# Study of the Operation of the Energy Generating Platform on the Basis of a Multiplier with Spur Gears

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***Abstract*— The development of new renewable sources of clean electric energy (EE) is an urgent scientific and technical task. At the same time, special attention is paid to autonomous decentralized sources of green energy, namely, devices that can be installed in places with a high foot traffic density. EE is being generated thanks to pedestrians moving on such devices. The aim of the work is to study the process of generating renewable energy by an energy-generating platform (EP) based on a multiplier with spur gears, depending on the number and connection scheme of stepper motors to the electric machine unit of the EP. Experimental studies of the electric power generation process have been carried out, depending on the number and connection scheme of stepper motors (SM) to its electric machine unit. Such a platform has compact overall dimensions and it is intended to be installed both indoors and outdoors, in places with high foot traffic. To conduct experimental research, a prototype of the EP with an electric machine unit was developed. The analysis of the conducted experimental studies and the subsequent processing of their results made it possible to determine that the use of two SMs in the EP electric machine unit increases the value of the generated electricity by ~44%. When performing one step on the EP, the installation generates approximately 1.11W of electricity. The connection of two SMs increases the value of the generated electricity by 1.69 times (in direct motion) and 1.38 times (in reverse motion). Knowing the EP potential capabilities and the passing people number, it is possible to calculate the EE value which the EP can generate in a certain time of work, which allows you to determine the required number of such devices at the facility to provide it with the green EE fully or partially.**

***Keywords—energy-efficiency; green energy; multiplier; converter; energy conversion; renewable energy; energy-generating platform.***

## I. INTRODUCTION

Currently, issues related to energy saving and environmental protection are becoming increasingly relevant. This is especially true for large cities and megacities, where there is a large concentration of people and transport. To solve these problems, new approaches and, accordingly, new technologies are required. In addition, environmental norms and requirements are being tightened worldwide year after year. Therefore, simultaneously with the development of new technologies, the issues of providing them with energy sources that meet modern environmental standards are becoming particularly relevant [1-5].

At the moment, there is a clearly visible world trend - the introduction of alternative low-power renewable electrical energy (EE) sources. They are entrusted with the functions of unloading and balancing the electrical grid load. Basically, these renewable sources are understood as various kinds and types of solar power plants, wind generators, geothermal

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power plants, etc. However, it is not always possible to apply the sources of energy listed above. This is due to the design features of renewable sources, the conditions for their effective use, size, the availability of a suitable place and many other specific factors that are dictated by the specific conditions of their operation. In turn, in large cities, requirements for the location and compactness of renewable energy sources come to the fore, which often can offset all their advantages. In this case, small systems or devices having good mobility and which can be easily installed anywhere to provide alternative power supply are quite attractive from an economic and environmental point of view. At the same time, we mean that this energy source is able to partially or fully provide electricity to specific consumers [6-9]. Therefore, the development and subsequent implementation of small devices that can be installed in fact at any accessible place, and capable to generate electricity, is an is a pressing challenge. The solution to this problem will not only solve the issue of finding a suitable power source, but will also facilitate the accelerated transition to clean, renewable EE sources.

This paper presents one of the technical solutions for the energy-generating platform (EP), which can be considered as a low-power renewable power source [10]. We carried out experimental studies on the process of generating electricity by the EP depending on the number and connection schemes of electrical generators to its electric machine unit. Such a platform has compact overall dimensions and it is intended for installation in places with high foot traffic. At the same time, it can be installed both indoors and outdoors. For conducting experimental studies, a prototype of the EP was developed. The EP electric machine unit can work with one or two electric generators - stepper motors (SM). When performing a step on the energy-generating platform, the process of generating electricity is going on, this consists of converting the kinetic energy of the step into electrical energy. The paper [8] presents a model for the use of piezoelectric tiles in one of the buildings at Macquarie University in Sydney, Australia. The authors of the work reveal the possibilities of this tile, as a source of electricity for electric consumers of buildings. A fairly large number of works are devoted to the use of piezoelectric elements, which, for example, in the composition of floor or paving slabs can convert the kinetic energy of a step into electrical energy [11-14]. The disadvantages of such devices include the fact that they are so low-power that a serious problem arises with the conservation and transmission of the energy generated by them. Also, it should be noted the resource and reliability of piezoelectric elements, which are at least an order of magnitude smaller in comparison, for example, with electrical machine energy converters. The Pavegen tiles technical solution looks quite promising and effective [15, 16]. The authors of this invention do not disclose the principle of its operation, but it is noted that it has an electromechanical and piezoelectric basis. This allows you to convert kinetic energy into electrical energy when pedestrians move along it. The patent [17] and article [18] describe inventions that use piezoelectric generators. These devices are proposed to be used to collect energy on roads, but their disadvantage is the complexity of installation, the availability of specially prepared roads and the need for expensive equipment. Articles [19, 20] discuss the efficiency of EE production on an asphalt paved road using piezoelectric transducers, as well as give specific circuitry solutions for the practical implementation of these devices. The article [21] presents mathematical and simulation models of energy collection systems for industrial applications. These systems depend on the natural conditions in which they are operated. This means that in case of adverse conditions, the operation of these energy collection systems will be ineffective. The authors of [22] presented a mechanism where mechanical energy is converted into chemical energy and stored in this state, but the authors did not indicate the operational characteristics of this invention. In [23], a device is presented that converts mechanical energy into electrical energy on roads. The authors quantified the efficiency of energy conversion, and also compared the device they developed with similar analogues. This device belongs to stationary and requires special equipment for its installation. The use of electrical machines in electromechanical energy converters is a fairly effective solution. However, the question arises whether this process will be effective if the system (device) itself has low power. A description and study of such devices is given in [9, 10, 23, 24]. In [24], a “Power Generating Slab” was introduced, in which mechanical energy is converted into electrical energy by rotating the shaft of the micro-generator. According to the authors, one step on this device is able to generate the voltage impulse from 10 V to 12 V. However, the authors did not disclose the technical details of the design of this device, and, most importantly, what energy indicators of the generation of electricity such a device has. In [25], a device was proposed which, for generating EE, must be installed on bridges. It converts the vibration of the bridge caused by the movement of cars into an electrical signal. According to the principle and conditions of its work, it is obvious that it has a limited scope of application. In [26], a variant of the technical solution for generating EE for portable equipment was presented. Basically, it can be used as a manual LED flashlight, which in its design contains a geared SM. The publication does not provide specific numerical values of the energy that this device generates. It is also not indicated which gearbox is used and its technical characteristics are not presented.

A review of publications on the subject under discussion shows, that it is relevant and of interest not only to scientific society, but also to the general public. The aim of the work is to study the process of generating renewable energy by an energy-generating platform based on a multiplier with spur gears, depending on the number and connecting scheme of stepper motors to its electric machine unit.

## II. Energy Generating platform

Depending on the operating conditions (as well as on the technical specifications), the energy-generating platform (EP) may include several electrical machine units that work in parallel and convert kinetic energy into electrical energy. If a sufficiently small device is considered, for example, performing the functions of paving slabs or steps, then it is most rational to integrate one or two electric machine units into one device. With increasing platform area, it is necessary to increase the rated power of electric machines (EM). This can be done by increasing their number, i.e. using parallel connection in the generator operating mode. However, the question arises of how much the amount of garnished EE will increase with an increase in the amount of SM. Also, it should be noted that due to the non-symmetrical arrangement of the working elements in the machine unit of the energy-generating platform (EP), the analysis suggests that when you step on the platform from different sides (meaning from which side pedestrians will reach it), different amounts of energy will be generated. We will conventionally call these pressures - forward and reverse effects on the pressure cap of the energy generating platform (EP).

The answers to these questions were obtained as a result of experimental studies presented in this paper.

As electric generators in electronic drives, the DSHI-200 stepper motors are used, similarly to [27]. The main difference between the present studies and those carried out in [27] is, that a gear with spur wheels is used here. It is expected that the use of this type of multiplier will increase the efficiency of the EP, which will lead to large values of the generated EE.

For the manufacture of an experimental sample of EP, a multiplier with spur type gears was developed, (shown in Figure 1).

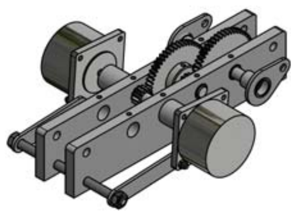

Fig. 1. Multiplier-based electric machine unit with spur wheels

In fig. 2 is a schematic diagram of the electrical-principle EP, where the active resistance R - is the resistance of the shunt, from which the voltage signal is taken.

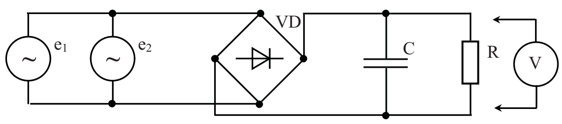


Fig. 2. electrical circuit diagram of EP

In accordance with the developed design based on the multiplier with spur gears (Fig. 1) and the electrical circuit diagram presented (Fig. 2), the design of the EP was developed, the general view of which is shown in Fig. 3.

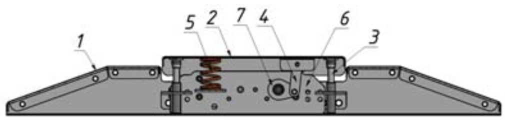


Fig. 3. General view of the EP, where: 1 – housing(body), 2 - pressure cover, 3 - guides, 4 - crank drive; 5 - springs, 6 - multiplier; 7 - the drive wheel of the crank mechanism)

To determine the performance of electric generators as part of an energy generating platform, it is necessary to determine the value of the power of the generated EE. To do this, the value of the generated voltage signal is taken from the pins of the stator winding of electric generators (DSHI-200) through an electric shunt with active resistance R. With a known value of the shunt resistance, from the measured voltage signal $u = f(t)$, we can calculate the dependence of the generated power on time $p = f(t)$ in accordance with Ohm's law [28]:

$$u(t) = R \cdot i(t), \tag{1}$$

Where $u(t)$ is the signal of alternating voltage, V;

$R$ is the active resistance (shunt), Ohm;

$i(t)$ - AC signal, A.

The instantaneous power allocated to the shunt resistance will be determined by:

$$P = ui = Ri^2 = \frac{u^2}{R}, \tag{2}$$

Where P is the instantaneous power, W;

$u = u(t) = U_m \sin(\omega t + \psi_u);$

$i = i(t) = I_m \sin(\omega t + \psi_i).$

It is known that for active resistance $\psi_u = \psi_i$, then the function of the power signal will be determined:

$$p(t) = u(t) \cdot i(t) = U_m I_m \sin^2(\omega t + \psi_u); \tag{3}$$

From equation (3) it can be seen that the value of the power signal changes in time and it will always be greater than zero. In such cases, it is customary to consider the average power over a period $T$:

$$P = \frac{1}{T}\int_0^T p dt = \frac{U_m I_m}{T}\int_0^T \sin^2(\omega t + \psi_u) dt. \tag{4}$$

By integrating the obtained curves $p = f(t)$, it is possible to determine the value of the generated power by the electric generators of the energy generating platform.

## III. Experimental Studies of the Energy Generating Platform

In accordance with the developed design of the energy generating platform (Fig. 3), as well as the designed multiplier with spur gear type (Fig. 1) and the electrical circuit diagram shown in Fig. 2, an experimental version of the energy generating platform was made. The appearance of the power generating platform, as well as the design of its electric machine assembly, is shown in Figure 4.

a b

Fig. 4. Energy generating platform: a - appearance; b - electric machine unit

The design features of the developed energy-generating platform make it possible to conduct studies in the mode of EE generation separately for each electric motor, as well as for the parallel connection of two electric motors.

The purpose of the experimental studies is to figure out the feasibility of using more than one stepper motor in an electric machine assembly as an EE generator, as well as to measure the value of the generated electricity of an energy generating platform by performing the step on EP (amount of electricity in average for one performed step).

The tasks of the experimental studies are: to study the possibility of generating electricity from an energy-generating platform when connecting one motor drive in an electrical machine unit; investigation of the possibility of generating electricity from an energy-generating platform by connecting two electric motors operating in parallel in an electrical machine unit; to measure and define of the average value of the generated electricity of the energy-generating platform with one press to the cover of the energy generating platform (step) in the forward and reverse direction.

## IV. Experimental Conditions

The shunt resistance (Fig. 1) corresponds to $R$ = 18 Ohms. The voltmeter V measures the voltage signal at the resistance of the shunt $R$ and calculates the load current. Then, the electric power released at this resistance is calculated.

Six series of measurements were carried out in 30 steps per EP. In experimental studies involved 5 people weighing from 50 kg to 90 kg. Walking speed ≈ 5 km/h. Measurement of signals was carried out while walking in both forward and reverse directions. This is done in order to bring the experimental conditions as close as possible to real conditions, where people will step on the EP moving in different directions.

The results of experimental studies for one series of 30 steps in the form of an oscillogram of the dependence $u = f(t)$ are presented at Fig. 5.

One step generates two voltage pulses:

-the first corresponds to the movement of the cover of the EP downward, under the action of external pressure of performed step;

-the second corresponds to the movement of the cover of the energy generating platform upward, under the action of the springs on which it is mounted. (Fig.6.).

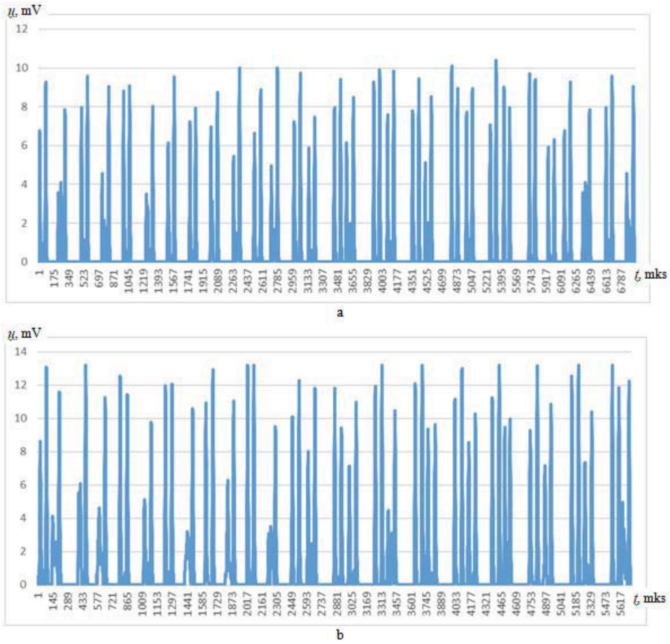


Fig. 5. Oscillograms of the dependence u = f (t), measured performing 30 steps on the EP: a - when connecting a single motor drive; b - when connecting two SM

Fig. 6. Experimental studies of the energy generating platform

## V. Processing of Experimental Studies

A graph of the generated power in accordance with formulas (2) and (4) can be obtained by integrating the measured signal, Fig. 4 using the trapezoidal method [24, 25]:

$$\int_a^b f(x)dx \approx \frac{h}{2}\cdot\left(f(x_0)+2\sum_{i=1}^{n-1} f(x_i)+f(x_n)\right), \quad (5)$$

where [a; b] are the boundaries of integration;

$h = \dfrac{a-b}{n}$ - step of division;

$i$ = 0,1, ..., n;

$f(x)$ is the value of the function.

In accordance with formula (5), one can obtain an expression for calculating the electric power that is released on the resistance of the shunt of the energy generating platform:

$$P = \int_0^T p(t)dt \approx \frac{h}{2}\cdot\left(p(t_0)+2\sum_{i=1}^{n-1} p(t_i)+p(t_n)\right). \quad (6)$$

Using expression (6), it is possible to integrate the received signal and determine the value of the generated power.

Figure 7 shows the obtained graphical dependences $p = f(t)$ at one step on an energy-generating platform with one and two main stepper motors working. Graphs, Fig. 7,a,b conform with pedestrians' forward motions, and graphs, Fig. 7,c,d conform with pedestrians' reverse motions.

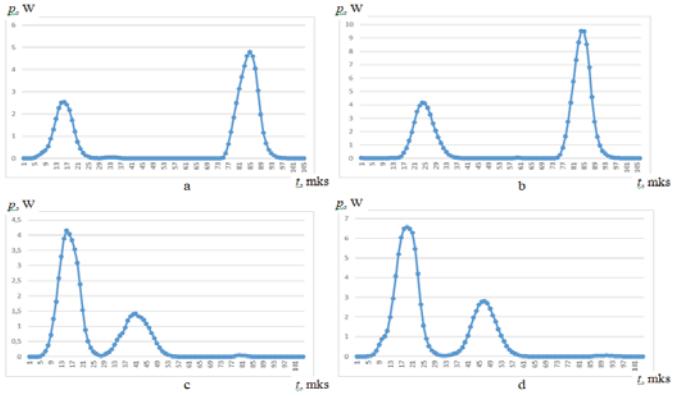


Fig. 7. Dependence of the generated power on time at one step on the EP: a, c - when connecting one SM; b, d - when connecting two SMs

The value of the generated electric power, which was allocated on the active resistance of the shunt of the energy generating platform, is determined by the expression (6) for all 6 series of experimental studies with 30 steps each.

The calculation results are given in table 1, where *k* is the gain factor, shows how many times the energy-generating platform with two connected stepper motors generates more electricity than connected to one stepper motor.

TABLE I. THE VALUE OF THE GENERATED POWER

| | Series 1 | | | Series 2 | | |
|---|---|---|---|---|---|---|
| | 1 SM | 2 SM | $k_1$ | 1 SM | 2 SM | $k_2$ |
| *P*, W direct | 1891,78 | 3180,1 | 1,68 | 1915,1 | 3523,12 | 1,84 |
| *P*, W reverse | 1248,26 | 2006,46 | 1,61 | 1505,6 | 1596,49 | 1,06 |
| | Series 3 | | | Series 4 | | |
| | 1 SM | 2 SM | $k_3$ | 1 SM | 2 SM | $k_4$ |
| *P*, W direct | 2175,9 | 3257,24 | 1,5 | 1902,58 | 3226,4 | 1,696 |
| *P*, W reverse | 1287,9 | 1968,87 | 1,53 | 1350,14 | 1904,6 | 1,411 |
| | Series 5 | | | Series 6 | | |
| | 1 SM | 2 SM | $k_5$ | 1 SM | 2 SM | $K_6$ |
| *P*, W direct | 1982,12 | 3500,3 | 1,766 | 2012,08 | 3356,24 | 1,668 |
| *P*, W reverse | 1400,2 | 1868,44 | 1,334 | 1402,46 | 1886,12 | 1,345 |

## VI. Analysis and Discussion of the Results

The experiments were carried out under the same initial conditions, the same people took part in the studies to obtain a more accurate result.

An analysis of the results of the experimental studies, as well as their processing, show that for the forward and reverse directions of motion of the energy generating platform, it generates different EE values. So, in the forward direction of movement, the average value of the generated EE in one step when connecting two electric motors is ~1.11 W, while the reverse ~0.62 W. While when connecting a single motor drive, ~0.66 W and 0.46 W are generated, respectively. The results obtained indicate, that the connection of two motor drives increases the value of the generated electricity:

- In direct motion (forward), 1.69 times;
- In opposite (reverse) - 1.38 times;

The difference in the generated energy between direct and reverse pressing on the energy generating platform is:

- When connecting two SM ~43%;
- When connecting one SM ~31%;

In turn, the difference in the generated energy when connecting two SM in comparison with the connected one SM is ~44%.

The processing of the obtained results shows the obvious benefit of using two electric motors in the electrical machine unit of the energy generating platform. The differences in the values of the generated electricity with forward and reverse pressure, on the energy generating platform, is due to the design features of this device. Because the crank mechanism is shifted relative to the center of the pressure cap of the energy generating platform (see Fig. 3), then the pressure from the pressing will be transmitted to the SM in different ways and will depend on the center of application of force to the pressure cap. Also, it should be noted, that with direct (forward) movement along the energy generating platform, more EE is generated during the back motion of the platforms cap. In turn, during the reverse movement along the energy generating platform, a process of greater generation of electricity is observed in the downwards direction (respectively, when the EP cover is pressed and moving down). This can be explained by the peculiarities of the motility of the human step. In this regard, we can conclude that when the energy-generating platform is installed flush with the surface of the road (sidewalk, floor), a different picture of the electricity generation process will be observed in comparison if this platform performs the functions of, for example, stairs. The real picture of electricity generation can only be seen after conducting relevant experimental studies.

During experimental studies, it was also revealed that the value of the generated energy from one step to the energy-generating platform, largely, depends not on the weight of the person, but on how sharply the step is taken. The faster the pace of walking and the more abruptly the steps are taken, the more energy is generated. The last note should be taken into account when calculating the installation location of this device. Therefore, the correct placement of the energy generating platform, taking into account the main flow of pedestrians, can significantly increase its effectiveness as a source of electricity.

## VII. Conclusions

The development of new renewable sources of clean EE is an urgent scientific and technical task. To solve it, comprehensive measures are carried out using methods and ways of converting various types of energy into electrical energy. At the same time, special attention is paid to autonomous decentralized sources of green energy, namely, devices that can be installed in places with a high foot traffic density. EE is being generated thanks to pedestrians moving on such devices.

Experimental studies of the process of generating electricity from an energy-generating platform, depending on the number and connecting scheme of SM to its electric machine unit were carried out. Such a platform has compact overall dimensions and it is intended for installation both indoors and outdoors, in places with high foot traffic.

For experimental research, a prototype of an energy-generating platform with an electric machine unit was developed.

The analysis of the experimental studies and the subsequent processing of their results made it possible to determine that the use of two SMs in the EP electrical machine unit increases the value of generated electricity by ≈44%. In this case, it is necessary to take into account the direction of pedestrians' movement for performing steps on the EP. So, with forward movement the EP generates about 1.11W from one step, and with the reverse ≈ 0.62W. This discrepancy is explained by the EP design features. The graphical dependences $p = f(t)$ during one step on the EP are shown in Fig. 7. Analysis of these graphs shows that one step causes two pulses of electricity generation: the first - when you press EP cap; the second - when it is released. In this case, during forward movement, more electricity is generated in the process of back motion of the platforms cap, but during the pedestrians' reverse movement – while EP cover moves in downwards direction. The difference in the generated energy between the forward and reverse people's movement along the EP is in the range of 31 ... 43%.

Knowing the EP potential capabilities and the passing people number, it is possible to calculate the EE value which the EP can generate in a certain time of work.

Based on the obtained results, we can conclude, that we have a fairly efficient device which can work as a renewable source of electricity, while being easily installed in the existing infrastructure. The installation of several EPs at a specific facility can fully or partially provide its electricity needs.

## References


[1] Tong Y., Nengmin W. Urban Innovation Based on the Environmental Management //2009 International Conference on Environmental Science and Information Application Technology. – IEEE, 2009. – T. 1. – C. 132-136.

[2] Zenina, N., Merkurjevs, J., Romanovs, A. TRIP-based Tran Intelligent Transport System Measure Evaluation based on Journal of Simulation and Process Modelling, 2017, Vol.12 2123.

[3] Romanovs, A., Pichkalov, I., Sabanovic, E., Skirelis, J. Industry 4.0: Methodologies, Tools and Applications . In: Proceedings of the Open International Information Sciences eStream 2019, Lithuania, Vilniu IEEE, 2019, pp.1-4

[4] Romanovs, A., Sokolov, B., Lektauers, A., Potryasaev, S., Interactive Technology for Natural-Technical Objects Integ Computer: Lecture Notes in Computer Science. Vol.8773. Cham: Springer International Publishing AG, 2014. pp.17 e-ISBN 978-3-319-11581-8. Available from: doi:10.1007

[5] Andrey Gnatov. Joint Innovative Double Degree Master Program «Energy-Saving Technologies in Transport» / Andrey Gnatov, Shchasyana Argun, Olga Ulyanets // 2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON) – May 29 – June 2, 2017. – Kyiv, Ukraine – P. 1203–1207, IEEE Catalog Number: CFP17K03-USB. – ISBN: 978-1-5090-3005-7.

[6] Hnatov A. Energy saving technologies for urban bus transport / A. Hnatov, Shch. Arhun1, S. Ponikarovska // International Journal of Automotive and Mechanical Engineering. 2017. – №14(4). – C. 4649-4664. doi: https://doi.org/10.15282/ijame.14.4.2017.5.0366.

[7] Patlins A. et al. Sustainable pavement enable to produce electricity for road lighting using green energy //2018 Energy and Sustainability for Small Developing Economies (ES2DE). – IEEE, 2018. – C. 1-2.

[8] Xiaofeng Li, Strezov V. Modelling piezoelectric energy harvesting potential in an educational building. Energy Conversion and Management. 2014;435-442. doi:10.1016/j.enconman.2014.05.096

[9] Patlins A., Hnatov A., Arhun S. Safety of pedestrian crossings and additional lighting using green energy. – Proceedings of 22th International Conference. Transport Means. 2018. (submited).

[10] Пат. 121490 України, H02K H02K 7/00, H02K 7/12, H02K 35/00, H02K 35/02, H02N 2/18. Електромеханічний пристрій перетворення кінетичної енергії в електричну з мультиплікатором / Гнатов А. В., Аргун Щ. В., Дзюбенко О. А; заявник та патентовласник Харківський нац. автом.-дорожн. ун.-т., Гнатов А. В. – № u 2017 05464; заявл. 02.06.2017; опубл. 11.12.2017, Бюл. №23.

[11] Kamal P. N. M., Buniyamin N. Using Piezoelectric Elements as Footsteps Energy Harvester: an Investigation //2018 IEEE 8th International Conference on System Engineering and Technology (ICSET). – IEEE, 2018. – C. 1-6.

[12] Panthongsy P. et al. Performance and Behavior Analysis of Piezoelectric Energy Harvesting Floor Tiles //2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST). – IEEE, 2019. – C. 1-4.

[13] Dalabeih D., Haws B., Muhtaseb S. Harvesting kinetic energy of footsteps on specially designed floor tiles //2018 9th International Renewable Energy Congress (IREC). – IEEE, 2018. – C. 1-4.

[14] Elbakush E. et al. On the performance of human energy harvesting technology //2017 IEEE Green Energy and Smart Systems Conference (IGESSC). – IEEE, 2017. – C. 1-6.

[15] Sultan, Moiz; Liu, Dedra; Ammad, Ali. New SUB atrium features: Pavegen energy-generating steps. 2011. DOI: 10.14288/1.0108431.

[16] Pultarova T. Energy: Is feet-to-heat paving system the next big step in renewables? //Engineering & Technology. – 2015. – T. 10. – №. 6. – C. 19-19.

[17] Пат. 2 482 568 Росії, H01L 41/11. Сбор энергии с дорог и взлетно-посадочных полос / Абрамович Х., Хараш Е., и др. – заявл. 20.03.2012; опубл. 20.05.2013.

[18] A. Kokkinopoulos, G. Vokas, P. Papageorgas. Energy Harvesting Implementing Embedded Piezoelectric Generators – The Potential for the Attiki Odos Traffic Grid. Energy Procedia, Volume 50, 2014, Pages 1070-1085. https://doi.org/10.1016/j.egypro.2014.06.126.

[19] Cafiso Salvatore; Cuomo M. Experimental Analysis for Piezoelectric Transducers Applications into Roads Pavements". Advanced Materials Research. – 2013. – no. 684. – pp. 253–257. DOI: 10.4028/www.scientific.net/AMR.684.253.

[20] Papagiannakis A. T., Dessouky S. Montoya A. Energy Harvesting from Roadways / 7th International Conference on Ambient Systems, Networks and Technologies (ANT) / 6th Interna-tional Conference on Sustainable Energy Information Technology (SEIT) / Madrid, SPAIN: May 23-26, 2016. no.83. – pp. 758-765.

[21] Zdenek Hadas, Ludek Janak, Jan Smilek. Virtual prototypes of energy harvesting systems for industrial applications Mechanical Systems and Signal Processing, Volume 110, 15 September 2018, Pages 152-164. https://doi.org/10.1016/j.ymssp.2018.03.036.

[22] Pan J. F., Zou, Yu Cheung. The direct-drive sensor less generation system for wave energy utilization. International journal of electrical power & energy systems, 2014. – no.62. – pp. 29-37.

[23] Francisco Duarte, Adelino Ferreira, Paulo Fael. A New Electromechanical Device to Convert Vehicles Mechanical Energy

into Electrical Energy. 2017 International Renewable and Sustainable Energy Conference (IRSEC). Page s: 1 – 7. DOI: 10.1109 / IRSEC.2017.8477383.

[24] Datta Rajesh Kumar, Rahman Sazid. Power Generating Slabs: Lost energy conversion of human locomotive force into electrical energy / International Conference on Electrical and Computer Engineering / Dhaka, Bangladesh: DEC 20-22, 2014. – pp. 718-721. DOI: 10.1109 / ICECE.2014.7026831.

[25] Carmine Stefano Clemente, Daniele Davino, Ciro Visone. Experimental Characterization of a Three-Rod Magnetostrictive Device for Energy Harvesting. IEEE Transactions on Magnetics. 2017, Volume: 53 , Issue: 11. DOI: 10.1109 / TMAG.2017.2696306.

[26] How to Build a Hand Crank Flashlight: https://www.brighthubengineering.com/diy-electronics-devices/109647-how-to-build-a-magneto-crank-flashlight/. 18.10.2013.

[27] Patlins, A., Hnatov, A., Arhun, S., & Dzyubenko, O. (2019). Design and research of constructive features of paving slabs for power generation by pedestrians. Transportation Research Procedia, 40, 434-441. Doi: https://doi.org/10.1016/j.trpro.2019.07.063.

[28] Bird J. Electrical Circuit Theory and Technology. 5th ed. Routledge; 2014.


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