P.D. Mykytyuk

THERMOELECTRIC POWER SUPPLY FOR SECURITY ALARM SYSTEMS

P.D. Mykytyuk
(Institute of Thermoelectricity, 1, Nauky Str.,
Chernivtsi, 58029, Ukraine)

• *The creation of safe autonomous thermoelectric sources of power supply with low wattage possessing significant service life enables the appearance of modern devices of various purposes with minimum electric power consuming level. Topical is, in particular, the research in the field of creation of such sources of power supply for burglar alarm systems. The results of theoretical and experimental research together with achievements in the field of creation of basic physics of thermoelectric devices for the direct transformation of the heat energy of the soil into electric one are presented in this paper. The said research resulted in the creation of autonomous renewable sources of power supply for burglar alarm systems with service life up to 25 – 30 years. Comparative analysis of the main characteristics of soil thermoelectric sources of power supply for burglar alarm systems is given. Prospect spheres for application of soil thermoelectric sources of power supply using soil heat fluxes are defined.*

Introduction

Maintenance of the operating capacity of various self-contained systems of long-term use is impossible without the appropriate power supplies.

Modern electronic devices are characterized by rather low energy consumption levels (from tens of milliwatts to several watts). Such progress in the field of electronics has increased a demand for efficient rechargeable low-power supplies which lead to creation of *Ni-Cd* batteries that are most widespread today. They possess a large number of “charge-discharge” cycles, a low cost and practical feasibility. However, they feature low specific power intensity and a large self-discharge preventing from long keeping such current sources in idle state, as well as the so-called “memory effect”.

Attempts aimed at improving *Ni-Cd* batteries resulted in creation of nickel-metal-hydride (*Ni-MH*) batteries. Just as *Ni-Cd*, they have rated voltage 1.2 V, but twice better power intensity, admit an accelerated charge and are practically free of “memory effect”.

Today, lithium batteries possessing higher voltage (~ 3.6 V) and relatively low self-discharge are used with increasing frequency.

Nevertheless, all power supplies commonly used nowadays have identical shortcomings: necessity of maintenance in recharging, large self-discharge, restricted service life of 2 to 3 years, necessity of utilization. Therefore, a problem of today is to seek alternative power supplies suitable for self-contained devices with the service life more than 10 years.

One of alternative variants of solving the problem of creating a self-contained environmentally friendly power supply with a long service life is to employ thermoelectric power supplies using renewable thermal energy of soil which possesses an unbounded reserve of low-grade energy. Information on creation of such power supplies is the objective of this paper.

Physical fundamentals of thermoelectric conversion of soil heat

The basic advantage of thermoelectric energy conversion method is the possibility of its operation at low temperature drops, which is typical of soil. Besides, thermoelectric generator (TEG) offers a number of other advantages, namely service life 25 to 30 years, noise-free operation, independence of attitude in space, its efficiency and service life independence of power, etc. [1].

A detailed analysis of literature on soil physics [2-6] has shown that temperature gradient is constantly present in soils, being concentrated in the active layer. For the majority of climatic zones and soil types the temperature drop ΔT in the active layer is little different from ΔT in "soil-air" system. Moreover, thermal processes occurring in soil are distinguished for a greater stability. They are less affected by the dynamic changes in the environmental conditions on the soil surface. The in-depth analysis and experimental studies of thermal processes occurring in soil with a change in heat exchange conditions on its surface, allowed taking into account the peculiarities of heat fluxes formation in soil when selecting and studying a physical model of soil thermoelectric generator (STEG) converting the energy of active soil layer, Fig. 1. The model is a cylinder-shaped STEG of height H and diameter D the heat-absorbing surface of which is located at the depth h from the soil surface. In the investigation of the model the following notations were assumed: k_0 – soil thermal conductivity, r and Z – cylinder coordinates, T_1 and T_n – temperatures of operating surfaces of STEG.

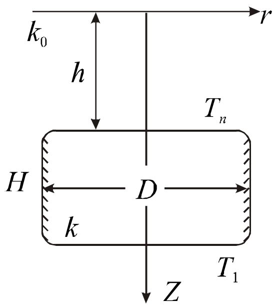

Fig. 1. Schematic of a physical model of STEG.

Using a multifactor computer design and the Rankine source-and-sink method, the distribution of temperature ΔT and heat flux q in soil with a TEG arranged in it was found. The analytical expressions for ΔT and q are of the form:

$$\Delta T = \frac{q_0}{k_0}\exp(-\gamma h)F\left(k,\frac{H}{D}\right), \tag{1}$$

$$q = q_0 \exp(-\gamma h)kF\left(k,\frac{H}{D}\right), \tag{2}$$

where q_0 is amplitude of specific heat flux on soil surface, k is the ratio of TEG thermal resistance to that of equivalent soil volume, H/D is TEG form-factor, F is a composite function of intrinsic arguments, $y = \sqrt{w/2x}$, w is cyclic frequency of specific heat flux on soil surface, x is soil thermal diffusivity.

The expression was also obtained for the determination of TEG electrical power W with regard to dependence on its geometrical dimensions and the depth of occurrence in soil:

$$W = Vq_0^2\frac{\exp(-2\gamma h)}{\sqrt{2}}Z^* kF^2(k,\frac{H}{D}), \tag{3}$$

where V is TEG volume, Z^* is thermoelectric figure of merit.

From (3) it follows that power output W is linearly dependent on TEG volume V, square-law dependent on the amplitude of heat flux q_0 on soil surface, is exponentially reduced with the depth of TEG location in soil and non-monotonously depends on parameter k and TEG form-factor H/D.

A condition for optimal selection of TEG thermal resistance for specific soil type and form-factor H/D is a relation having the form

$$k_{opt} = \frac{4}{\pi}\frac{H}{D} \approx 1.3\frac{H}{D}. \tag{4}$$

Relation (4) enables optimization of TEG for its thermophysical characteristics and similar characteristics of soil to achieve the best parameters of STEG.

The investigations resulted in creation of physical fundamentals for thermoelectric devices of direct conversion of thermal energy of soil into electric energy [7, 8].

Experimental investigations aimed at creating STEG

The low-grade character of thermal processes in soil places particular demands on the main structural component of STEG – its multi-element thermopile. Multi-element nature of thermopile is one of governing factors in the design of STEG working at low ΔT and q existing in soil.

Investigations showed that to manufacture a thermopile, is it optimal to use thermoelectric materials based on Bi_2Te_3. Such material can be used to make thermoelement legs with cross-section of order 0.15 to 0.25 mm. The referred material in the temperature range typical of STEG (250 to 330 K) has the best thermoelectric figure of merit Z^*.

At the Institute of Thermoelectricity a technique was created for manufacturing multi-element thermopiles with miniature thermoelement legs calculated for service life at least 25 to 30 years. Such thermopiles were used to create a unified construction of STEG which is used as a basic one to study the effect of various factors on its operating capacity. Integrated studies of STEG operation have proved the diurnal and seasonal character of changes in its output characteristics. The obtained results are in good agreement with the data reported in the literature on the character of heat fluxes in soils[5]. A typical behaviour of power output and electromotive force ε of STEG within 24 hours for moderate climate conditions (Chernivtsi, Ukraine) is shown in Fig. 2 and Fig. 3.

From Figs. 2 and 3 it is seen that the dynamics of change in the output characteristics of STEG is characterized by a sharp maximum at noon (from 12:00 to 15:00). At night time it is reduced. In so doing, due to heat flux reversal, at night time there is a change in polarity of STEG-generated current.

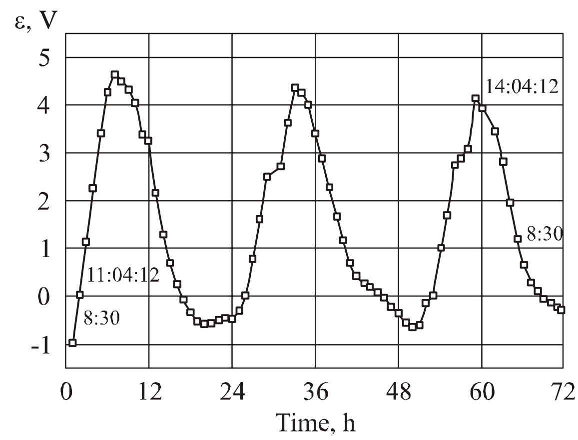

Fig. 2. Diurnal changes in STEG thermopower.

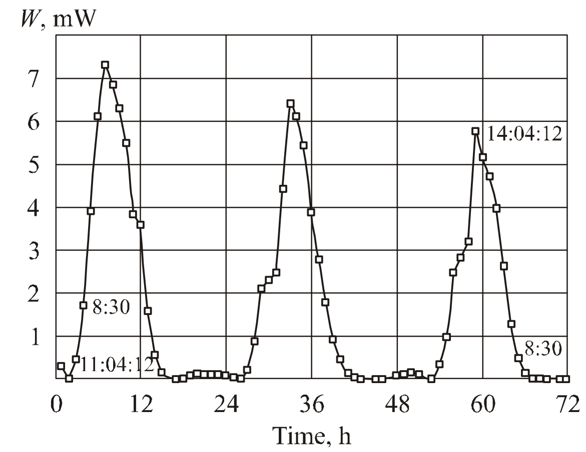

Fig. 3. Dynamics of diurnal changes in STEG power output.

Throughout a year, Fig. 4, the lowest amount of electric energy is generated by STEG in March and October, and maximum in June and August. For other climatic zones these parameters can be different, depending on specific climatic conditions.

Investigations showed that the efficiency of STEG operation essentially depends on the depth of occurrence in soil of its heat-absorbing surface. Maximum W values are typical for its location close to soil surface. With a deeper location of STEG in soil, the efficiency of operation is exponentially reduced with the depth, Fig. 5.

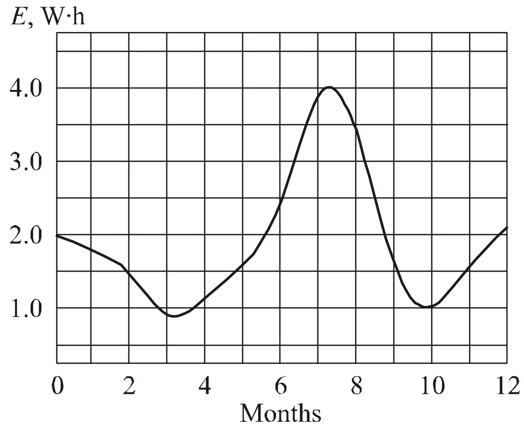

Fig. 4. Electric energy generated by STEG throughout a year.

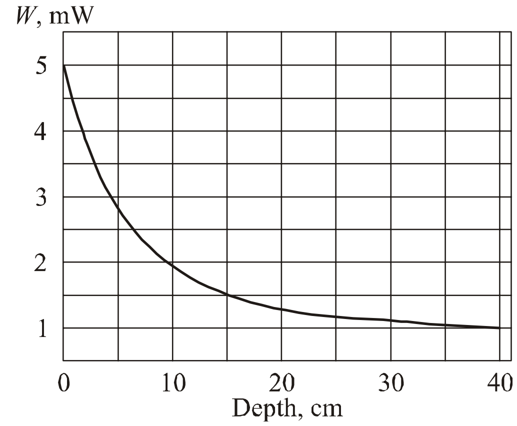

Fig. 5. Dependence of STEG power output on the depth of its occurrence in soil.

On the whole, the results of investigation have proved the theoretical prerequisites on the possibility of STEG creation and its suitability for use in different climatic zones, as well as permitted to elaborate practical recommendations for optimal arrangement of STEG in soil with regard to climatic conditions of their use an to create an unparalleled parametric series of STEG with voltage output 3, 6, 12 V and service life of 30 years.

Rational application areas of STEG

Wide opportunities of STEG application are primarily due to the fact that modern electronic devices have a low energy consumption level compatible with power produced by STEG. Another advantage of STEG is its maximum proximity to consumer, as it can be placed in soil at any necessary point. Complete self-containment, ecological cleanliness, service life 25 to 30 years extend considerably the sphere of possible applications of STEG.

Such unique feature of STEG as the absence of give-away factors, allows particularly efficient use of the following power supplies for elements of security alarm systems: motion sensors, alarm annunciators, detection systems, perimeter security systems, etc., whose main energy consumption parameters are listed in Table.

As is evident from Table, the elements of security systems consume less than 0.5 W of electric energy. Their required electric power supply is provided by the above mentioned chemical sources or special power supplies depending on centralized electric power lines.

Security devices mainly work in standby mode which for the majority of chemical sources is inefficient and even destructive, since it leads to accelerated self-discharge and fast service life reduction, whereas for STEG the work in standby mode is beneficial. Moreover, to assure the necessary voltage, one must use batteries of chemical sources which are considerable in number. All of them require constant recharging. Naturally, the independence and long service life in this case are out of question, just as with the use of special power supplies.

As the same time, we have demonstrated [8] that even for moderate climate conditions through use of STEG one can obtain up to 5 watts of electrical energy from 1 m^2 of soil. In Table are given the areas of heat-absorbing pads of STEG (S_{abs} STEG) that are capable of electric power supply to corresponding types of security systems instead of chemical power supplies. Besides, the possibilities of STEG application go beyond their use as power supplies for security systems.

Table

Serial №	Type of security system	Voltage requirement, V	Current requirement, mA	Power requirement, W	S_{abs} STEG, m^2
1.	Motion sensor SPR-600	7.8 – 16	9	0.07 – 0.14	0.014 – 1.025
2.	Motion sensor (Crow) SPR – 100	7.8 – 16	8 – 14	0.062 – 0.22	0.0124 – 0.044
3.	Security annunciator “Strizh”	10 – 15	< 12	0.12 – 0.18	0.024 – 0.036
4.	Annunciators “Zhuk” – 1.2	12 – 24	< 27	0.32 – 0.64	0.064 – 0.128
5.	Acoustic security annunciator “Solo”	10 ÷ 15	< 25	0.25 – 0.375	0.05 – 0.075
6.	Optico-electronic annunciator “Rukh”	10 ÷ 15	< 25	0.25 – 0.375	0.05 – 0.075
7.	Security annunciator “Duet”	10.2 – 15	< 30	0.31 – 0.45	0.062 – 0.09
8.	Perimeter security annunciator “Barrier-300t”	12	40	0.48	0.096
9.	Vibration detection system SL – 3	12	35	0.42	0.084
10.	IR annunciator, passive ID 40-70	8 – 28	16	0.128 – 0.45	0.026 – 0.09

At the present time, wide acceptance has been gained by microsystems that realize signal processing with conversion of physical quantities [9]. Such systems are used to create various devices for detection and identification of objects. The detection devices are based on a seismic concept that lies in the analysis of seismic disturbances of soil due to motion. Such seismic pickups are notable for miniature design, low energy consumption levels, standby mode of operation. Thus, seismic pickups of SD and SDG series consume as little as 0.4 mA with the voltage of 5 V. Point vibration pickup of VD series consumes as little as 0.11 mA with the voltage of 5 V. The recorders of seismic signals “Baikal – ACN” are powered from direct current source with rated voltage 12 V of current strength 25 mA. The referred types of seismic pickups consume even lower electric power than the security systems listed in Table. Therefore, the use of STEG for power supply to seismic pickups is also well grounded.

Efficient is the use of STEG for power supply to alarm devices and highway location in remote and deserted regions. Especially with STEG location under asphalt coating whose solar energy absorption coefficient is 89%.

By means of STEG one can realize constant monitoring of weather conditions for meteo and agricultural investigations which is rather costly for remote and hard-to-reach area.

It is obvious that the possibilities of STEG application go beyond the above mentioned lines of their application determined in the context of today.

Conclusions

The possibility and expedience of creating self-contained low-power power supplies with service life 25 to 30 years based on the concept of thermoelectric conversion of thermal energy of active soil layer are confirmed. The promising areas of STEG application are determined. The prospects for STEG use in security alarm systems are emphasized.

References

1. L.I. Anatychuk, *Thermoelements and Thermoelectric Devices* (Kyiv: Naukova Dumka, 1979), p. 767.
2. A.F. Chudnovsky, *Thermal Physics of Soils* (Moscow: Nauka, 1976), p. 352.
3. S.V. Nerpin, A.F. Chudnovsky, *Physics of Soil* (Moscow: Nauka, 1967), p. 12 – 237.
4. A.N. Shulgin, *Temperature Regime of Soil* (Leningrad: Gidrometeoizdat, 1957), p. 19 – 33.
5. V.N. Dimo, *Thermal Regime of Soils* (Moscow: Kolos, 1972), p. 16 – 61.
6. S.V. Nerpin, A.F. Chudnovsky, *Energy and Mass-Exchange in “Plant-Soil-Air” System* (Leningrad: Gidrometeoizdat, 1975), p. 23 – 86.
7. P.D. Mykytyuk, *J. Thermoelectricity* 1, 84 – 89 (2003).
8. L.I. Anatychuk, P.D. Mykytyuk, *J. Thermoelectricity* 3, 91 – 100 (2003).
9. N.I. Malashevich, A.S. Roslyakov et al, *Izvestia VUZov, Electronics* 61(86), 29 – 32 (2010).

Submitted 15.11.2012.