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EFFECT OF AIR COOLING ON THE EFFICIENCY OF A THERMOELECTRIC GENERATOR IN A CAR WITH A PETROL ENGINE

The paper is concerned with a physical model of a thermoelectric generator (TEG) for a petrol engine with a system of heat removal from TEG, comprising an air-to-liquid heat exchanger and an electric fan. A mathematical and computer description of the model is presented. Computer simulation of the model for a 70 kW petrol engine is considered. Optimal hot side temperatures of the generator and optimal powers of the fan are found whereby maximum net power is attained and, accordingly, maximum real efficiency of TEG with regard to expenditures on the fan supply for ambient temperatures in the range of –40…+50^{O}C. A comparison of such efficiencies to those previously obtained for a diesel engine is made. It is shown that a real efficiency of TEG with a heat exchanger for a petrol engine is 1.3 – 1.5 fold higher than for a diesel engine of the same power.

Key words: heat recovery, thermoelectric generator, internal combustion engines.

Introduction

The use of waste heat from the internal combustion engines is one of most discussed subjects among practical applications of thermoelectricity. The ultimate purpose of such application is fuel saving due to the use of engine exhaust heat for electric energy generation [1, 2].

As is known, the presence of a thermoelectric generator in a car has a considerable impact on its operation. The negative factors include, for instance, additional resistance to gas motion in vehicle exhaust system, additional expenditures of engine power on the transportation of TEG proper; and the expenditures related to the necessity of heat removal from a thermoelectric generator. Some of these impacts are discussed in [3-5]. It is shown that for cars these costs can sometimes exceed the effective work of TEG.

Expenditures on heat removal from TEG for a car with a diesel engine are considered in [6]. The values of these expenditures for 75 kW engine are determined. It is established that expenditures on heat removal from a one-sectional TEG can reach 15-25% of the electric energy produced by TEG, or about 6-12% of TEG power in the form of engine's mechanical energy. In general, it is shown that for a diesel engine the use of TEG with regard to expenditures on heat removal adds 1.5-4% to engine power in the form of electric energy, which, accordingly, can give about 2-6% of fuel saving when doing away with a dynamo.

It is interesting to establish similar regularities for petrol engines, since the exhaust gas temperature in them is known to be much higher compared to diesel engines, which can give more optimistic figures of fuel saving.

The purpose of this work is to estimate the efficiency of using a thermoelectric generator for a car with a petrol engine with regard to energy spent on heat removal from TEG.

Physical model and computer design of TEG for a car

The work of a thermoelectric generator as part of a car can be represented by a schematic shown in Fig. 1.

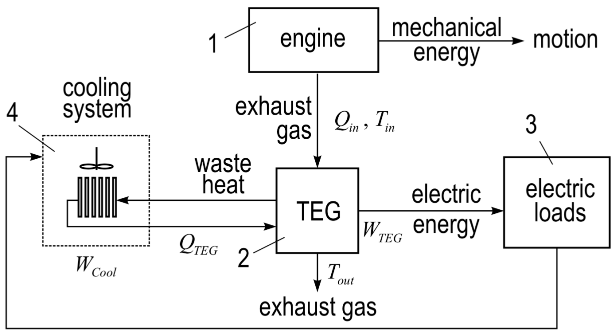

Fig. 1. A model of TEG operation in a car with regard to electric energy spent on heat removal from TEG.

Exhaust gas of thermal power Q_{in} from engine 1 comes to thermoelectric generator 2 of thermal resistance R_t at temperature T_{in} and leaves the generator at temperature T_{out}. The TEG generates electric energy W_{TEG} at efficiency η_{TEG}. A case is considered when part of this electric energy W_{cool} is spent on the operation of cooling system 4 which removes thermal power Q_{TEG} from the TEG. The ambient temperature is T_{amb}.

Computer model and design methods for this model are given in [6]. The main relations for the calculations are as follows:

$$T_{out}\left(R_t\right)=\left(Q_{in}\left(1+\frac{T_{amb}}{T_{in}-T_{amb}}\right)+\frac{T_0}{R_t}\right)/\frac{1}{R_t}+\frac{Q_{in}}{T_{in}-T_{amb}}, \tag{1}$$

$$\eta_{TEG}(R_t)=\frac{T_{out}-T_0}{T_{out}}\frac{M-1}{M+T_0/\mathrm{T}_{out}}, \tag{2}$$

where

$$M=\sqrt{1+Z\frac{(T_{out}+T_0)}{2}}. \tag{3}$$

The effective efficiency of TEG is introduced by the expression:

$$\eta_{ef}=(W_{TEG}-W_{cool})/Q_{in}. \tag{4}$$

These methods are not essentially different from the design methods for a diesel engine. The difference lies primarily in higher temperatures of exhaust gases (~800°C) and the use of alternative thermoelectric materials suitable for operation at elevated temperatures.

Such a model has two values that should be optimized, namely the hot side temperature of TEG and the electric power spent on the operation of cooling system.

Example of parameters calculation of TEG for a petrol engine

As an example, we shall calculate the basic parameters of TEG for a stock 70 kW petrol engine UMZ-3318 in continuous operation mode. In this operation mode, the exhaust gas temperature is about 790°C. For such a TEG, *n-PbTe* and *p*-TAGS materials that have the best figure of merit in the operating temperature range were selected. The *ZT* value of a module of such a couple is given in Fig. 2 [8].

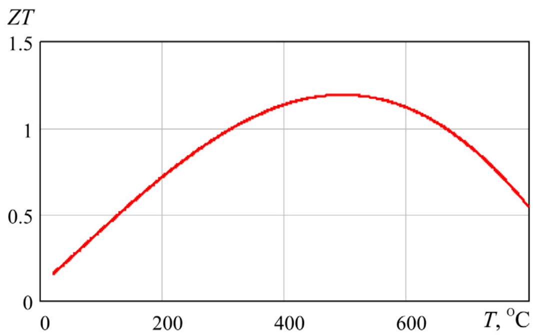

Fig. 2. Temperature dependence of ZT for n-PbTe and p-TAGS based modules.

The characteristics of air-to-liquid heat exchanger necessary for calculations were taken from [6].

TEG hot side temperature optimization. In the beginning, optimization for the efficiency of the hot side temperature of TEG took place which at constant thermal power of exhaust gases is a function of TEG thermal resistance. Fig. 3 shows the result of such optimization. It is seen that optimal temperatures change only slightly. It allows without essential efficiency loss using in thermal generator one averaged thermal resistance of thermopile. Fig. 4 gives the values of efficiency and electric power of TEG depending on the hot side temperature at different cold side temperatures of TEG. It is seen that with a reduction of cold side temperature, maximum efficiency and power is shifted towards lower temperatures, as in Fig. 3, and the efficiency value in this case is somewhat increased (Fig. 5) due to a combined effect of the thermodynamic efficiency and the temperature dependence of *ZT* of modules.

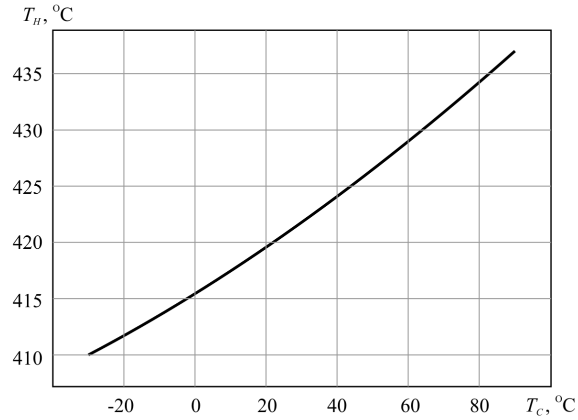

Fig. 3. Optimal hot side temperature of TEG versus its cold side temperature.

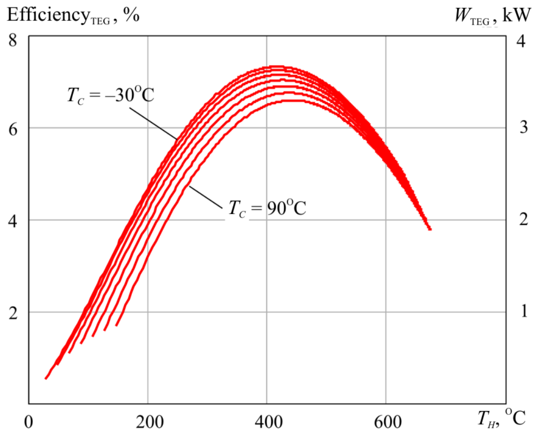

Fig. 4. Efficiency and electric power of TEG versus its hot side temperature. T_C varies from –30°C to +90°C.

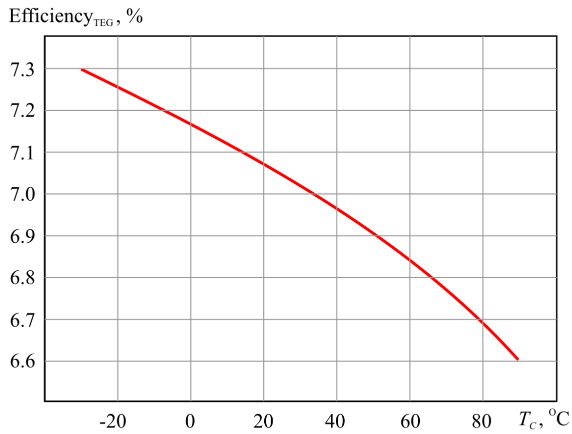

Fig. 5. TEG efficiency versus its cold side temperature.

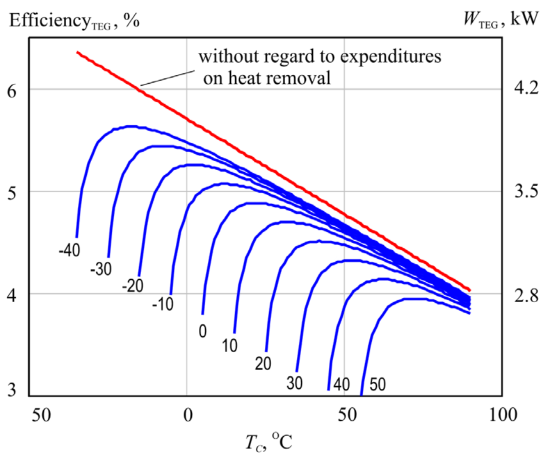

Fig. 6. Dependences of the efficiency and electric power of TEG on the cold side temperature of TEG (Ambient temperature, °C is indicated beside the plots).

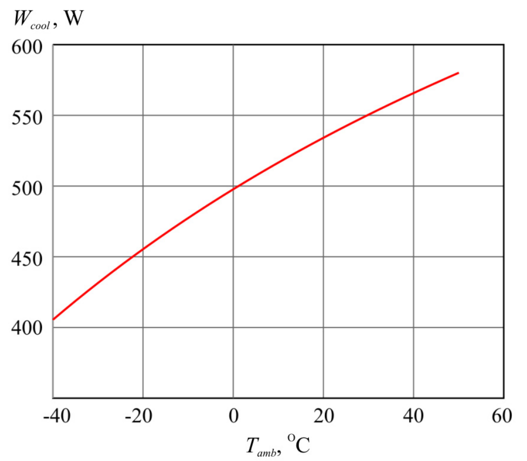

Fig. 7. Dependence of the optimal electric supply power of cooling system on the ambient temperature.

Calculations of extreme efficiency and power of TEG with regard to the fact that part of its electric energy is spent on providing the work of heat removal system were made with the aid of computer simulation according to Eqs. (1-4).

Fig. 6 shows the result of optimization of "TEG-cooling system" system for different ambient temperatures. From the plots it is seen that there exist pronounced optimal operating modes of TEG cooling system. The values of optimal powers of cooling system fan are given in Fig. 7. They make ~10%...20% of thermal generator power.

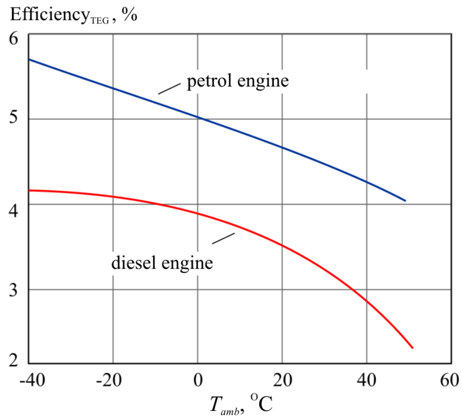

Fig. 8. Dependence of TEG efficiency on the ambient temperature.

Fig. 8 gives a comparison of TEG efficiency with a heat removal system for diesel [6] and petrol engines. As is evident, the use of TEG with a petrol engine yields better parameters, namely the efficiency is less dependent on the ambient temperature. It can assure ~1.3-1.5-fold higher efficiency and electric power and, accordingly, fuel saving about 4 – 6.5%.

Conclusions

1. Computer simulation has been used to establish essential dependence of the efficiency of using TEG in a car with a petrol engine on the electric power spent on heat removal from the thermal generator.
2. It has been also established that the extreme values of efficiency and power are attained with TEG optimization for hot side temperature and for the electric power spent on fan supply in a system of heat removal from the thermal generator.
3. Computer simulation of TEG with a system of heat removal for a 70 kW petrol engine, the ambient temperatures –40…+50°C and the use in TEG thermopiles of materials based on *PbTe* and TAGS have yielded the following results: optimal hot side temperatures of the generator 410-435°C; the generator efficiency with regard to expenditures on heat removal 4-6.5%; the electric power 2.8-4.5 kW; expenditures on heat removal 400-550 W; improvement of the efficiency and power of generator for a petrol engine as compared to a diesel engine by a factor of 1.3-1.5; the expected fuel saving 4-6.5%.

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