PAPER • **OPEN ACCESS**

Device for generating electrical energy based on thermal expansion of a solid material

To cite this article: A Parsokhonov *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1076** 012010

Device for generating electrical energy based on thermal expansion of a solid material

A Parsokhonov[1,3], P Kalandarov[2], O Olimov[1] and A Akhmedov[1]

[1]Jizzakh Polytechnic Institute, Islam Karimov main Street 4, 130100, Jizzakh, Uzbekistan
[2]Tashkent Institute of Engineers of Irrigation and Agricultural Mechanization National Research University, 39 Kara Niyazov Street Tashkent, 100000, Uzbekistan

[3]E-mail: abdulkobi@mail.ru

Abstract. Popular renewable energy sources such as hydraulic, wind and solar energy, taken together, cannot completely replace natural sources. As a new alternative, this paper considers the thermal expansion energy of a solid material. A kinematic diagram and the principle of operation of a device that converts the thermal expansion energy of a steel rod into electricity are presented. Calculations show that new materials with given characteristics are needed to produce sufficient power.

1. Introduction

There are various methods for converting energy, but the method of direct energy conversion, which can seriously claim a place in small and even medium-sized power generation, is the method of converting thermal expansion into electricity. One can find a number of developments aimed at solving this problem. The analysis of our research is aimed at solving problems in the field of renewable energy sources based on thermal expansion of solid and liquid materials. The principles of obtaining electrical energy by thermal expansion and the possibilities of a new method are published, and the results are patented in the Intellectual Property Agency of the Republic of Uzbekistan [1].

2. Methods and materials

Liquid materials are more attractive than solids due to their large coefficients of thermal expansion and the possibility of using volumetric expansion, while in the case of solids only linear expansion can be used. On this basis, we have taken the opportunity to experimentally show the production of electricity by thermal expansion of pure water [2]. The results of the calculations showed that very high pressures are needed to obtain high power, and today we cannot offer a choice of strong and durable materials that could withstand sufficiently high pressures. Hence, we also made an attempt to create a unique device using a combination of both liquid and solid thermal expansion [3].

However, our further research was directed towards the creation of a device for the production of electricity through the thermal expansion of solid material only. In this case, the solution of the problem is reduced to amplifying a relatively small linear displacement and converting it into rotational motion. For this, the speed of the generator driven by thermal expansion must be as low as possible. The analysis shows [4] that there is a wide range of low speed generators, starting from 300 W, 20 rpm up to 30 kW, 100 rpm. We limited ourselves to a generator with a power of 5 kW, 150 rpm and tried to prove that it is possible to drive this generator due to the thermal expansion of a solid material. So, due to some losses, we must rotate the generator shaft at least at a speed of 100 rpm. How to do it? To implement these problems, it is necessary to make engineering calculations to select the design and ensure the principle of its operation.

3. Outcomes

Let us to consider a number of technical solutions for the implementation of the task.

3.1. *The choice of design and principle of operation*

Amplification of a small movement is carried out in two stages: by a lever-amplifier and compound gears. The scheme of the lever-amplifier is shown in figure 1. It can rotate around the attachment point O under the action of force F.

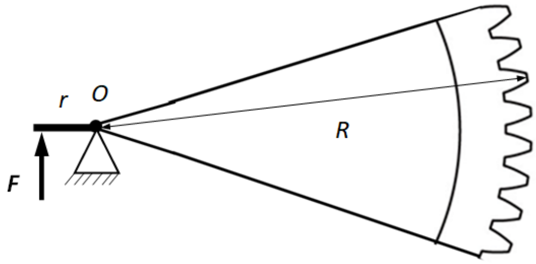

Figure 1. The lever system.

The left side of the lever consists of a strong rod with a length of r = 1 m. The right side is a segment of a large gear with a radius of R = 10 meters. The force F due to the thermal expansion of the steel rod turns the lever, and the teeth on the right side turn the compound gear I.

The main part of the device is schematically shown in figure 2. Three identical compound gears are connected in series to the lever-amplifier. Small gears have a radius of 1 meter and 6 teeth. Large gears have a radius of 10 meters and 90 teeth. The generator shaft will be attached to the fourth gear.

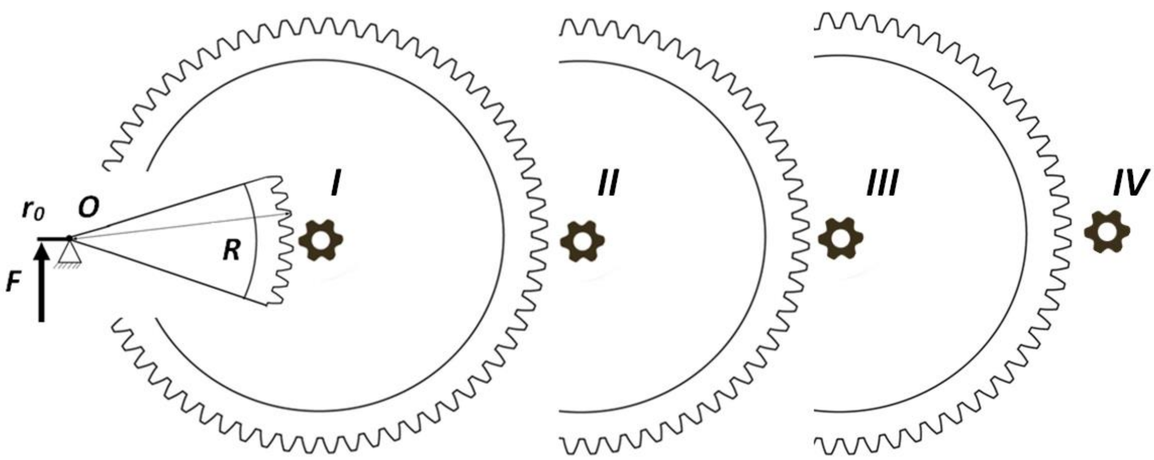

Figure 2. The scheme of the main part of the device. I, II, III - composite gears, IV - gear for connection with the generator shaft.

3.2. *Calculations*

Device parameters and initial conditions are presented in table 1.

Table 1. Device parameters and initial conditions.

1	Initial length of steel rod L_0, m	500
2	Cross-sectional area of steel rod A, м^2	0.26
3	Change in temperature in direct sunlight ΔT, ^{o}C	70
4	Thermal expansion time t, hour (second)	1 (3600)

The linear expansion ΔL = 0.42 m can be calculated using the expression

$$\Delta L=\alpha L_0 \Delta T, \quad (1)$$

where $\alpha=12\cdot10^{-6}$ $^o C^{-1}$ – coefficient of linear thermal expansion of steel [5]. On sunny days this can be achieved easily. One end of the steel rod is fixed motionlessly, and the other end will move 0.42 m in 1 hour. The thermal expansion forces depend on the change in temperature, the initial length of the steel rod, its cross-sectional area, the coefficient of thermal expansion and Young's modulus. Let us now turn to some calculations regarding the stress-strain of steel. It is obvious that the elongation of steel is accompanied by the stress-strain state forces according to [5]:

$$F/A = Y\ \Delta L/L_0, \quad (2)$$

where the left side of the equation describes the stress, and the right side describes the deformation, F is the force arising due to the elongation of the steel rod, $Y=2.10 \times 10^{11}$ N/m^2 is Young's modulus for steel. The value of the required force F depends on the power of our device. This force $F=4.5864\cdot10^7$ N can be determined by solving equation (2) for F:

$$F = AY\ \Delta L/L_0. \quad (3)$$

This is the limit of the force that the system can physically withstand. This means that the forces arising during thermal expansion should be less. Now let's try to estimate the force that occurs in 1 hour of thermal expansion, where the temperature change is 70^{o}C. It is well known that the power of rotational motion is defined as [5]

$$P = \tau\cdot\omega, \quad (4)$$

where τ is the torque and ω is the angular velocity. Torque, in turn, is defined as

$$\tau = P/\omega = F\cdot r, \quad (5)$$

where F is the force, r is the radius of rotation. As can be seen from (4), the power is directly proportional to the torque and angular velocity.

To estimate the angular velocity of the lever, it is necessary to calculate the approximate angle by which the left side of the lever will turn. The distance h = 0.42 m traveled by the end of the lever can be represented as a chord of length h of a circle with a radius of 1 m, as shown in figure 3.

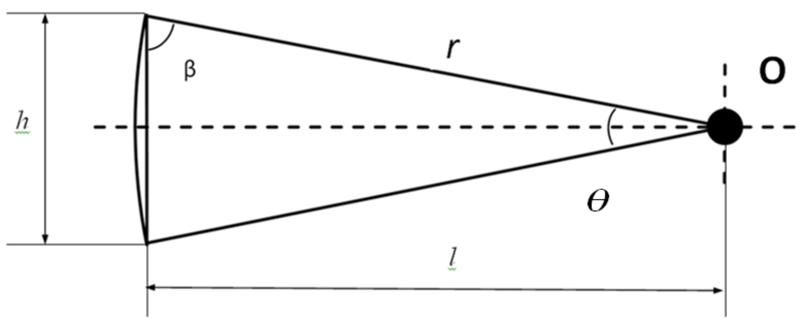

Figure 3. Scheme for determining the angle of rotation.

The steel rod expands and will turn the left side of the lever clockwise around the attachment point (point O in figure 3) due to the sliding contact. According to the figure, we can write

$$\frac{r}{\sin 90} = \frac{h/2}{\sin(\theta/2)} = \frac{l}{\sin\beta}, \qquad (6)$$

and

$$sin\,(\theta/2) = \frac{sin90\cdot(h/2)}{r} = \frac{h}{2r} = 0.21, \qquad \Theta = 2\cdot12.123^{o} = 24.246^{o}.$$

Now it is possible to calculate the angular velocity, ω_0=1.175·10^{-4} rad/s, the torque, τ_0=4.255·10^{7} Nm, and the force, f_0=4.255·10^{7} N, generated in the left side of the lever during one hour of thermal expansion with using the following expressions:

$$\omega_0 = \frac{\theta}{t} = \frac{\frac{24.246^{o}}{360^{o}} rot\cdot 2\pi rad}{3600sec} \qquad (7)$$

$$\tau_0 = \frac{P}{\omega_0} = \frac{5\,000}{1.175\cdot 10^{-4}} \qquad (8)$$

$$f_0 = \frac{\tau_0}{r} = \frac{4.255\cdot 10^{7} Nm}{1m}. \qquad (9)$$

This is the force with which we are going to get a rotational movement. As mentioned above, we can adjust this force from zero to the maximum value (4.255·10^{7} N) by changing the load, which consists of a lever system, compound gears and a generator. In other words, the force can be changed by changing the power of the generator we are using. But we cannot increase the power of the generator indefinitely, since the maximum force is limited by the geometry and physical properties of the steel rod.

Obviously, the right side of the lever has the same angular velocity as the left side. Thus, we can define the distance l = 4.2 m traveled by the right side of the lever as an arc with an angle of 24.246° from the following proportion:

$$\frac{2\pi R}{360^{o}} = \frac{l}{24.246^{o}}, \qquad (10)$$

where R = 10 m is the radius of the right side of the lever. The right side of the lever is a part of gear with a radius of 10 meters and 90 teeth. Then for the distance l = 4.2 m there are 18 teeth. Three compound gears are attached to these teeth. The first compound gear rotates three times in 1 hour, and its 90-tooth gear also rotates three times. The second compound gear makes 45 revolutions, and the third gear - 675 revolutions. Angular velocities, torques and tangential forces of compound gears are presented in table 2.

Table 2. Angular velocities, torques and tangential forces of compound gears.

Compound gears	Angular velocity, ω=Θ/t		Torque, τ=F·r=P/ω,	Force, F=τ/r=P/(ω·r), N	
	rad/sec	rpm	N·m	r=1 m	r=10 m
I	5.236·10^{-3}	0.05	9.549·10^{5}	9.549·10^{5}	9.549·10^{4}
II	7.854·10^{-2}	0.75	6.366·10^{4}	6.366·10^{4}	6.366·10^{3}
III	1.178	11.249	4.244·10^{3}	4.244·10^{3}	4.244·10^{2}

The generator shaft makes 10125 revolutions per hour or 168.75 revolutions per minute. Shaft angular velocity ω_{Sh}=17.672 rad/s, its torque τ_{Sh}=2.829·10^{2} Nm and tangential force F_{Sh}=2.829·10^{2} N can be calculated using the following expressions:

$$\omega_{Sh} = \frac{\theta}{t} = \frac{10125\, rot\cdot 2\pi rad}{3600sec} \qquad (11)$$

$$\tau_{Sh} = \frac{P}{\omega_{Sh}} \qquad (12)$$

$$F_{Sh} = \frac{\tau_{Sh}}{r_{Sh}} \tag{13}$$

4. Discussion

Thermal expansion of solids results in excessive forces that can destroy railroads, bridges, and buildings if not provided for appropriate measures. These huge forces can be used to produce useful energy under certain conditions. The main problem in generating electricity from the thermal expansion of solids is the amplification of very small movements due to the elongation of solid materials. Therefore, the need for very low speed generators of sufficient power is vital.

The results of the study of a number of works [6-14] coincide and confirm the approach to solving problems for the production of electricity due to the thermal expansion of a solid material, however, the practical use of methods and instruments to control the composition and properties of materials is required. Research is still limited and hampered by the complexity and heterogeneity of raw materials and the diversity of their physicochemical properties. Continuous fixation of the change in the state of the material under study makes it possible to establish with high accuracy the nature of the majority of physical and chemical processes occurring in the material, which requires engineering calculations to select the design of the device and ensure its operation. To solve these goals, it is necessary to develop a mathematical model of the device, to take into account the parameters of the components and changes in the ambient temperature, which will make it possible to predict the feasibility of using the device.

5. Conclusion

As a result of the analysis and evaluation of the possibilities of the chosen method for creating a device for the production of electricity based on the thermal expansion of a solid material, the applicability of this method in the energy complex is considered. The main problem in creating such devices is the gain of small displacement. To solve this problem, two maneuvers were carried out in the work: (1) amplifying by a lever system; (2) transformation of rectilinear motion into rotational and further amplifying by composite gears.

Relationships between the length of a solid material, its cross-sectional area, temperature change, and the parameters of a lever system and compound gears have been developed. It can be seen from theoretical calculations that in order to obtain greater electrical power, solid materials with a large thermal expansion coefficient and a large Young's modulus are needed.

References

[1] Parsokhonov A 2018 Patent 6(206), IAP 05611

[2] Parsokhonov A and Iskanov K 2019 A New Type of Renewable Resource: The Natural Thermal Expansion and Contraction Energy of Matter, *Int. J. Innov. Sci. Res. Technol.* **4** 83-8

[3] Parsokhonov A, Yuldashev U, Nurullaev O, Olimov O, Akhmedov A, Bekmurzaev A and Sayliev A 2020 A Device for Electricity Generation using Alternative Renewable Energy Sources. *Sci. J. Test Engineering & Management*. May-June pp 26630-7

[4] Retrieved from: http://windkraft.com.ua/category/generatory/ (accessed June 17, 2022)

[5] Nolan P J *Fundamentals of College Physics* **1** 449-67

[6] Kalandarov P I 2021 Estimate of Precision of Thermogravimetric Method of Measuring Moisture Content: Estimate of Precision and Effectiveness Gained with the Use of the Method *Agro-Industrial Complex Measurement Techniques* **64(6)** 522-8 https://doi.org/10.1007/s11018-021-01963-9

[7] Iskandarov B P and Kalandarov P I 2013 An analysis of the effect of interfering factors on the results of measurements of the moisture content of a material at high frequencies *Measurement Techniques* **56(7)** 827-30 DOI:10.1007/s11018-013-0290-2

[8] Kalandarov P I and Iskandarov B P 2012 Physicochemical measurements: Measurement of the moisture content of brown coal from the angrensk deposit and problems of metrological assurance *Measurement Techniques* **55(7)** 845-8. DOI: 10.1007/s11018-012-0049-1

[9] Narkevich M., Logunova O S, Kalandarov P I, *et al* 2021 Results of a pilot experiment on

monitoring the condition of buildings and structures using unmanned aerial vehicles *IOP Conference Series: Earth and Environmental Science* **939(1)** 012030. DOI:10.1088/1755-1315/939/1/012030
[10] Pavlova L M., Stern Yu I and Mironov P E 2009 *Thermodynamic modeling of thermal expansion of anisotropic crystals* (M: MIET) pp 181-193
[11] Pavlova Ji M., Stern Yu I and Mironov P E 2011 Thermal expansion of bismuth telluride *Thermophysics of High Temperatures* **49(3)** 379-89
[12] Pyrzowski L 2018 Testing Contraction and Thermal Expansion Coefficient of Construction and Moulding Polymer Composites *Polish Maritime Research* **25(1)** 151-8https://DOI.org/10.2478/pomr-2018-0036
[13] Mazurkiewicz L, Malachowski J, Tomaszewski M, Baranowski P and Yukhymets P 2018 Performance of steel pipe reinforced with composite sleeve *Composite Structures* **183** 199-211. DOI: 10.1016/j.compstruct.2017.02.032
[14] Choi H K, Nam K W and Ahn S H 2013 Strength characteristics of FRP composite materials for ship structure, *Journal of Ocean Engineering and Technology* **27(4)** 45-54 DOI: 10.5574/ksoe.2013.27.4.045