on the service life of internal combustion engines. Quick heating of "cold" engine creates temperature stresses leading together with mechanical loads to quick parts wear and their lifetime reduction [1, 3, 4]. Another negative factor of cold start is large fuel consumption due to its condensation and reduced volatility [2]. That is why prior to startup the engine must be warmed up [5, 6]. At the present time there are a lot of various methods for easy startup of engines in cold weather. In general, they are classified as group and individual [7].

Group methods realize start heating of engine by heat carriers heated from the external energy sources (electric grids, boiler facilities, and portable gas generators): water steam, hot air, infra-red rays, etc.

Individual heating methods include standard (required by design of engines) and supplementary heating means (liquid and air heaters, electric torch air heaters, and heating plugs mounted directly on the engines). The benefit of individual heating methods is their independence, i.e. they do not depend in their operation on the presence of external energy source.

Autonomous start heating of cooling liquid is one of the most widespread and efficient individual methods of engine warm-up at low temperatures. Such heaters are fit for practically all types of internal combustion engines, so they are used in cars and trucks, as well as in buses, planes, yachts and boats [8, 9].

However, despite powerful capabilities, starting pre-heaters have not found wide use yet. It is primarily due to their high cost. However, it is not the only constraining factor: according to statistics, even in economically developed Nordic countries the autonomous starting pre-heaters are installed only in one automobile of a thousand [10].

Therefore, the purpose of this paper is analysis of the benefits and drawbacks of start heating of automobile engines at low temperatures and expansion of the opportunities of practical use of starting pre-heaters with the aid of thermoelectric power converters.

Drawbacks of "cold" engine start

The main reasons complicating startup of internal combustion engine at low temperatures include [11 – 13]:

1. Resistance increase with crankshaft rotation due to increased viscosity of engine oil. Many years of experience in transport means operation show that at temperature –18°C the resistance to crankshaft rotary moment increases by a factor of 2 – 2.5.

2. Starter power decrease with reduction of dry starting current and accumulator capacity. For a completely charged accumulator battery of capacity 50 – 60 A·h, dry starting current is within 300 – 500 A. If starter current at temperature 25°C can reach 400 A at voltage 9 V, then at temperature – 30°C it will decrease to 200 A. And with each new starting attempt, its value will decrease. Though manufacturing techniques of accumulator batteries improve every day, they do not affect the degree of starter current reduction at low temperatures.

3. Fuel condensation and its volatility decrease. The quality of air-fuel mixture depends on fuel volatility. For instance, petrol fuel volatility occurs mainly in the range from 35°C to 200°C. In so doing, "light" fractions are volatilized which are most critical in the period of cold engine start. However, according to standards, the content of such fractions in petrol fuel is restricted, since their large amount in the hot engine will cause formation in fuel system of vapour locks that result in the internal combustion engine wobble. In this connection, "winter" petrol that has volatility almost three times higher compared to "summer" petrol is provided, which should assure a reliable engine startup at – 15…– 20°C. However, the use of "winter" petrol already at temperature +5°C leads to formation of vapour locks. With "summer" petrol sort engine startup is complicated at – 5°C, and at – 20°C it becomes impossible.

Effect of said factors at low temperatures is manifested simultaneously and leads to reduction of engine service life and increase of fuel consumption at its startup [13]. Preliminary investigations show that with each "cold" start of internal combustion engine (at temperature lower than + 5°C), the loss in its service life is nearly 400 – 600 km. Taking into account that over the year there are 100 – 120 days with the temperature lower than 0°C, the loss in engine service life will be ~80000 km [11].

4. Increase in the norm of toxic substances emission with exhaust gases. According to medical men, high emission of toxic substances into environment with the exhaust gases of automobiles leads to propagation of various allergic and asthmatic diseases and, as a consequence, to reduction in life expectancy at least by 4 – 5 years.

It has been established that the emission of toxic substances in the cars during first kilometers after "cold" engine start is 70 – 80% of total amount of automobile emission during this period. It is due to low efficiency of catalyst work under conditions of low temperatures. Depending on the ambient temperature, the automobile must drive several kilometers prior to the catalyst will be heated and start cleaning efficiently the exhaust gases.

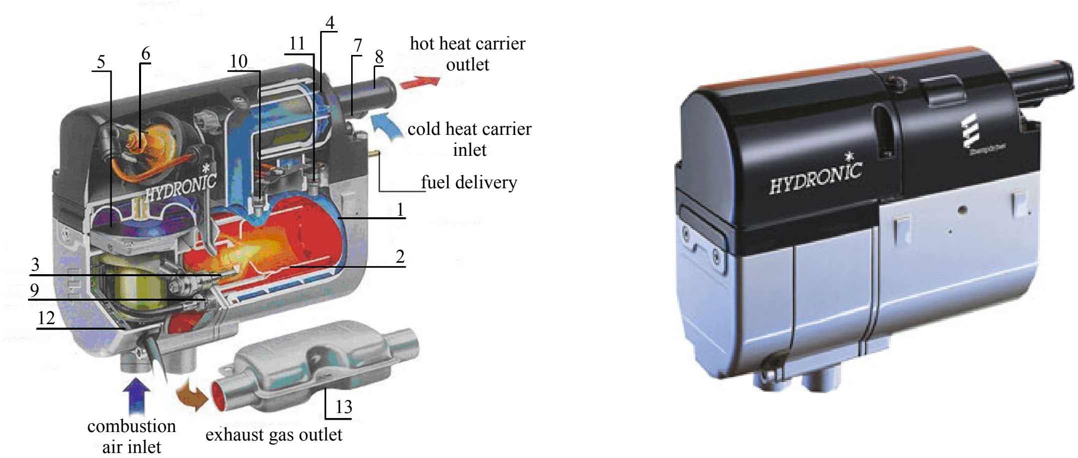
Investigations of Norwegian Automobile Federation have shown that the emission at one "cold" engine start is 100 – 300 g. If throughout the year 500 such starts are made (on the average 2 times a day), the annual average emission of one automobile with account of start emission is 69 kg. In so doing, the total amount of yearly emissions of all automobiles, for instance, for a city with population ~1 million inhabitants, will be 20000 tons.

Operating principle and structural features of starting pre-heaters

At the present time, autonomous starting pre-heaters for preliminary warm-up of engines of transport means at low temperatures are commercially produced by a number of foreign companies: Eberspacher, Webasto, Truma (Germany), Ateso (Czech Republic), Mikuni (Japan), Tepolostar (Russia) [14 – 17]. Staring pre-heaters are mainly classified:

- by the type of fuel as diesel, petrol and gas. Separation of heaters according to the type of fuel and the necessity of creation of corresponding structures is due to the fact that the heaters are mounted on a car with diesel, petrol and liquefied gas-operated engines. From the standpoint of ease of use, the fuel that the engine is operated by is advisable for the heaters;
- by the type of heat carrier heating as liquid and air.

Fig. 1 shows a schematic and appearance of a liquid starting pre-heater Hydronic (Eberspacher) of thermal power 4 kW.



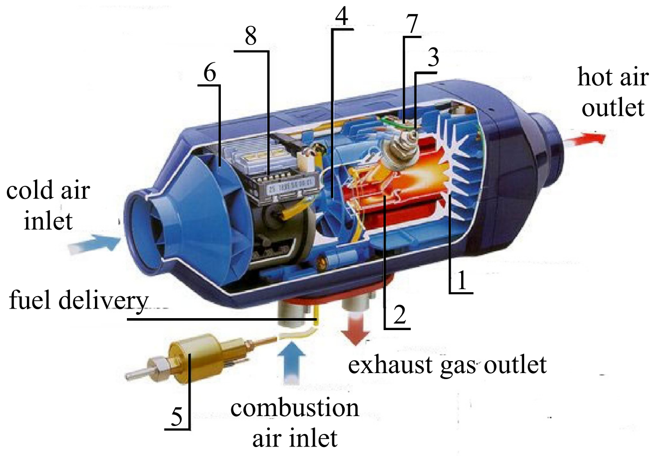
a) *b)*

Fig. 1. Schematic (a) and appearance (b) of a liquid starting pre-heater Hydronic:
1 – heat exchanger; 2 – combustion chamber; 3 –igniter;
4 – liquid circulation pump, 5 – fan; 6 – fuel pump;
7, 8 – inlet and discharge branch pipes; 9 – flame sensor; 10 – temperature sensor;
11 – overheat sensor; 12 – electronic unit; 13 – silencer [15].

A starting pre-heater combines in one housing heat exchanger 1, combustion chamber 2 with igniter 3, liquid circulation pump 4, fan 5 and pump 6 for air and fuel delivery to combustion chamber. The operating principle lies in heating of cooling liquid (heat carrier) of automobile engine. For this purpose, the heater through branch pipes 7 and 8 is connected to engine cooling system loop, which in turn is connected to automobile heating radiators. Liquid circulation in cooling system and heating radiators is done by a liquid pump. Fuel to the heater comes directly from the automobile tank or is taken from a separate special container. The presence of flame in combustion chamber is controlled by sensor 9. Sensors 10 and 11 are used to control heat carrier temperature. The diagnostic system in electronic unit 12 controls the work of the heater and disconnects it in case of emergency. The device is started manually or by means of a timer programmable for a specific time from a remote control desk. To provide for a noise-free work, the heater is additionally equipped with silencer 13.

Thus, liquid starting pre-heaters provide for not only engine warm-up at low temperatures, but also heating of cabins, passenger compartments and transport means. Moreover, this type of heaters can be also used in summer for blowing of passenger compartments when air-conditioner is inoperative.

In some cases the use of liquid starting pre-heaters is impossible (automobiles with air-cooled engine) or unreasonable – for instance, for heating of passenger compartments of buses, sailboat cabins, cabins of trucks during stops, and auto campings. For such cases autonomous air heaters of passenger compartments have been created (Fig. 2).



a)

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Fig 2. Schematic (a) and appearance (b) of autonomous air heater of passenger compartment Airtronic (Eberspacher) of thermal power 4 kW:
1 – heat exchanger; 2 – combustion chamber; 3 – igniter;
4 –fan for air supply to combustion chamber; 5 – metering fuel pump;
6 – cold air supply fan; 7 – overheat sensor; 8 – electronic unit [15].

Just as for liquid heaters, the basic structural elements of autonomous heaters are heat exchanger 1 and combustion chamber 2. Air blown by fan 4 is mixed with the fuel delivered to combustion chamber by metering pump 5. Firing of fuel-air mixture is done by ceramic igniter 3. Air flow created by means of another fan 6, passes through the external finned part of heat exchanger to be heated by thermal energy from combustion of diesel or petrol fuel. Following this, the hot air is fed to passenger compartment or cabin. Located on heat exchanger housing is overheat indicator 7, and air temperature sensor (not shown in Fig. 2), necessary for control of thermal condition, is arranged in cold air flow directly in front of the heat exchanger. Control unit 8 maintains given air temperature in passenger compartment, changing the number of fan rotations and consumption of fuel coming to combustion chamber. The exhaust system provides for a discharge of combustion products beyond the cabin of passenger compartment.

Moreover, this type of heaters can be also used in summer for blowing of passenger compartments when air-conditioner is inoperative.

An alternative to autonomous air heaters of buses, microbuses, off-roaders, jeeps and special machines are non-autonomous air heaters (Fig. 3). Such devices are composed of a radiator heated by engine heat carrier and a fan delivering heat from the heated radiator to space. On delivery of heat carrier to radiator, the heater through deflectors or air ducts blows hot air to passenger compartment. Pumping of heat carrier is done by a standard automobile pump, so the heater works only when the engine is in operation.

Fig. 3. Nonautonomous air heater Xerox-4000 (Eberspacher):
1 – heat exchanger; 2 – inlet and discharge branch pipes; 3 – fan [15].

The unique feature of these devices lies in the fact that they are used in transport means with large internal volumes as supplementary heaters for standard heating system.

Benefits of engine start heating

From technical standpoint, engine start heating at low ambient temperatures as compared to "cold" start provides for the following [11, 18]:

– engine startup at 1 – 2 attempts due to reduced time of starter rotation by a factor of 2 – 3;

– reduction of engine oil viscosity and increase of its pumping rate;

– increase of crankshaft speed;

– reduction of fuel consumption by 0.1 – 0.5l per one start. Preliminary studies that were conducted in the Technological Institute of Oslo (Norway) show that with the use of start heating fuel consumption at startup is reduced by 15 – 30% for petrol engines and 8 – 12% for diesel engines. In so doing, already after passing the distance of 3 – 4 km the engine is warmed-up completely, and fuel consumption practically does not depend on the fact whether or not start heating took place. Thus, the most evident fuel saving at engine warm-up occurs in the process of startup itself and with the first 2 – 3 km of running. This allows saving 90 – 150 liters of fuel during one winter season;

reduction of engine service life loss. Fig. 4 shows the results of study on automobile engine oil after 30 starts at ambient temperature – 20°C with and without start heating. As is seen from the presented data, the content of metals in the oil of automobile for which start heating was used is more than 3 times less than for automobile with no start heating. It is due to the fact that at low temperatures the rate of oil flow is reduced, and it cannot efficiently oil the surfaces of parts, which results in their quick wear due to friction and engine service life reduction in general. Engine start heating allows increasing the operational period of internal combustion engine and essentially saves its service life. For instance, under conditions of middle climate zone and the North where the temperature does not raise above +5 °C within six months, with a daily use of start heating the saving of engine service life is 50-60 thousand km;

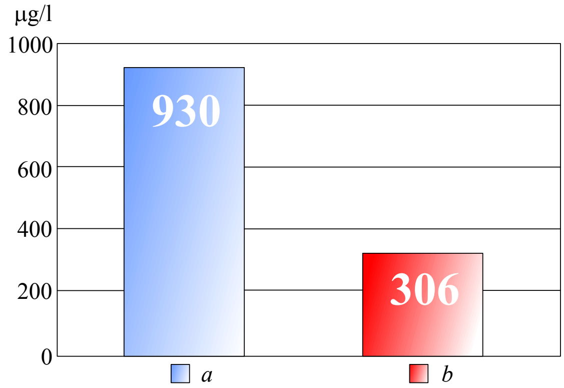

Fig. 4 – Metal amount, μg in 1 l of car engine oil:
a) without start heating; b) with start heating.

– reduction of toxic substances emission to environment with the exhaust gases. Figs. 5, 6 show the results of recent research on the determination of toxic emissions with exhaust gases for automobile with a preheated and cold engine.

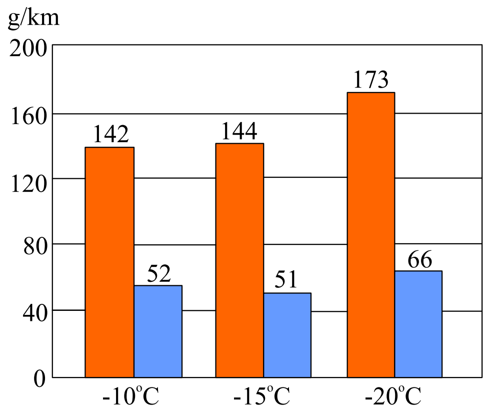

Fig. 5. Carbon monoxide level in automobile exhaust with a cold and preheated engine.

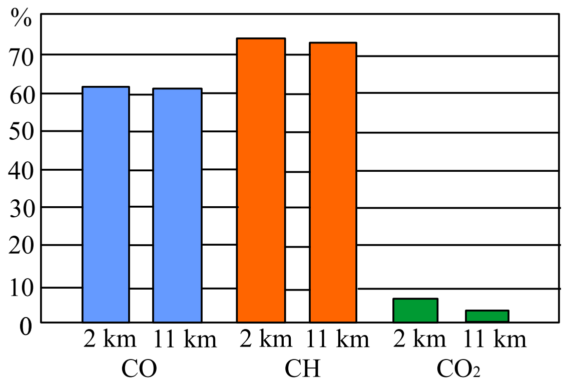

Fig. 6. Relative reduction of emission in automobile exhaust with a preheated engine.

From the analysis of presented data it follows that depending on the number of cold starts during the year engine preheating allows reducing toxic emissions of automobile during the first kilometers of running by 60-80%. Moreover, at the startup of preheated engine the content of toxic gases in the exhaust is reduced by a factor of ~ 5, which in turn allows reducing the early amount of emissions from one automobile by 80%. Given below are the values of reduction of yearly emissions with the use of start heating of automobile engine, on condition of its yearly mileage 10000 km (Table 1).

Table 1

Reduction of yearly automobile emission
with the use of start heating

Emission level	Without start heating	With start heating
Carbon monoxide (CO), kg	63	12.6
Hydrocarbons (CH) + nitrogen oxides (NO_x), kg	6	1.25
Total emission, kg	69	13.8

It is noteworthy that today the norms of toxic emissions with exhaust gases are regulated by international standards EURO-4 – for cars and EURO-5 – for trucks. Apart from the total norm of emissions for heated engine, these standards partially specify the amount of emissions under start-up conditions.

Another benefit of engine start heating lies in higher safety of travel. Psychologists emphasize essential effect of cold on humans. The actions of chilled person are delayed and retarded, his attention is diminished. These factors account for accident statistics according to which 15 % of all traffic collisions occur within the first 15 minutes of travel. Under comfortable conditions provided by start heating of engine and passenger compartment, such negative factors are completely excluded.

Use of thermoelectric generators for engine start heating

Despite several positive features, automobile heaters, as mentioned above, do not find mass application, in particular, in cars and microbuses.

This is mainly due to the need for electric energy for power supply to components of starting pre-heaters, namely fuel pump, fan for air supply to combustion chamber, circulation pump for pumping of liquid heat carrier.

Preliminary studies have shown that in operation of liquid heater of thermal power 4 kW and electric power requirement 37 – 40 W, making 60 W together with a standard fan of automobile heating system, a battery of capacity 60 A·h during 4.5 h loses 50% of capacity. One should also take into account the fact that under reduced temperatures the capacity of automobile battery loses is further reduced by another 15 – 20% [19]. So, liquid starting pre-heaters are recommended to be used not more than for 40 min in automobiles with the engine up to 3 liters, and not more than for 1 h in other automobiles, which can be insufficient for warm-up of internal combustion engine to operating temperature [20]. In so doing, the work of standard automobile heating system should be adjusted so that the electric current of fan motor does not exceed 2.5 A.

Practice shows that by strong frosts (– 10…– 30 °C) the problem of passenger compartment warm-up becomes irrelevant. The problem of automobile operation in principle is much more acute. Under such conditions, essential rise in the temperature of passenger compartment by means of start heating is practically impossible. Though air heaters allow passenger compartment to be warmed before everything else, to warm up the engine, battery capacity is not sufficient. To prevent from a “deep” battery discharge, by strong frosts it is recommended not only to disconnect the function of compartment heating, but also to refuse from the use of additional equipment installed in the car (audio- and video complexes, GPS-navigators, warning systems). Drivers who throughout the day use a car for less than 30 min (home-office-home), and in so doing a heater operates for 20 – 30 min prior to each engine startup, will not avoid weekly battery charging.

It is noteworthy that none of known models of starting pre-heaters solve the problem of battery discharge. The most widespread ways of cold engine heating without the use of battery energy is electric heating and heating by means of thermal accumulators. However, in this case a driver is permanently tied to external energy source.

Said problem can be solved with the aid of a thermoelectric generator operated from heater and providing for autonomous power supply to its components [22]. A schematic of thermoelectric automobile heater is given in Fig. 7.

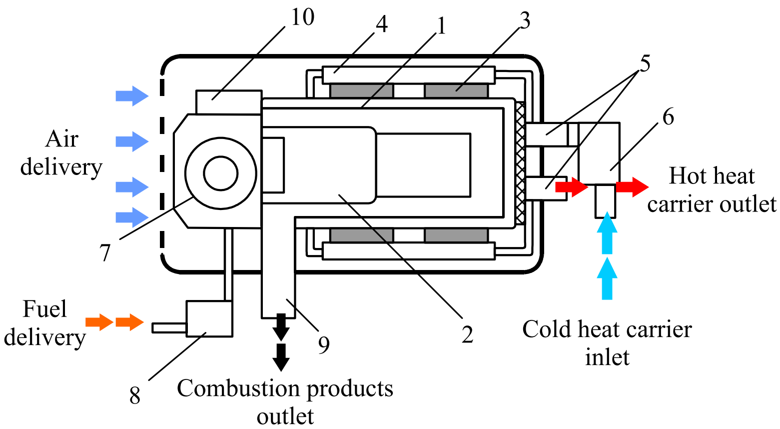

Fig. 7. Schematic of thermoelectric automobile starting pre-heater:
1 – hot heat sink; 2 – heat source; 3 – thermoelectric modules; 4 – liquid cold heat exchangers;
5 –inlet and outlet connecting branches; 6 –liquid circulation pump; 7 – fan; 8 –fuel pump;
9 –exhaust pipe; 10 –electronic unit.

Structurally, such thermoelectric heater is composed of hot heat sink 1 which accommodates heat source 2 inside. On the external surface of the heat sink there are thermoelectric modules 3, the heat from which is rejected by liquid heat exchangers 4. Liquid heat exchangers are combined into one hydraulic loop which is connected to engine cooling system by connecting branches 5. Circulation of liquid heat carrier in heater-engine loop is done by pump 6. Moreover, the heater must comprise fan 7 and fuel pump 8 – for air and fuel delivery to combustion chamber. Combustion products are rejected to environment by exhaust pipe 9. The heater start and control is done by electronic unit 10.

The heater will work as follows. Thermal energy obtained due to fuel combustion heats the hot heat exchanger, passes through thermoelectric converter and is rejected by liquid heat carrier circulating in the heat exchanger of the heater and engine cooling system. Due to the difference in temperatures between the hot and cold sides, thermal converter generates an electric current. Thermal energy rejected by heat carrier from thermal converter is used for engine warm-up and heating of automobile passenger compartment.

Apart from preliminary engine warm-up and heating of compartments, vehicle cabins at reduced ambient temperatures, the thermoelectric heater will provide for electric energy supply to:

– inherent components: fuel and circulation pumps, fan, electronic unit;
– battery during engine warm-up;
– standard fan of automobile heating system;
– automobile warning systems;
– automobile audio and video equipment.

Besides, thermoelectric starting pre-heaters can find wide practical application in ambulances to maintain stable temperature conditions in passenger compartment and power supply to medical devices (cardiographs, defibrillators, etc.) and in transport means of military purpose – for additional power supply to communication systems during engine warm-up.

Thus, owing to the fact that the thermoelectric heater will not depend in its operation on the availability of battery or other external source of electric energy, this opens up vast prospects for such devices in various scopes of activity.

Conclusions

1. It is shown that the drawbacks of transport means startup under low ambient temperatures include reduction of engine service life and overconsumption of fuel during first kilometers of running.
2. It is determined that the use of start heating allows increasing engine life by 50 – 60 thousand km per year and reducing emissions of toxic substances by a factor of 5, saving 90 – 150 l of fuel during one winter season. Moreover, comfortable conditions provided by start heating of engine and automobile compartment exclude completely the possibility of accidents caused by the effect of cold on the driver.
3. It is shown that the main drawback of starting pre-heaters is a need for electric energy for power supply to components (fuel and circulation pumps, fan, and electronic control unit), leading to battery discharge. It creates essential difficulties during engine startup.
4. The possibility of creation and the expedience of using thermoelectric generator to solve the problem of automobile battery discharge during the operation of starting pre-heaters are substantiated. With the aid of thermoelectricity the process of start heating becomes completely autonomous, without the use of battery electric energy. Moreover, excess energy of thermal generator can be used for battery charging and power supply to other automobile equipment. This opens up new vistas for thermoelectric starting pre-heaters in various scopes of activity.

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