Structural synthesis of converters of natural temperature differences

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Abstract. The work is aimed at using structural synthesis methods to find the principles of operation of a heat converter operating in mountainous regions and outer space. The idea of a converter of temporary temperature differences in motion is proposed. The technique is based on the structure synthesis of substance and energy transformations with selection of the most rational combinations of physical phenomena and using of material properties where said phenomena manifest themselves. It has been considered the operation principle and described the construction of heat converter engine which can operate under extreme conditions, for example, with elevated radiation and low temperatures in space.

1. Introduction

Renewable energy is obtained from inexhaustible resources, such as, for example, wind, solar, etc. Renewable energy systems (RES) are being widely accepted as an alternative to standard conventional energy sources due to depletion of natural resources and their consequential environmental impact [1-3]. The necessity to prevent the weather changes and the increase in the costs of traditional sources of energy have motivated many nations to provide innovative energy strategies promoting the use of RES. Renewable now are established around the world as mainstream sources of energy. Rapid growth of RES particularly in the power sector is driven by several factors including the improving cost-efficiency of renewable technologies, dedicated policy initiatives, better access to financing, concerns about energy security and the environment, growing demand for energy in developing and emerging economies, and the need for access to modern energy. These trends are also manifested in the development of technical means, for example, non-traditional thermal signal converters, motors [4-8], etc. Therefore, an automated search for new principles for the operation of alternative energy sources based on information technology is promising [9-10].

2. Problem definition

To search for the principles of operation of converters of natural temperature extremes, the material and energy aspect of the description of the processes occurring in the converter was proposed [10]. It was stated that the processes taking place in the converters are based not only on the energy transformations that are traditionally considered, but also on the transformations of matter that occur in their structural elements. Material transformations are changes in the properties of transducer elements [10]. It is well known that energy is a general quantitative measure of the movement and interaction of matter of any
kind. Matter is a qualitative essence of the type of material, and its state can be represented by equivalent energy. The need to consider energy transformations is determined by the interaction of the signal energy and the processes taking place. But energy transformations do not occur without material changes. Therefore, the need for a focused and joint consideration of the features of energy and substance transformations that occur during the formation of ongoing processes is necessary and essential. The aim of this work is to assess the feasibility of implementing search results in relation to heat converter designs capable of operating in mountainous regions and outer space.

3. Theory
Central points of synthesis technique [10-11]:

- development of the mechanism of action of the principle using a generalizing algorithm, presented in the form of finite sets, as a result of analysis of more than 200 principles of the conversion of matter and energy;
- development of a database of physical phenomena in a form convenient for machine processing, provided that the description of the phenomena is based on material and energy transformations containing information about the properties of substances of a substance;
- evaluation of transformation structure properties.

The analysis of transformations in physical effects has allowed to assigning 2 main algorithms from a large number of working algorithms: transducer of energy \( A_{E_1} \) end substance converter \( A_{E_1} \):

\[
A_{E_1}: E_{inp} \Rightarrow S_{act} \Rightarrow E_{out} \tag{1}
\]

\[
A_{E_2}: S_{inp} \Rightarrow S \Rightarrow (S_{inp} \times S)_{act} \Rightarrow E_{out}, \tag{2}
\]

where \( E_{inp}, E_{out} \) – entrance and output type of energy (signal);
\( S_{act} \) – the substances of converters capable of converting the input type of energy into another type;
\((S_{inp} \times S)_{act}\) – composition of the substances capable to generate energy;
\( \Rightarrow \) – symbol of transformation of energy or substances.

For example, the main algorithm (1) just describes transformations of thermal type of energy \( E_{ther} \) to electric type \( E_{elec} \) (\( S_{act} \) – the thermocouple: Seebeck’s effect).

The second main algorithm (2) describes, for example, the principle of action of chemical heat converters.

The generalizing algorithm has the following appearance:

\[
A = \{V^a_{b}\}_{a=0}^{3} \subset \{E_{inp} \equiv E_{out}\} \subset \{A_{E_1}\}, \{A_{E_2}\},
\]

where \( V^a_{b} \) – permutation; \( \subset \) – content mark\( \{V^a_{b}\}\);
\( a \) – total number of working algorithms in their set;
\( b \) – the number corresponding to amount of the found physical effects of the working algorithms defining the principles of transformations of signals;
\( 3 \) – cycles in the formed working algorithms;
\( E_{inp} \equiv E_{out} \) – condition of merge of uniform entrance and output types of energy.

For example, the algorithm of the simplest engine is based on a sequence of 4 working cycles (Carnot cycle):

\[
S_1 \Rightarrow E_{ther_1} \Rightarrow \underbrace{S_2 \times S_3}_{\in E_{ther_0}} \Rightarrow S_2' \times S_3 \Rightarrow E_{mech_1} \Leftrightarrow S_4 \Rightarrow E_{mech_2} \tag{3}
\]

The engine consists of a cylinder \( S_3 \) filled with a working substance \( S_2 \) (water) and equipped with a piston \( S_4 \). The cylinder is brought into contact with a heater (fuel burns out \( S_1 \)), and a refrigerator \( E_{ther_0} \).
As a result of heating, the working substance $S_2$ changes its state of aggregation $S_2^*$ (it passes into a gaseous state – steam). In the cylinder, the pressure $E_{mech1}$ increases, which drives $E_{mech2}$ the piston $S_4$. Upon contact with the refrigerator $E_{ther}^0$, the working $S_2$ substance also changes $S_2^*$, goes into a liquid state; the pressure decreases $E_{mech1}$ and the piston $S_4$ moves to its original state.

For the synthesis of heat converters, a special program was developed [10].

4. Experimental results

As a result of synthesis received the structure of a low-temperature engine (figure 1, 2). Her algorithm is as follows:

$$E_{opt} \Rightarrow S_5 \Rightarrow E_{ther1} \Rightarrow S_2 \times S_3 \Rightarrow \begin{cases} E_{ther} \Rightarrow S_2^* \times S_3 \Rightarrow E_{mech1} \Rightarrow S_4 \Rightarrow E_{mech2} \\ \end{cases} (4)$$

A thermal energy converter can be used, for example, to generate electrical energy. The difference between algorithm (4) and algorithm (3) is the conversion of solar energy $E_{opt}$ into thermal energy $E_{ther}$, for example, using an optical lens $S_5$.

In the initial state, until the working fluid is super cooled $S_2$ (distilled water, its saline solution, etc.), the lens 9 ($E_{opt}$) is closed from the action of sunlight by the screen 11, as shown in the figure 1, 2. The cold flow of the environment through the end face 6 of the heat-conducting chamber 7 is transferred to one of the chambers to the piston 3 ($S_4$) and a layer of porous material (polyurethane) 4, where crystallization of the working fluid begins.

The cold environment stream $E_{ther}^0$ through the end face 6 of the heat-conducting chamber 7 is transferred to one of the chambers to the piston 3 ($S_4$) and a layer of porous material (polyurethane) 4, where crystallization of the working fluid. Polyurethane foam 4 acts as a center of crystallization and provides a seal to the piston during the stroke due to the wedging effect. With the complete crystallization of the working fluid, for example, water, its volume increases by 11%. This leads to a large overpressure in the chamber up to $250 \times 10^6$ N.
The piston 3 moves; through a common rod 2 and using another piston 18 compresses a substance with elastic properties in the second chamber and drives the gear 20 of the drive mechanism of the boost gear 14 (figure 1).

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An electric generator 27 is installed on the power take-off shaft 26. The flywheel consists of two spring-loaded symmetrical halves 30, 32 and ensures their movement perpendicular to the axis of the power take-off shaft (figure 3).

The flywheel has an identical half-coupling 24 figure. 2.) conical recess 31 (figure. 3.). Since the output shaft of the gearbox through the coupling half 24 is mechanically connected with the flywheel
25, it begins to rotate quickly. Due to the centrifugal forces of the half flywheel, overcoming the compressive forces of its two springs 28, 33 (figure 3); they disengage from the gearbox coupling half and provide rotation of the generator rotor.

Out of engagement with the gearbox occurs at the initial moment of unwinding of the gearbox (gear 20 has not yet rested at the end of rack 19). The optical screen 11 (figure 4) through the "different shoulders" lever 10 is connected to the rod 2.

Therefore, at the time of crystallization, the screen moves in the opposite direction with respect to the movement of the pistons with the rod. The slot 12 of the optical screen 11 is installed opposite the semi-cylindrical lens 9, making light rays accessible to it. Solar energy through the lens is concentrated in the area of the working fluid 5, heating it through the heat-conducting walls of the chamber 7 (figure 1).

Over time, the centrifugal forces in the flywheel decrease and at a certain point in time, its angular velocity becomes equal to zero, and its recesses mesh with the gearbox clutch 14. Under the influence of solar energy, the working fluid thaws, returning to its original volume.

The stored potential energy of a substance with elastic properties 17, for example, a spring, goes into kinetic, which leads to a displacement of pistons 3, 18 with a common rod 2 in the opposite direction. Screen 11 is set to its original state, blocking the flow of solar energy; the gearbox and flywheel spins in the opposite direction, the working fluid is cooled, etc.

5. Results and discussion
Let us evaluate the efficiency of such a converter when using optical radiation as a concentrator – a semi-cylindrical lens 9 (when placing its linear focus in the region of the working fluid 5 in the chamber).

The focal length $f$ of the lens is determined by the formula [11]:

$$\frac{1}{f} = (n - 1)\left[\frac{1}{r_1} - \frac{1}{r_2}\right] + \frac{(n-1)^2}{\pi r_1^2}d,$$

(5)

where $n$ is the refractive index of the lens; $r_1, r_2$ is the radius of the lens; $d$ is the thickness of the lens.
Given that one of the radii $r_1$ is equal to infinity, the calculation by formula (5) is simplified. If the light source is at infinity, the length of the linear focus $x$ is equal to the length of the cylindrical lens $l$ [12].

The sun is at a finite distance, so the length of the linear focus is $x = (1 - \beta)$, where $\beta$ is the increase in the lens in the plane.

We determine the temperature at the focus of the lens under the influence of solar energy in terrestrial conditions. The illumination in the focus of the $El$ lens is determined by the formula [13, 14]:

$$El = \frac{1}{4} \pi B_s \tau \left(\frac{D}{f}\right)^2,$$

where $Bs$ is the brightness of the sun; $\tau$ is the transmittance of the optical system; $D$ is the diameter of the entrance pupil of the optical system.

The focus brightness $Bl$ is calculated by the formula:

$$Bl = \frac{Es}{\pi},$$

where $Es$ is the energy illumination of the Sun.

It is known that brightness is related to temperature by the formula:

$$Bl = \frac{\sigma}{\pi} T^4,$$

where $\sigma = 5.7 \times 10^8 \text{W/m}^2\text{K}^4$.

Taking $\tau = 1$; $\left(\frac{D}{f}\right)^2 = 2$, after which formula (6) takes the form

$$El = \frac{1}{4} Es$$

We carry out transformations of formula (9) taking into account expressions (7), (8):

$$El/\pi = \frac{1}{4} \cdot \frac{Es}{\pi} ; \frac{\sigma}{\pi} T^4 = \frac{1}{4\pi} Es \text{ and } T = \sqrt[4]{\frac{1Es}{4\sigma/\pi}}$$

According to the well-known technique [11], the temperature concentrated by the lens was calculated for the energy luminance range from 16 to $1.6 \times 10^3 \text{W/m}^2$ existing on the globe [11]. It was taken into account that the mechanical equivalent of light $A = 0.0016 \times 10^3 \text{W/m}^2$.

Then the temperature at minimum illumination $Es = 16 \text{W/m}^2$ will be $T = 4 \sqrt[4]{\frac{1.16 \times 10^3}{4 \times 5.7 \times 10^{-8}}} = 578.45 \text{K}$.

Therefore, this temperature is quite sufficient to heat the working fluid and reduce the reversibility of energy conversion.

6. Conclusion

Obtained as a result of structural synthesis, the thermal energy converter will allow the use of environmental energy to generate additional energy. It can operate in mountainous areas as an engine, converter and other technical devices.

Generators created on its basis can be used in the northern regions almost all year round. They will allow the use of free environmental energy to generate additional energy when growing vegetables in greenhouses, space greenhouses and other needs [14].

When choosing special materials for creating an extreme temperature converter, it can perform its functions even with a high radiation background of the environment.

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