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The principle of heat conversion into mechanical work

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Nomenclature

A – the amplitude of ambient temperature variation, °C; c – specific heat of the plate J/(kg K); F – surface area of the plate, m^2; $f'(\tau)$ – derivative function of ambient temperature variation in time; t_0 – initial temperature of the plate's surface, °C; $\bar{t}_{eno}$ – initial ambient temperature, °C; t_{en} – ambient temperature at any moment of time, °C; $\bar{t}_{en}$ – average ambient temperature, °C; Δt – temperature change in the plate's material, °C; T – temperature variation period, s; V – volume of the plate taking part in the accumulation process, m^3; x, z – linear dimensions of the plate, m; Q_r – the flow of radiation energy, W; Q_c – convection flow, W; Q_{ac} – accumulated heat amount; α_k – heat transfer coefficient, W/(m^2 K); δ – thickness of the plate, m; τ – time, s; ρ – plate material density, kg/m^3.

1. Introduction

None of the processes of animate and inanimate nature can occur without movement. Any movement in the liquid or gaseous environment needs a driving force. Energy of different forms – mechanical, thermal, electrical, chemical, magnetic, nuclear – is generated by different types of the driving force. Energy has the ability to transform from one state to another. Conversion of heat to mechanical work in the heat engine is cyclic during the development of appropriate thermodynamic processes [1-3]. The driving force in the processes of heat conversion between the gaseous (liquid) environment and the surface is generated by the difference in temperatures, humidity or gas concentration, i.e. gradients or respective mechanical energy causing a forced movement [4-5].

The processes taking place in the nano, micro and mini channels are relevant to all life nature and science of technology fields [6, 7]. High heat fluxes from compact electronic packages are one of the critical barriers in the development of new-generation power electronics [7]. Therefore, investigating nano, micro and mini channels focus is concentrated on the properties of energy transmitting fluids [8], their velocity in the channels [9], the dependence on the channel parameters [7], heat exchanges [10, 11].

Heat conversion processes were observed in nature where thermal energy of low potential is transformed to mechanical work. Nature, in its long development has created channels of energy conversion for realisation of vital functions [6]. Idealization approach was used to substantiate the proposed plate design where heat is converted to mechanical work. The purpose of this research work is to introduce the principle of operation and the principal scheme of a engine that converts heat to mechanical work.

2. Research object

The research object is a plate *1* (Fig. 1). Its construction is close to anatomical shape of the schematic plant leaf [12, 13]. Plate thickness δ is 100 – 500 μm. The bottom side of the plate has a lot of holes *2* (up to 400 holes per mm^2), where the hole gap area makes 0.52 – 5.28% of the plate's surface area. Channels of the holes *3* connect to the cavities *4* located on the bottom side of the plate. The relation of the surface area of the cavities and the external surface of the plate depends on the conditions in the gaseous environment and is equal to 6.8 – 30.0.

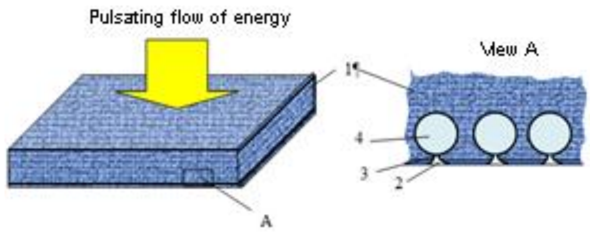


Fig. 1 The principal scheme of the plate converting heat to mechanical energy (description provided in the text)

A plate of this design (Fig. 1) can convert heat to mechanical energy if favourable conditions for heat conversion are created.

The plate converts heat to mechanical energy in the presence of a variable flow of heat. The easiest way to create the pulsating flow of heat is by delivering radiation energy to the plate at certain regularity.

3. Analysis of non-stationary energy circulation in the plate

The non-stationary process of energy circulation of the plate, participating in the heat exchange by radiation and convection [14, 15], can be expressed by the following plate energy balance equation:

$$\pm Q_{ac} \pm Q_r \pm Q_c = 0\,. \qquad (1)$$

Generally, the pulsating flow of radiation energy Q_r and pulsating flow of convective heat transfer to the surface of the plate generate accumulated heat Q_{ac} pulsations. The pulsating thermal accumulation, expressed as dynamic energy balance, causes the change in the plate's temperature Δt. Plate temperature change t creates energy deficiency (or surplus), which in the Eq. (1) is compensated by heat Q_{ac} accumulated in the plate.

The initial temperature of the plate is $t_0 = const$ in the presence of stationary heat transfer $Q_{ac} = 0$. Radiation energy Q_r absorbed on the plate will be transferred to the environment by convective heat transfer:

$$Q_r = \alpha_k F\left(t_0 - t_{en_0}\right). \tag{2}$$

The easiest way to create pulsating energy is by changing the flow of radiation energy. The change in radiation energy flow will cause a change in temperature Δt. The change in convective heat transfer Q_c is expressed by the following equation:

$$dQ_c = \alpha_k F\left(\Delta t - t_{en}\right)d\tau . \tag{3}$$

The amount of accumulated heat Q_{ac} will also change as a result of temperature change caused by the pulse of radiation energy. The heat accumulated in the material is expressed by the equation:

$$dQ_{ac} = \rho c V \frac{d\left(\Delta t\right)}{d\tau}. \tag{4}$$

The effect of radiation energy pulses expressed in Eqs. (1)-(4) produces the following plate (cooling) balance equation:

$$\alpha_k F\left(\Delta t - t_{en}\right)d\tau = -\rho c V \frac{d\Delta t}{d\tau}. \tag{5}$$

For the balance Eq. (5) a modified general equation of the system and environment temperature differences is applied:

$$\Delta t = \left(t_0 - t_{en_0}\right)e^{-\frac{\alpha_k}{\rho c V}(\tau-\tau_0)} + t_{en} - e^{-\frac{\alpha_k}{\rho c V}\tau}\int_{\tau_0}^{\tau} e^{\frac{\alpha_k}{\rho c V}\tau} f'(\tau)\,d\tau . \tag{6}$$

Estimating that the plate volume $V = F\delta$ (here δ is the plate thickness) and the plate surface area $F = 2(xz + \delta x + \delta z) = 2(xz + \delta(x + z))$ we receive the equation of temperature change due to energy pulsation:

$$\Delta t = \left(t_0 - t_{en_0}\right)e^{-\frac{\alpha_k 2(xz+\delta(x+z))}{\rho c \delta xz}(\tau-\tau_0)} + t_{en} - e^{-\frac{\alpha_k 2(xz+\delta(x+z))}{\rho c \delta xz}\tau} \times \int_{\tau_0}^{\tau} e^{\frac{\alpha_k 2(xz+\delta(x+z))}{\rho c \delta xz}\tau} f'(\tau)\,d\tau . \tag{7}$$

Eq. (7) obviously reveals that the key parameters influencing the change in the plate's temperature are the initial temperatures of the plate and ambient environment, dynamics of ambient temperature variation over time, heat transfer coefficient α_k and physical characteristics of the plate's thickness δ and the material ρ, c.

For the analysis of Eq. (7) we assume that ambient temperature t_{en} is the time function $f(\tau)$:

$$t_{en} = f\left(\tau\right) = \bar{t}_{en} + A\cos\left(\frac{2\pi\tau}{T}\right). \tag{8}$$

In that case the derivative of the time function $f'(\tau)$ is:

$$f'\left(\tau\right) = -A\frac{2\pi}{T}\sin\left(\frac{2\pi\tau}{T}\right). \tag{9}$$

Marking the ratio $\frac{2\pi}{T}$ as ω, integrating the derivative expression, entering the relative angle β, the tangent of which is $tg\beta = \frac{2\pi\delta c\delta xz}{T\alpha 2(xz+\delta(x+z))}$, and finally restructuring the obtained expression according to trigonometric functions we obtain the following equation of the change in the plate's temperature caused by energy impulses:

$$\Delta t = \left[t_0 - t_{en0} - A\sin\beta\sin\left(\omega\tau_0 - \beta\right)\right] \times e^{-\frac{\alpha_k 2(xz+\delta(x+z))}{\rho c\delta xz}(\tau-\tau_0)} + A\sin\beta\sin\left(\omega\tau - \beta\right) + \bar{t}_{en} + A\cos\left(\omega\tau\right). \tag{10}$$

The parameter values assumed for the numerical analysis of temperature changes Δt in the plate from Eq. (10) were as follows: plate thickness δ = 10 - 100 μm; α_k = 0.00125 W/(m^2 K); c = 3.58 J/(kg K); ρ = 0.9 kg/m^3; t_0 = 20°C; t_{en0} = 24°C; $\bar{t}_{en}$ = 22°C; A = 2°C. Temperature pulsations in the plate of different thickness at various ambient temperature change impulses obtained from Eq. (10) are presented in Fig. 2. It is seen from Fig. 2 that higher temperature changes of 2.3 - 3.1°C occur in the plate of smaller thickness δ, whereas the temperature change Δt is only 0.3 - 0.5°C in 10 times thicker plate when the period of ambient temperature t_{apl} pulsations is 6 s and 10 s.

4. Analysis and summary of process plate in gaseous cavities

Temperature variations in the plate bring about respective thermodynamic processes in gaseous cavities of the plate. Thermodynamic processes occur in the conversion of heat to mechanical energy only if the following conditions are met:

1. The presence of two sources of heat of different temperatures. This condition is met in the case under investigation. A radiating source of high temperature (the Sun or a special device) is present in the ambient environment of the plate.

The radiation energy absorbed by the plate is converted to heat. The plate temperature rises and exceeds the ambient temperature.

The plate and the surrounding gaseous environment represent two different sources of heat with different temperatures.

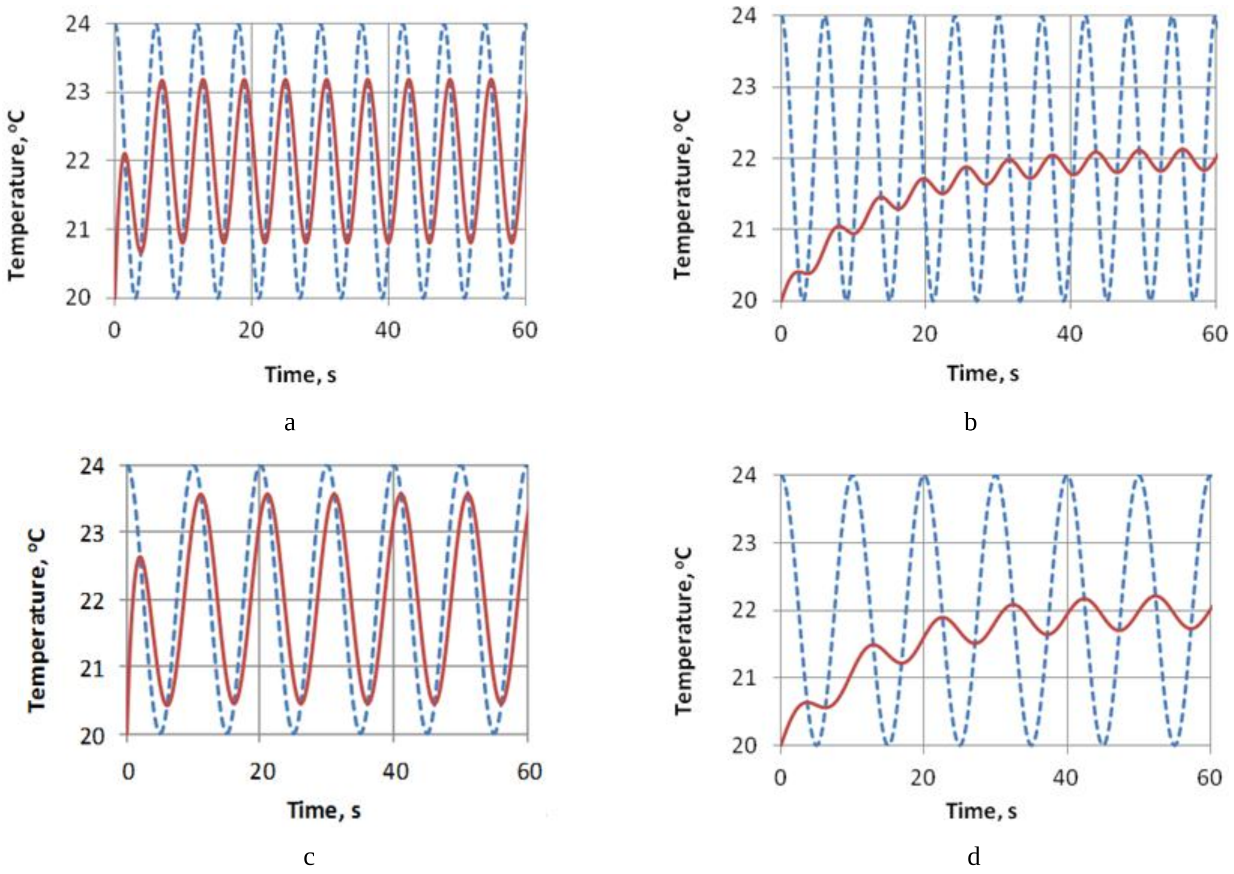


Fig. 2 Temperature change in the plate with the change of ambient temperature due to radiation energy impulses every 6 s (a, b) and 10 s (c, d), when the plate thickness is 10 μm (a, c) and 100 μm (b, d). The plate temperature is represented by the solid line; the ambient temperature is marked by the dotted line

2. The process of energy conversion requires cyclic processes of regular variation. This condition is met in the case under investigation by using a source of radiation energy that changes cyclically. Such a source can be created by using a revolving disk with holes or by changing the position of the plate to the Sun at regular intervals. The analysis of energy processes in the cavities of the plate has revealed that the plate's temperature and pressure in the cavities of the plate undergo cyclic changes in the presence of radiation energy source of cyclic nature. The temperature and pressure in the cavities fluctuate.

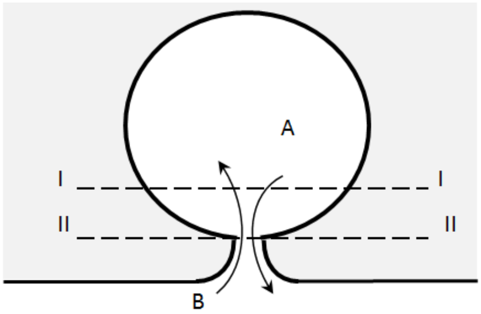
When the plate's temperature falls, the process of plate cooling and the conversion of heat q_2 begins and the volume of gas in the cavities of the plate decreases. Forced intake of ambient air occurs (Fig. 3). When the plate's temperature rises heat q_1 is supplied, the pressure in the cavities of the plate builds up, expansion process occurs and a part of gas is released from the cavities of the plate to the ambient air. There is a closed cycle and it is possible to prove thermodynamically that energy conversion is probable when the temperature of the plate changes. That leads to the conclusion that a engine can exist in the plate and produce mechanical energy from heat. Such an engine operates when the plate is affected by the alternating source of heat.

We usually assume that a mechanical engine is required to convert heat to mechanical energy. However, there are engines where mechanical energy is produced by the flow of gas. The potential energy of the pressure is converted to kinetic energy of the flow and the latter is converted to mechanical work. Technically the conversion of potential energy to kinetic energy occurs in special tubes (de Laval nozzles). The combination of the plate's cavities, channels and stomas is very similar to the design and operating principles of a rocket (jet) engine.

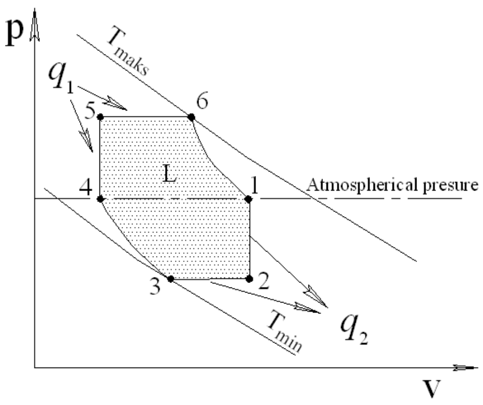
Energy conversion is possible only if there is the aforementioned variation of temperature in the plate. Accurate description of thermodynamic processes and the cycle of heat conversion to mechanical energy in the plate is complicated. Therefore thermodynamic idealization is used to this end. Taking into consideration the stomas and the channels of the plate, along which the forced reciprocal flow of cavity content and of ambient air occurs, we may compare the conversion of energy in the stoma with the operating principles of a rocket's jet engine.

The diagram of the plate's cavity is presented in (Fig. 3, a) for thermodynamic analysis of the engine in the plate. This schematic presentation will be used to analyze the thermodynamic processes and the cycle of heat energy conversion to mechanical energy.

For thermodynamic analysis of moto engine cycles the assumption is made that the same amount of air (absolutely dry in this case) present in the plate's cavities is used in the cycle. The alleged membrane is used for the analysis. The membrane separates the cavity volume *A* from the incoming ambient air *B* (Fig. 3, a). In the case of continuous energy conversion and the highest plate temperature there will be the maximum air content in cavity *A* (Fig. 3, a) and in cavity *B* the air content will be minimum (cavity $B = 0$). The pressure in the plate cavity is equal to the pressure of ambient air. The alleged membrane will be in position II–II. Point *1* represents the thermodynamic state of the air in cavity *A* in the coordinate system *p-v* (pressure – volume) (Fig. 3, b). In point *1* volume *v* of cavity *A* is maximal and pressure *p* equals the atmospheric pressure.



a



b

Fig. 3 Engine diagram (a) and thermodynamic cycle (b) in *p–v* coordinate system: A is the cavity in the plate; B is the ambient environment of the plate; I–I, II–II are border positions of alleged membrane; L is the cycle area; *1 – 6* are characteristic points of thermodynamic states describing the parameters of the plate's cavities

As the temperature of the plate drops the pressure in cavity *A* decreases and vacuum is created. Pressure in ambient environment exceeds the pressure in plate cavity. When pressure difference $p_1 - p_2$ occurs the ambient air enters cavity *B* of the plate through the stoma. When ambient air enters cavity *B* the vacuum in cavity *A* does not reach the maximum value but is maintained at a certain constant level $p_2 = const$, which to a large extent depends on the size of cavity *4* and the hydraulic resistance of channel *3*. Therefore, with the fall of temperature in cavity *A* (during the cooling process), the pressure difference between cavity *A* and the ambient environment remains constant $p_1 - p_2 = const$, the volume of cavity *A* decreases. When the minimum temperature is reached in cavity *A* (point *3*) the compression process in the cavity of the plate continues because of higher pressure in the ambient environment. It is a polytropic compression process, which continues as long as the pressure in cavity *A* becomes the same as the pressure in the ambient environment (point *4*).

At the end of adiabatic compression (without heat transfer with the environment in process *3–4*) in point *4* the volume in the plate's cavity *A* reaches the minimum value. The alleged membrane reaches the minimum volume border position I–I.

With the rise of the plate's temperature (heat is supplied from the ambient environment) the pressure in cavity *A* increases and reaches point *5*. As the temperature in cavity *A* rises (in the process of heating) the difference in pressures in cavity *A* and the ambient environment remains constant $p_5 - p_4 = const$ although the volume of cavity *A* decreases. When the maximum temperature is reached (point *6*), higher pressure in cavity *A* of the plate causes the polytropic pressure drop to continue until the pressures reach the balance in point *1*. At the end of polytropic expansion (process *6–1*) in point *1* the plate cavity volume reaches the maximum value. The alleged membrane reaches the maximum volume border position II–II.

The cycle is accomplished and returns to the initial position. A new wave of the plate's temperature variation will repeat the afore-discussed cycle in the cavity of the plate.

Schematic presentation of the processes occurring in the cavities of the plate makes the investigation easier and enables to prove that in the cavity of the plate there exists a heat engine cycle where mechanical energy is produced. Although real processes occurring during this cycle deviate from the theoretical processes discussed above, the fact that such an engine does exist in the plate has been proven. Basing on the laws of thermodynamics we may state that mechanical work *L* performed by the cavity mechanism present in the plate is represented by the cycle area *1–2–3–4–5–6–1* (Fig. 2, b) in the coordinate system *p–v* (pressure – volume)

The thermodynamic cycle of the plate's cavity may be used to discuss its thermal efficiency. The thermal efficiency of all heat engines is rather low. As it is impossible to estimate the real processes of the plate's cavity cycle we can only discuss the expected maximum thermal efficiency by using the Carnot cycle. With temperature change by 1°C the thermal efficiency will be below 0.0034. Thermal efficiency increases with bigger difference in temperatures. When the plate's temperature changes by 3°C the thermal efficiency (according to the Carnot cycle) reaches 0.01. The thermal efficiency of the plate's cavity is 30–50 times lower than the thermal efficiency of known heat engines. That is because the plate's cavity operates at very low temperature differences. Technologically it is impossible to develop a heat engine with a small difference in temperatures. The research investigates the smallest engine because there are as many engines in 1 mm^2 as there are cavity mechanisms in the idealized plate (up to 400 units).

5. Conclusions

1. The plate's cavity connected with the ambient environment by the channel and the surface acts as a heat engine in the presence of regularly varying flow of heat.

2. The thermal efficiency of engine increases with bigger temperature difference, smaller thickness of the plate and bigger volume of the plate's cavity.

3. Engines with the same principal scheme do exist in nature. Mechanical energy generated by such engines is used to intensify the metabolic transfer with the environment.

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ŠILUMOS Į MECHANINĮ DARBĄ TRANSFORMAVIMO PRINCIPAS

R e z i u m ė

Straipsnyje nagrinėjami šilumos apykaitos procesai plokštelėje, dėsningai tiekiant kintantį šilumos srautą. Pateikta plokštelės konstrukcija, kurioje šilumos energija transformuojama mechaniniu darbu. Naudojantis idealizacijos metodu pateiktas variklio, transformuojančio šilumą į mechaninį darbą veikimo principas ir jo princinė konstrukcija. Pateikiamas variklio termodinaminis ciklas ir jame vykstančių procesų apibūdinimas. Temperatūrai kintant 1°C, terminis variklio naudingumo koeficientas bus mažesnis už 0.0034. Teoriniame šilumos transformavimo mechanine energija cikle nepatiriama energinių nuostolių, nes galutiniame rezultate mechaninė energija, suaktyvinusi apykaitos procesus pasienio sluoksnyje ir atlikusi mechaninį darbą, vėl virsta šiluma.

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THE PRINCIPLE OF HEAT CONVERSION INTO MECHANICAL WORK

S u m m a r y

The article analyses the processes of heat circulation in the plate regularly supplying the varying flow of heat. The construction of the plate where the heat energy is transformed into mechanical work is presented. Applying the method of idealization the working principle and the principal construction of engine converting heat to mechanical work are introduced. The thermodynamic cycle of engine with the processes within are examined. With temperature change by 1°C the thermal efficiency coefficient of engine will be below 0.0034. The theoretical cycle of heat transference into mechanical energy does not encounter the loss of energy. This results from the assumption that after having activated the circulation processes in the border layer and performed a certain mechanical work finally the mechanical energy is reconverted to heat.

Keywords: engine, heat, conversion, mechanical energy.

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