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EFFICIENCY CRITERION OF THERMOELECTRIC ENERGY CONVERTERS USING WASTE HEAT

The paper analyzes the efficiency criterion of thermoelectric energy converters using waste heat (thermoelectric recuperators). Conclusions are drawn in which cases it is economically feasible to use such recuperators. Bibl. 7, Fig. 2.

Kay words: thermoelectric generator, waste heat recovery.

Introduction

General characterization of the problem.

The use of thermoelectricity for the utilization of waste heat in order to obtain electrical energy has been and remains the subject of interest of specialists dealing with thermoelectricity for the last almost three decades. Among them, waste heat from internal combustion engines, smelting furnaces, cement kilns, chemical and oil refining industries and much more, where a significant part of the waste heat is simply released into the environment. Waste heat in everyday life also takes a significant place [1, 2].

Due to the growing trend of combating CO_2 emissions, many countries have begun to assess the potential of their thermal waste [3, 4]. Paper [5] analyzes the available statistics and concludes that in developed countries, industry accounts for 50% to 80% of energy consumed by the country as a whole. At the same time, on average, 20% of the consumed energy is lost with thermal waste, and in some countries, such as Ireland, Turkey, Spain, Cyprus, this value reaches 50 - 70%.

Therefore, it is *currently important* to create thermoelectric generators (TEG), which will be used as waste heat recuperators and return part of the heat loss in the form of electricity.

The classical theory of thermoelectric generators determines the efficiency of the main criterion of their quality. The difference in the use of a heat generator as a recuperator is that the waste heat is free, and therefore the efficiency of the generator does not play a decisive role. The question of what criterion should be used to evaluate thermoelectric energy converters that will use thermal waste becomes *relevant*. Thus, there is a fundamentally new situation to describe the quality of the thermoelectric recuperator.

The purpose of this work is to determine the efficiency criterion for a thermoelectric recuperator that uses waste heat.

Quality criterion for TEG as a waste heat recuperator

In conditions when the efficiency is not a governing factor for assessing the quality of a thermoelectric recuperator, the first place should be given to the economic feasibility of using a TEG as a recuperator.

Proceeding from the fact that the result of the TEG operation is additional electrical energy, it will be expedient to use it if the cost of the electrical energy produced by it is economically rational for its use in each specific case, and in the presence of an electrical network should be lower than the cost of industrial electrical energy. It is clear that this cost in the recuperation mode does not include the price of heat energy, which is determined by the cost of energy carriers, such as hydrocarbons, nuclear fuel and others, since waste heat is free.

Therefore, the cost of electric energy m_0 produced by a thermoelectric recuperator will be determined as follows:

$$m_0 = \frac{S_0}{N}, \tag{1}$$

where S_0 is the unit cost of the thermoelectric recuperator, N is the service life.

Therefore, in the case of using TEG as a heat waste recuperator in the first place are the requirements for its minimum unit cost S_0 and maximum service life N.

The unit cost of the recuperator includes the cost of the generator S_1 , the cost of its installation and maintenance S_2 , the cost of heat removal from the generator S_3 and the cost of voltage stabilization S_4 (Fig.1). Depending on the operating conditions, there may be other costs

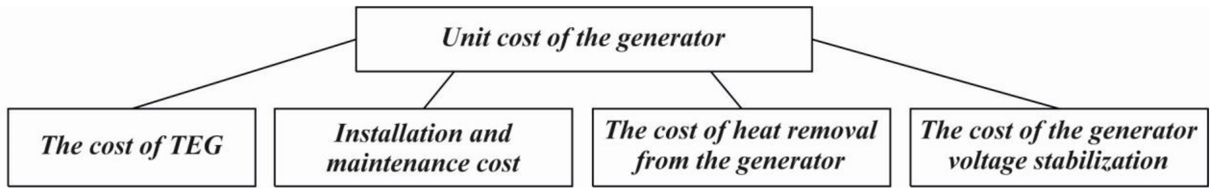

Fig. 1. Components of the unit cost of the generator.

The combination of these costs forms the unit cost of the recuperator S_0 (\$/W), which is the ratio of all costs to its electrical power W:

$$S_0 = \frac{s_1 + s_2 + s_3 + s_4}{W}. \tag{2}$$

Estimates show that at present this value is about \$ 25/W [6]. According to (1), this value should be minimized.

On the other hand, the longer the generator's operating life N (hours), the lower the cost of the electrical energy m_0 produced by it.

The service life of the thermoelectric recuperator mainly depends on the service life of the thermoelectric modules used in the TEG. The best examples of thermoelectric generator modules, specially designed for thermoelectric recuperators, have a service life of about 100.000 hours [6].

Hence, it is possible to estimate the minimum cost of electrical energy of the thermoelectric recuperator. It will be about $ 0.25 per kWh, provided the optimal temperature on the TEG modules is ensured.

In the presence of industrial electrical networks, the economic feasibility of using a TEG as a recuperator is achieved when the cost of the electricity it produces is lower than the cost of industrial electrical energy, that is, on condition that

$$\frac{m}{m_0} > 1, \tag{3}$$

where m is the cost of industrial electrical energy, m_0 is the cost of electrical energy produced by thermoelectric recuperator.

Substituting (3) into (1), we obtain the efficiency criterion of thermoelectric recuperator A that should be more than unity:

$$A = \frac{mN}{S_0} > 1. \tag{4}$$

This criterion will characterize the feasibility of using thermoelectric generator as a waste heat recuperator and determine its payback period.

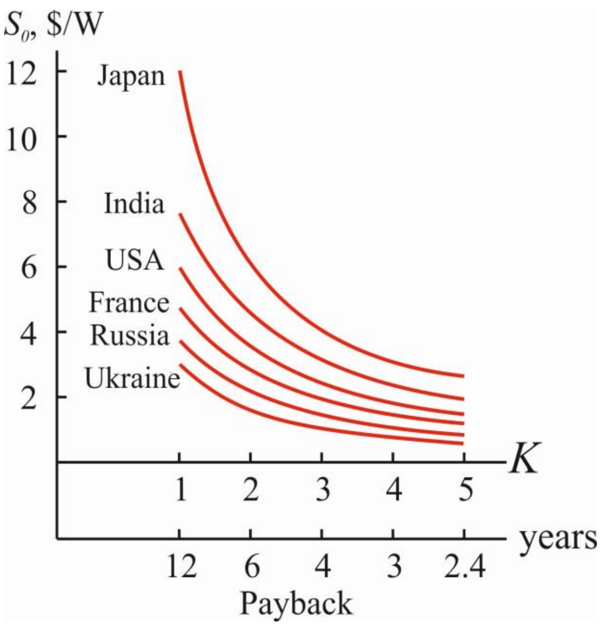

Fig. 2. Reasonable unit cost of TEG depending on the payback period.

The payback period of thermoelectric recuperator N_0 will be

$$N_0 = \frac{N}{A}. \quad (5)$$

The rest of the time ($N - N_0$) the recuperator will be profitable. The net profit P from the use of a thermoelectric recuperator will be determined as

$$P = mW\left(N - N_0\right). \quad (6)$$

For example, Fig. 2 shows the calculations of the reasonable unit cost of a thermoelectric recuperator depending on the payback time for different countries. The unit cost of the generator was determined based on the price of electricity in a particular country [7].

As can be seen from Fig. 2, at present, in order to achieve the economic feasibility of using thermoelectric recuperators, it is necessary to work towards a significant reduction in its unit cost. It is more appropriate to use thermoelectric generators in countries where electricity is the most expensive.

Conclusions

1. A universal criterion A for the efficiency of thermoelectric recuperators using waste heat has been obtained. It determines the economic feasibility of using the recuperator, the payback period and the profit obtained through its use.
2. It has been established that the economically feasible use of a thermoelectric generator is when the criterion $A > 1$.
3. It is shown that in order to reduce the payback period of the thermoelectric recuperator, and, accordingly, increase the net profit, it is necessary to increase the criterion A, that is, to work towards reducing the unit cost of the recuperator and increasing its service life.
4. It is more economically efficient to use thermoelectric recuperators in countries where electricity is more expensive.

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Submitte 20.08.2020

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КРИТЕРІЙ ЕФЕКТИВНОСТІ ТЕРМОЕЛЕКТРИЧНИХ ПЕРЕТВОРЮВАЧІВ ЕНЕРГІЇ, ЩО ВИКОРИСТОВУЮТЬ ТЕПЛОВІ ВІДХОДИ

У роботі проведено аналіз критерію ефективності термоелектричних перетворювачів енергії, що використовують відходи тепла (термоелектричних рекуператорів). Зроблено висновки, в яких випадках є економічно доцільним використання таких рекуператорів. Бібл. 7, рис. 2.

Ключові слова: термоелектричний генератор, утилізація відходів тепла.

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КРИТЕРИЙ ЭФФЕКТИВНОСТИ ТЕРМОЭЛЕКТРИЧЕСКИХ ПРЕОБРАЗОВАТЕЛЕЙ ЭНЕРГИИ, ИСПОЛЬЗУЮЩИХ ТЕПЛОВЫЕ ОТХОДЫ

В работе проведен анализ критерия эффективности термоэлектрических преобразователей энергии, использующих отходы тепла (термоэлектрических рекуператоров). Сделаны выводы, в каких случаях экономически целесообразно использование таких рекуператоров. Библ. 7, рис.2.
Ключевые слова: *термоэлектрический генератор, утилизация отходов тепла.*

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Submitted 20.08.2020