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Study of the Influence of Heat Exchanger Body Design Parameters on the Performance of a Thermoelectric Generator for Automotive Internal Combustion Engine

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This article presents a study of the influence of design parameters, such as the thickness and width of thermal fins and inter-fin grooves, on the performance of a thermoelectric generator for an automotive internal combustion engine. The overall dimensions of a thermoelectric generator and, as a consequence, the size of the surface, which exchanges heat with the exhaust gases, are often subject to limitations because it has to fit inside the vehicle's exhaust system. Changing the thermoelectric generator body design by adding fins that increase the heat exchange area can significantly increase the amount of the recuperated thermal energy. However, it inevitably increases the exhaust gas pressure drop in the thermoelectric generator, which is certainly a negative impact on the internal combustion engine as a whole. According to our research methodology the fin thickness ranged from 0.75 to 5.0 mm and the groove width from 1.0 to 8.0 mm. Consequently, we considered 48 variants of the thermoelectric generator heat exchanger in total. The obtained results show a high degree of non-uniformity of temperature distribution in the cross sections of the thermoelectric generator, which leads to uneven heating of the thermoelectric generator modules, reduced efficiency and overheating. This research enabled us to select a design of the fins, which allows to achieve the heat flow through the thermoelectric generator modules of 19kW with exhaust gas pressure drop of 2.5 kPa, while taking into account additional technical solutions. This research helps to improve the technical and economic parameters of a thermoelectric generator for an automotive internal combustion engine at the model design stage, which significantly accelerates the process of its development. Subsequent laboratory tests of the developed thermoelectric generator model enable us to refine the parameters of the mathematical model and significantly improve accuracy of the calculations.

Key words: Heat exchanger, Thermoelectric generator, Recuperation of heat energy, Direct conversion of heat into electricity.

Most modern vehicles are equipped with internal combustion engines (ICE). However, in such engines only 20-25% of the fuel combustion energy is spent to propel the vehicle, that is converted into useful work. At the same time, up to 40% of the burned fuel energy is irretrievably lost with the exhaust gas only (Bourhis and Leduc, 2010; Jadhao and Thombare, 2013). This is why recovery of the exhaust thermal energy is the most promising way to improve fuel efficiency by partial recuperation (Jianqin et al., 2011). Recovery of the ICE exhaust gas thermal energy can be achieved by thermodynamic, thermochemical or thermoelectric methods.

Thermodynamic exhaust gas heat

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recovery, performed with the help of devices implementing the Rankine or Erickson cycle or Stirling engines (Nadaf and Gangavati, 2014), produces mechanical energy, which has very limited practical application.

There are also methods of thermochemical recuperation, which make it possible to produce hydrogen-containing fuel with a high calorific value, further used to run an internal combustion engine, for example endothermic decomposition of methanol into synthetic gas (Khripach, 2004).

Thermoelectric recuperation of energy based on the Seebeck effect, lithium-hydride cycle, thermionic emission and other effects produces electrical energy, which can be used further to power electrical accessories, and, in the case of a hybrid vehicle, feed the traction motors driving the wheels. Each of the thermoelectric exhaust gas heat recovery methods has both undeniable advantages and some significant disadvantages (Legros et al., 2014).

The Seebeck effect is appearance of an electromotive force in the presence of a temperature difference between contacts of a closed electrical circuit consisting of dissimilar conductors. The performance of a thermoelectric generator (TEG) can be estimated from the efficiency coefficient, which depends not only on the materials used, but also on the temperature difference between its cold and hot junctions. Modern high-performance thermoelectric materials can convert up to 20% of thermal energy into electrical energy, but they are expensive and difficult to process (Zheng, 2008). On the other hand, low cost thermoelectric materials based on oxides of various elements and providing acceptable efficiency are being developed (Hung et al., 2015).

The most common material used in the design of thermoelectric generator modules (TGM) for exhaust gas heat recovery is bismuth telluride (Ismail and Ahmed, 2009). However, many researchers refuse to abandon attempts to increase the efficiency of this material without a significant cost increase (Toprak et al., 2003).

The overall dimensions of the TEG and, as a result, the size of its heat exchange surface are often limited because of the need to install it in a vehicle exhaust system (Khripach et al., 2014). As shown in (Lu et al., 2013), changes in the design of the TEG body that increase the heat transfer area and make the exhaust gas flow more turbulent can significantly increase the amount of the recuperated heat energy. The same paper also records a sharp increase of the values of exhaust gas pressure drop in a thermoelectric generator, which certainly has a negative impact on the ICE operation.

Thus, the main challenge in creating an efficient thermoelectric generator for an automotive internal combustion engine is to determine the design parameters of its heat exchanger, such as fin thickness (Ramade et al., 2014) or size of the heat exchanger (Esarte et al., 2001), that would be sufficient to maintain the necessary heat flow through the thermoelectric generator modules with minimal exhaust gas pressure drop.

To determine the design parameters of the TEG body's heat exchange apparatus, a mathematical model of heat transfer from the ICE exhaust gases through the thermoelectric generator modules to the coolant must be created, taking into account the temperatures and flow patterns of hot and cold coolant, heat transfer surface condition and the body geometry. Additionally, it is necessary to determine the drop of the exhaust gas pressure along the thermoelectric generator body length, which affects not only the heat exchange rate, but also the efficiency of the internal combustion engine as a whole. The mathematical model of heat transfer, that we have developed, and exhaust gas pressure drop calculation are needed to determine the main thermoelectric generator performance indicators, such as generated electric power and total pressure drop for different heat exchanger designs. Analysis of the obtained results provides a basis to select the optimal TEG fins configuration

METHOD

The thermoelectric generator considered in this study follows a previously developed concept and consists of the following components: a body, thermoelectric generator modules and a liquid cooling system. Liquid cooling of thermoelectric generator modules is significantly more efficient than air cooling and allows to produce considerable amount of electric power (Zhou et al., 2013), which is directly proportional to the power of the heat flow from the exhaust gas to the coolant flowing through the TGM.

The TEG body consists of four heat exchanger units, two flanges and eight rivet nuts for mounting coolers. The most important and complicated part is a heat exchanger unit of the TEG body. This item is a straight prism with triangular base, in which longitudinal and transverse grooves are made, forming the fins that significantly enlarge the heat transfer surface. In this case transverse cuts are also required to reduce internal stresses in the metal part caused by thermal expansion during operation of the thermoelectric generator as a part of the ICE exhaust system.

A model of the heat exchanger unit of the thermoelectric generator body is shown in Figure 2.

The heat transferred from the internal combustion engine exhaust gases through the wall to the coolant is directly proportional to the wall area and temperature difference between the heat exchanging fluids. If the heat transfer surface on one side of the wall is increased with metal fins, as it is done in this case, we should expect that the heat flux per area unit of the wall surface with the fins will increase in direct proportion to the size of the heat transfer surface. However, the effective temperature difference will decrease due to the temperature gradient along the fins. Therefore, the general increase in the heat flow will be less than expected (Kumar et al., 2013).

On the other hand, introduction of internal finning into the thermoelectric generator body design can significantly increase aerodynamic resistance to the exhaust gas flow, which adversely affects the key indicators of the internal combustion engine efficiency.

Thus, it is required to determine the optimal ratio of the fin thickness to the width of the groove between them (sizes a and b in Figure 2), which provides the required heat flow through the thermoelectric generator modules with minimal exhaust gas pressure drop. Computational studies have been conducted for various combinations of a and b, to achieve that. The thickness of the fins varied between 0.75 and 5.0 mm and the groove width between 1.0 and 8.0 mm. In order to determine the optimum ratio of the heat exchanger in the TEG body design parameters, it is necessary to develop a method to calculate the heat flow and electric power output, as well as the drop of exhaust gas pressure.

Method of calculating the heat flow and electric output of the TEG

In the general case a thermoelectric generator can be presented as a combination of three components: a heat source, a thermoelectric module and some coolant. In the case of the thermoelectric generator for an automotive internal combustion engine under consideration the source of thermal energy are the exhaust gases, and the engine coolant is the refrigerant. The scheme of the TEG heat transfer model used in the calculation is shown in Figure 3.

The power of heat flows can be determined on the basis of the heat transfer equations and thermal conductivity resulting from

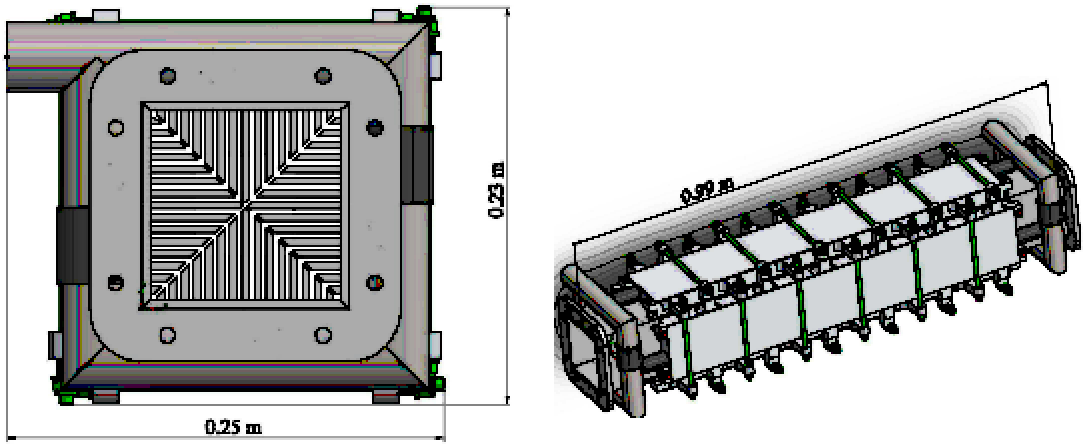

Fig. 1. Model of a thermoelectric generator for an automotive internal combustion engine in the solid representation

the Newton-Richman law:

$$Q_1 = \alpha_1 \cdot A_1 \cdot \Delta T_1 \quad ...(1)$$

$$Q_{TGM} = k_{TGM} \cdot A_{TGM} \cdot \Delta T_{TGM} \quad ...(2)$$

$$Q_2 = \alpha_2 \cdot A_2 \cdot \Delta T_2 \quad ...(3)$$

The heat transfer coefficients [alpha] from the hot to the cold medium, applied in these equations, depend on the coolant type, its temperature, temperature difference, flow regime, state of the heat transfer surface and body geometry, so they are functions of the heat transfer process and should be calculated independently at every moment of time (Lienhard and Lienhard, 2008; Lukanin and Shatrov, 2000).

Average thermal conductivity coefficient of the thermoelectric generator modules, taking into account additional hot and cold walls, also depends on the design of the thermoelectric generator module and materials used and may be determined by the formula:

$$k_{TGM} = \frac{1}{\frac{\delta_1}{\lambda_1} + \frac{\delta_{TGM}}{\lambda_{TGM}} + \frac{\delta_2}{\lambda_2}} \quad ...(4)$$

At the same time, you must separately take into account conversion of exhaust gas thermal energy in thermoelectric generator modules into electrical energy with a certain efficiency level, which depends on the temperature difference between the cold and hot junctions of the TGM (Meng et al., 2012):

$$Q_2 = Q_1 - N_{TGM} = Q_1 \cdot (1 - \eta_{TGM}) \quad ...(5)$$

The relations (1-5), as well as other laws applicable to the processes of steady heat and mass transfer, allow to determine the total exhaust gas heat flow to the coolant, and, therefore, the amount of the electric power generated by the TEG.

Metod to calculate the exhaust gas pressure drop

When the exhaust gas flows through the thermoelectric generator, the outlet pressure is reduced by the amount ”P as a result of hydraulic

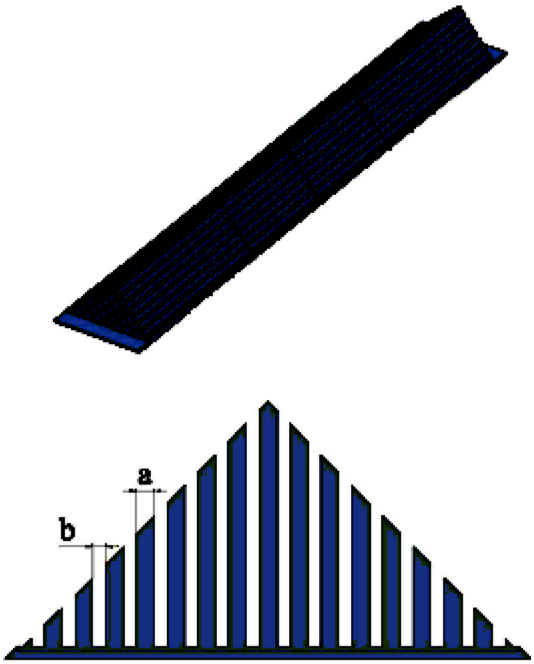

Fig. 2. Model of a TEG body heat exchanger unit in solid representation

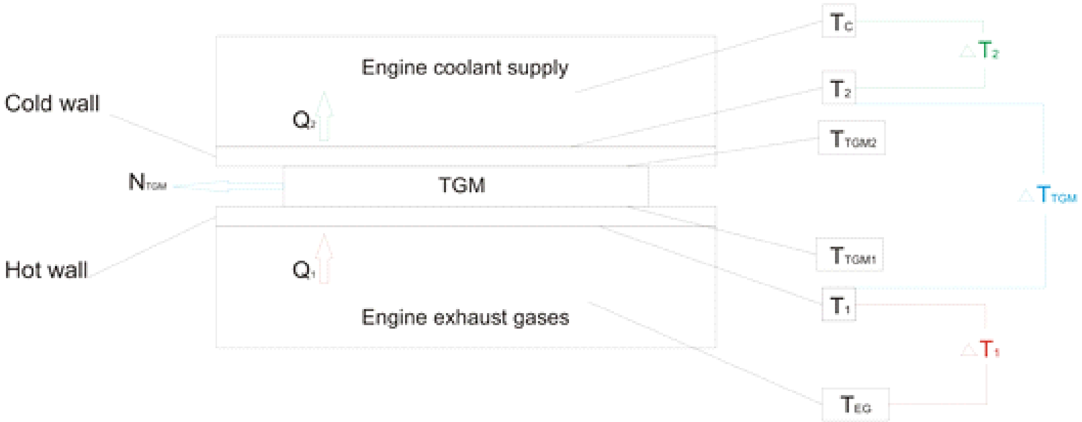

Fig. 3. Scheme of the heat transfer model in the thermoelectric generator

resistance. The change of pressure along the length of the generator is shown schematically in Figure 4. The total pressure drop can be represented by the sum of the pressure drops at each part of the TEG, which are caused by different kinds of resistance.

The pressure drop at each part of the thermoelectric generator must be determined independently but taking into account thermodynamic parameters of the exhaust gases in the corresponding flow section, such as temperature, density, velocity, etc. For example, to determine the exhaust gas pressure drop at the beginning and the end of the finned part of the body, you can use Borda-Carnot formulas, which describe sudden narrowing (Con) and sudden expansion (Exp) of the flow section:

$$\Delta P_{Con} = \frac{1}{2} d_{air} \left(\frac{1}{\mu} - 1 \right)^2 \left(\frac{A_1}{A_2} \right)^2 \cdot v_1^2 \quad ...(6)$$

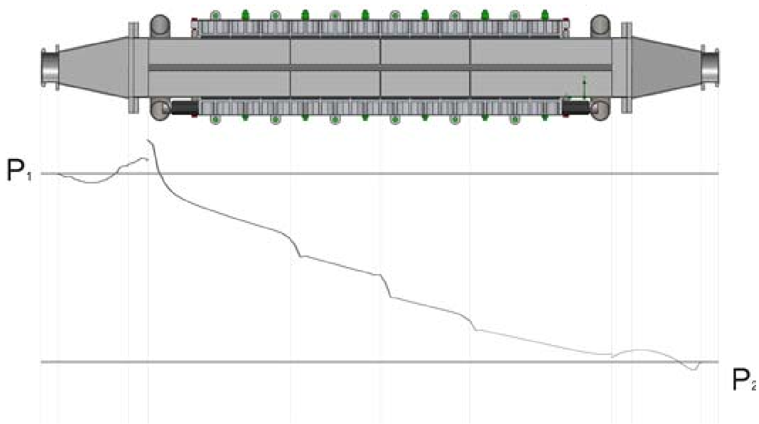

Fig. 4. Changes of pressure along the length of the generator

Table 1. User inputs and baseline configuration

Parameter	Value	Unit
Exhaust inlet and outlet pipe diameter	56	mm
TGM size (cross-section, height)	(0.056x0.056, 0.00445)	mxm, m
TGM thermal conductivity at 300°C	2.18	W/m*K
Temperature of the exhaust gases at the TEG inlet	520	°C
Mass flow of the exhaust gases	0.085	kg/s
Temperature of the coolant at the manifold inlet	82	°C
Mass flow of the coolant	0.2	kg/s
Pressure of the exhaust gas and coolant at the TEG outlet	101325	Pa
Thermal conductivity of the TEG body at 300°C	44	W/m*K
Cooler thermal conductivity at 300°C	230	W/m*K

Table 2. Obtained total heat flow power values, W

	b = 1.0mm	b = 2.0mm	b = 3.0mm	b = 4.0mm	b = 5.0mm	b = 6.0mm	b = 7.0mm	b = 8.0mm
a = 0.75mm	21166	19927	17666	15307	13548	12019	10874	9955
a = 1.0mm	21202	20588	18535	16268	13935	12587	11446	10720
a = 2.0mm	21378	20871	19330	17573	15694	14395	13214	11959
a = 3.0mm	20807	20747	19558	17885	16446	15171	13704	12943
a = 4.0mm	20416	20536	19422	17947	16702	15281	14235	13460
a = 5.0mm	20147	20341	19306	17886	16691	15443	14445	13825

$$\Delta P_{Exp} = -d_{air} \cdot \frac{A_1}{A_2}\left(1-\frac{A_1}{A_2}\right)\cdot v_1^2 \qquad ...(7)$$

Here, v and is the speed and density of the exhaust gas, respectively. As the research done by Weisbach shows, an additional factor that takes into account the impact of a sharp edge of a sudden narrowing can be determined according to the following relationship:

$$\mu = 0.63 + 0.37 \cdot \left(\frac{A_2}{A_1}\right)^3 \qquad ...(8)$$

Table 3. Obtained exhaust gas pressure drop, Pa

	b = 1.0mm	b = 2.0mm	b = 3.0mm	b = 4.0mm	b = 5.0mm	b = 6.0mm	b = 7.0mm	b = 8.0mm
a = 0.75mm	5561	2600	1922	1707	1615	1562	1507	1499
a = 1.0mm	6218	2806	2079	1828	1774	1689	1655	1630
a = 2.0mm	8802	3709	2452	2049	1843	1752	1719	1661
a = 3.0mm	10908	4460	2788	2167	1942	1833	1730	1713
a = 4.0mm	12436	5150	3061	2327	2041	1880	1782	1739
a = 5.0mm	13787	5832	3368	2469	2148	1938	1832	1795

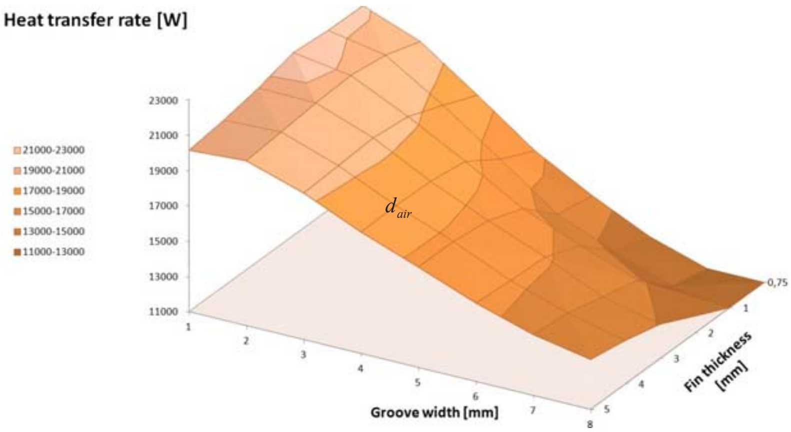

Fig. 5. Dependency of the heat flow through the thermoelectric generator modules from geometric parameters of the TEG body heat exchanger fins

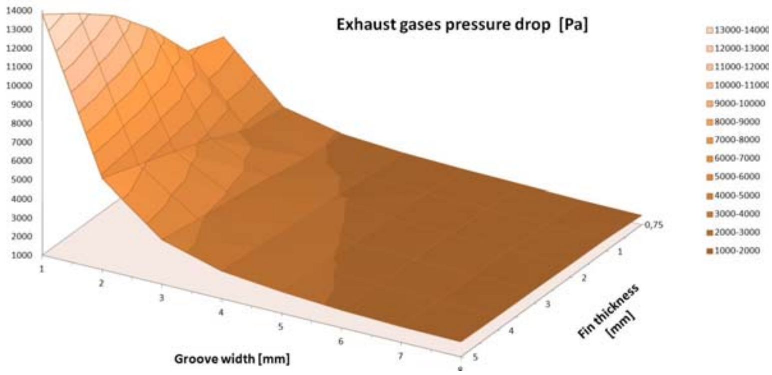

Fig. 6. Dependency of the exhaust gas pressure drop from geometrical parameters of the TEG body heat exchanger fins

The pressure drop in the hydraulic resistance areas without narrowings and expansions of the flow section is directly proportional to the square of the gas velocity and is determined according to the Darcy-Weisbach formula for a of non-circular pipe cross-section:

$$\Delta P = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2} \cdot \rho \qquad ...(9)$$

Here, D is the hydraulic diameter of the pipe's cross section, and L is the length of the section. The longitudinal friction loss coefficient [lambda] is determined depending on the Reynolds number value, that is kind of the exhaust gas flow, which can be laminar, transitional or turbulent in the current TEG section (Kadle and Sparrow, 1986; Zeitoun and Hegazy, 2004).

The given dependences (6-9), as well as other laws applicable to the processes of steady gas flow, allow to determine the total exhaust gas pressure drop and, therefore, assess the negative impact of the thermoelectric generator on the internal combustion engine operation.

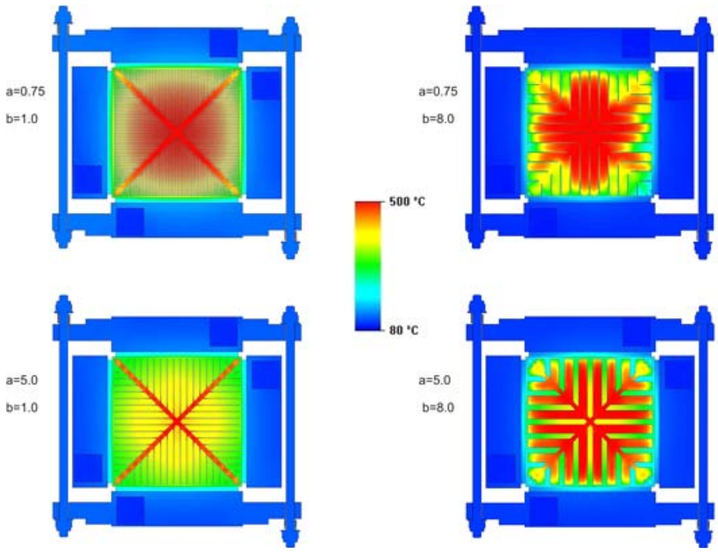

Fig. 7. Temperature in the cross section of the TEG with different heat exchanger designs

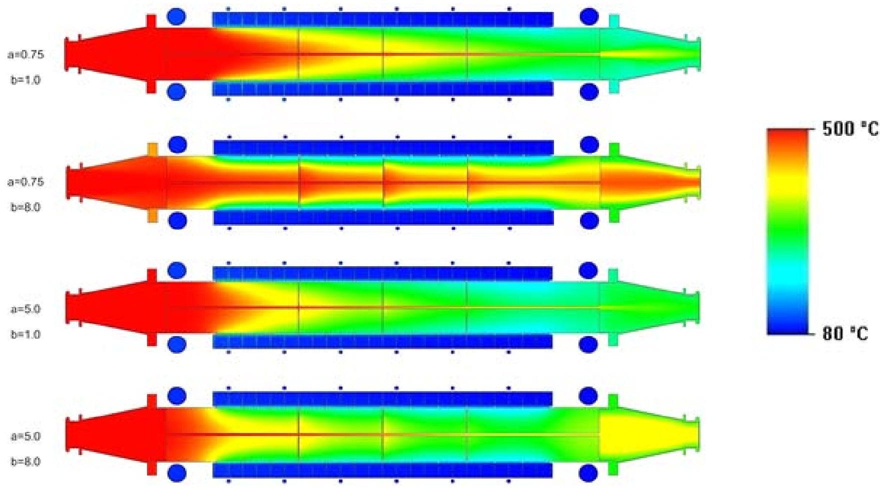

Fig. 8. Temperature in the longitudinal section of the TEG with different heat exchanger designs

Initial and boundary conditions set in this study

The initial conditions for the calculation of heat transfer in the studied thermoelectric generator were the values shown in Table 1.

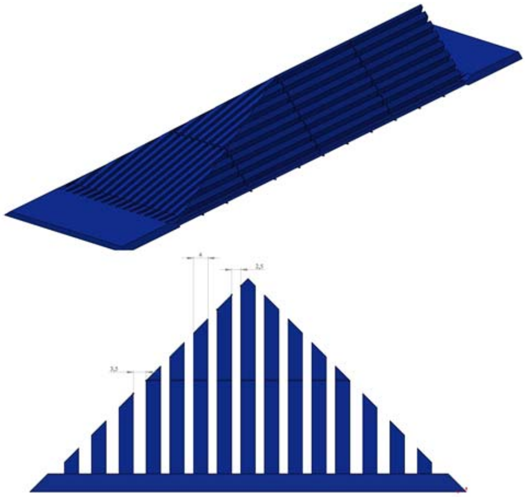

Fig. 9. Model of a redesigned TEG body heat exchanger unit

The presented initial conditions and, in particular, the thermodynamic parameters of exhaust gases and coolant allow to simulate the operation of the studied thermoelectric generator as a part of a vehicle with a gasoline internal combustion engine. However, in this study we did not take into account fluctuations of thermodynamic parameters of exhaust gases, which inevitably happen inside a real vehicle. It significantly simplified the calculations.

RESULTS

The heat flow through thermoelectric generator modules and exhaust gas pressure drop

According to the adopted research methodology the fin thickness ranged between 0.75-5.0 mm and the groove width ranged between 1.0-8.0 mm. We considered all 48 possible variants of TEG body heat exchanger finning.

For each of the considered 48 TEG body design variants we calculated the total values of the heat flow through the thermoelectric generator

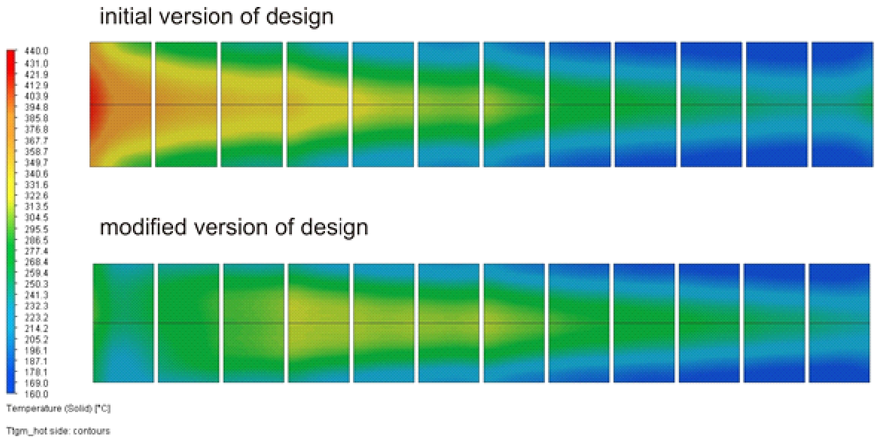

Fig. 10. Temperature distribution over the surface of the hot side of the thermoelectric generator modules with the original and modified versions of TEG body finning

Table 4. Calculated values of the main characteristics of the thermoelectric generator with the original and modified versions of the TEG body finning

Parameter and measurement units	Variant a/b = 4/3	Modified design
Heat flow through the thermoelectric generator modules [W]	19422	19064
Aerodynamic resistance to the flow of exhaust gases [Pa]	3061	2364
Maximum temperature on the hot side of the thermoelectric generator modules [°C]	421	317
Maximum temperature on the cold side of the thermoelectric generator modules [°C]	148	136

modules and the values of the exhaust gas pressure drop. Results of the calculations are shown in Tables 2 and 3.

On the basis of the obtained results we plotted the dependency of the total heat flow through the TEG modules and exhaust gas pressure drop from the geometrical parameters of the TEG body heat exchange apparatus fins, shown in Figures 5 and 6.

The obtained dependency of the heat flow through the thermoelectric generating modules and geometric parameters of the TEG body heat exchanger fins enables us to make the following conclusions:

- Thickness of a heat exchanger fin has little impact on the total heat flow and the impact becomes even less as the efficiency of heat transfer increases. For example, when the groove width equals 8 mm, changing the fin thickness from the minimum to the maximum causes total heat flow power increase of 32%. When the groove width is 1 mm, the same change of the fin thickness results in the total heat flow power change of only 6%, and downward.
- On the other hand, reducing the width of the groove between fins causes significant (from 37.8 to 74.4%) and, more importantly, constant increase of the heat flow through the thermoelectric generator modules.

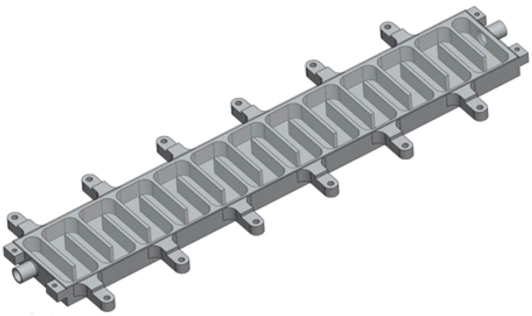

Fig. 11. Model of a cooler for the thermoelectric generator modules

The value of the exhaust gas pressure drop is not directly related with the efficiency of the thermoelectric generator. However, it has a direct impact on the internal combustion engine operation in a vehicle. Therefore, it is necessary to pay attention its maximum tolerable value, which, for convenience, can be set equal to the pressure drop of exhaust gases in catalytic converters. For a given exhaust gas flow, the pressure drop in a catalytic converter of an internal combustion engine is approximately 4 kPa.

Thus, to ensure efficient operation of the internal combustion engine, the TEG heat exchanger finning variants with minimal grooves cannot be deemed acceptable.

As a result, taking into account the competing demands to maximize the heat flow through the thermoelectric generator modules and, consequently, the electrical power output of the TEG, and to limit the exhaust gas pressure drop, we can choose the optimal (a=4.0, b=3.0) variant of the TEG body design.

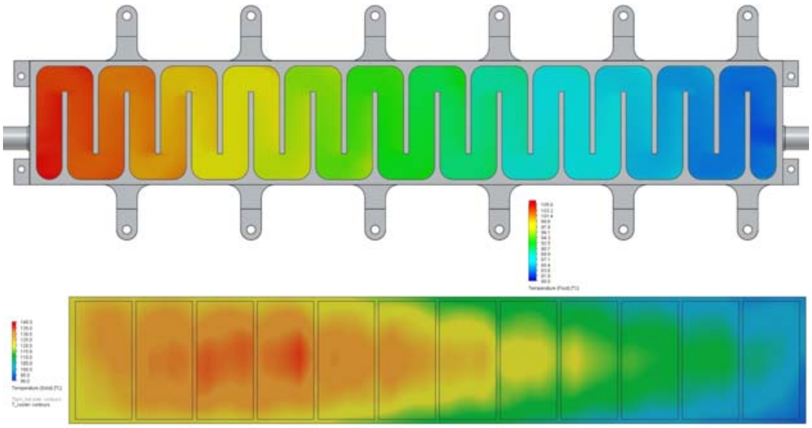

Fig. 12. Distribution of the coolant temperature in the thermoelectric generator modules cooler and the temperature of the bottom surface of the cooler

Temperature distribution in the longitudinal and transverse sections of the thermoelectric generator for automotive internal combustion engine

In addition to the calculation of the basic TEG performance characteristics we determined the distribution patterns of temperature fields in the longitudinal and cross sections for each finning variant.

Figure 7 shows the temperature distribution in the solid body and working fluids in cross section of the thermoelectric generator for the four most illustrative variants of the fin thickness “a” and the groove width “b” ratio.

The obtained results showed a high degree of non-uniformity of the temperature distribution, both in longitudinal and transverse sections of the thermoelectric generator. This, in turn, leads to uneven heating of the thermoelectric generator modules, reduces their efficiency and causes overheating, which is not acceptable. Thus, there is a need to introduce additional technical solutions into the TEG body design that would not only reduce the maximum temperature at the hot side of the thermoelectric generator modules, but also level the distribution of heat flows between individual elements to a large extent.

Temperature of the thermoelectric generator modules hot side.

In this study we used the characteristics of commercially available thermoelectric generator modules based on bismuth telluride. Their maximum efficiency reaches approximately 6.3%, when the temperature of the hot and cold sides is 30°C and 300°C, respectively. In this case the maximum allowable temperature of the hot side of the module is 330°C.

The computational studies showed that the maximum temperature on the hot side of the thermoelectric generator modules exceeds the limit with vast majority of the TEG body finning options. For example, in the heat exchanger design with the fin thickness of 4 mm and the groove width of 3 mm, the temperature on the hot side of the modules reaches 421°C. From this we can conclude that it is necessary to change the finning design to reduce the temperature gradient on the surface of the thermoelectric modules.

In order to reduce the maximum temperatures on the surface of the thermoelectric generator modules and make the distribution of heat flows in individual thermoelectric generator modules more uniform, we used the following technical solutions, which involved changes in the TEG heat exchanger design:

- reduction of the TEG body heat exchanger fin height in the first half in the direction of the exhaust gas flow,
- increase of the TEG body heat exchanger grooves between fins in the direction from its central part toward the peripheral parts.

The first solution will equalize the distribution of the heat flows and, consequently, the temperature in the longitudinal section of the TEG and second does the same in the lateral section. A model of the heat exchanger unit of TEG body with modified design, where the finning variant, which had been selected earlier, is preserved and additional design changing solutions implemented, is shown in Figure 9.

Numerical simulation of the thermoelectric generator with the modified design of the fins showed a significant reduction of the maximum temperature on the hot side of the thermoelectric generator modules (from 421°C to 317°C), while maintaining the same efficiency level of the TEG as a whole. Figure 10 allows to compare visually the temperature distribution over the surface of the thermoelectric generator modules’ hot sides in the original and the modified versions of the TEG body fins.

Comparison of the calculated basic performance values of the thermoelectric generator with the original and modified versions of the TEG body finning is shown in Table 4.

It follows from the results of the presented calculations, that the changes of the thermoelectric generator fins design made it possible not only to reduce the maximum temperature on the hot side of the modules to acceptable values, but also to considerably reduce the exhaust gas pressure drop while keeping the heat flow through the modules and, consequently, the generated electrical power almost unchanged. Reduction of the exhaust gas pressure drop by more than 22% is due to the replacement of an abrupt narrowing with a smoothly changing flow section.

Temperature of the cold side of the thermoelectric generator modules

The thermoelectric generating modules are cooled with four coolers, made of an aluminum alloy. The coolant circulating inside them is supplied from the cooling system of the internal combustion engine. Model of a thermoelectric generator module cooler is shown in Figure 11.

In the process of calculating a variety of TEG body heat exchanger design parameters the design of the coolers remained unchanged. The calculations for each variant yielded not only the general parameters, such as the coolant temperature at the outlet of the thermoelectric generator, but also the coolant temperature distribution in the longitudinal section of the cooler and, what is very important for proper operation of the thermoelectric generator modules, the temperature of the bottom cooler surface, which is in direct contact with the modules. Figure 12 shows the distribution of the coolant temperature in the cooler of the thermoelectric generator modules and temperatures at the bottom surface of the cooler, found during calculation of heat exchange processes with the final TEG body heat exchanger design.

The temperature of the cooler surface in contact with the thermoelectric generator modules changes between 94°C and 130°C along the TEG length, which corresponds to the normal TGM operating conditions. Thus, due to the fact that the coolant in the cooler and the exhaust gas inside the TEG body move in different directions, the temperature gradient between the hot and cold junctions of the thermoelectric generator modules along the TEG length changes by not more than 50°C, while the temperature change of the exhaust gases is over 220°C.

DISCUSSION

The main goal of studying the influence of design parameters of the automotive TEG body heat exchanger on its performance is to determine the ratio of fin thickness and inter-fin groove width, which provides the maximum TEG output power and keeps the exhaust gas pressure drop at a reasonable level.

In order to do this we conducted computational studies using the mathematical model of the thermoelectric generator, which is based on the source data simulating its performance in the exhaust system of an internal combustion engine installed in a vehicle. The calculations established dependencies of key thermoelectric generator performance indicators, such as the total heat flow through the thermoelectric generator modules and exhaust gas pressure drop, from the design of the heat exchanger.

Certain assumptions have been taken to simplify the calculations, but their influence on TEG operation is minimal. For example, we ignored losses of heat through convection and radiant heat transfer between hot generator parts and external environment, because they are relatively small and can be further minimized by using an outer case, which is needed anyway, in particular, to protect the TEG from external influences, while it is installed in a vehicle.

Also, the thermodynamic parameters of exhaust gases, such as temperature, pressure and mass flow rate were assumed to be constant at the thermoelectric generator's inlet. It allowed to use the dependencies for steady-flow heat transfer processes and greatly accelerated the calculations. The effect of oscillations of exhaust gas thermodynamic parameters, which happen during operation of an internal combustion engine, can be estimated further at the real TEG prototype test stage.

The studies of the effect that the TEG body design has on its characteristics enabled us to select the variant of finning, which allows, with additional technical solutions, to achieve the heat flow power through the thermoelectric generator modules of 19kW at the exhaust gas pressure drop value of 2.5 kPa. Additional technical solutions, in particular reduced TEG body heat exchanger fin height in the first half in the direction of the exhaust gas flow and wider inter-fin grooves in the direction from the central part toward the periphery, will not only reduce the maximum temperature on the hot side of the modules to acceptable values, but also significantly reduce the pressure drop of exhaust gases at practically the same heat flow through the modules and, consequently, the same generated electric power. The results of this study can be verified later by testing a prototype of the thermoelectric generator in the laboratory environment.

CONCLUSION

We examined different versions of the TEG body heat exchanger in accordance with the developed method. The total heat flow through the thermoelectric generator modules and exhaust gas pressure drop values were calculated for each of the versions. On the basis of the obtained results we chose one finning variant and developed additional technical solutions to reduce unevenness of the surface temperature on the hot side of the thermoelectric generator modules.

The design of the TEG body heat exchanger, which was developed taking into account the results of computational studies, provides TEG electrical power output of 1 kW with an exhaust gas pressure drop of less than 4 kPa.

This research helps to improve the technical and economic parameters of a thermoelectric generator for an automotive internal combustion engine at the model design stage, which significantly accelerates the process of its development. Subsequent laboratory tests of the developed TEG model enable us to refine the parameters of the mathematical model and significantly improve accuracy of the calculations.

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