Scientific Journal of Riga Technical University
Material Science. Textile and Clothing Technology

2011
Volume 6

The Structure of the Electromechanical Converter and Its Integration in Apparel

GalinaTerlecka[1], Ausma Vilumsone[2], Juris Blums[3], Ilgvars Gornevs[4], [1-4]*Riga Technical University*

Abstract. The research is dedicated to the investigation of the structure of the energy harvester with planar structure and its integration into the clothes. Electrodynamic converter consists of the set of flat, spiral-shaped coils and a block-shaped permanent magnet. During the human motions the generator elements move one relative to another and induce the pulses of voltage [2]. In order to increase the generator capacity, on the trajectory of the magnet movement several in series connected coils are located. Experimentally provides that the generated power reaches the maximum at the ratio of coil's diameter D and the length of the magnet L, L/D is in interval 1.25 - 1.5 and the distance between the coils is equal to D / 2. By optimization of coils and magnet dimensions the mean power of into the jacket integrated prototype about 0.2 mW is obtained. With the planar coil geometry the generator minimal volume and occupied space are achieved, therefore power density of generator (about 1.8 mW/cm3) is higher than that proposed by other researchers [4], and it is suitable to be fully integrated into clothing.

Keywords – smart clothes, human motion energy harvester, electrodynamic converter, wearable energy sources

INTRODUCTION

Scientific and technical progress has changed vigorously even the shapes and forms of the most usual things. Fashion industry is not an exception to the influence for change. From mobile phones to laptop computers, society has become increasingly dependent on portable electronic devices [8]. The accelerating process of integration and miniaturization of electronic units and components enables to obtain an electronic system which is completely integrated into garments and accessories, in certain cases even power-supply sources can be interwoven into the garments [4].

At the present moment portable devices possess huge calculating resources that are enough for autonomous performance of miscellaneous complicated tasks for their owners – communication and connection, personal identification, route navigation, safety assurance, monitoring of biological health, upholding of comfortable condition for the user. Built-in microdisplays, video cameras, personal communication devices, integrated equipment for data storage and operating, transducers and indicators – all these devices provide a wide variety of applications: communication and connection, military purposes, medical science and public health service, sports, fashion, personal safety assurance, etc. Wearable electronics, as well as garments and accessories must be comfortable in use and wearing.

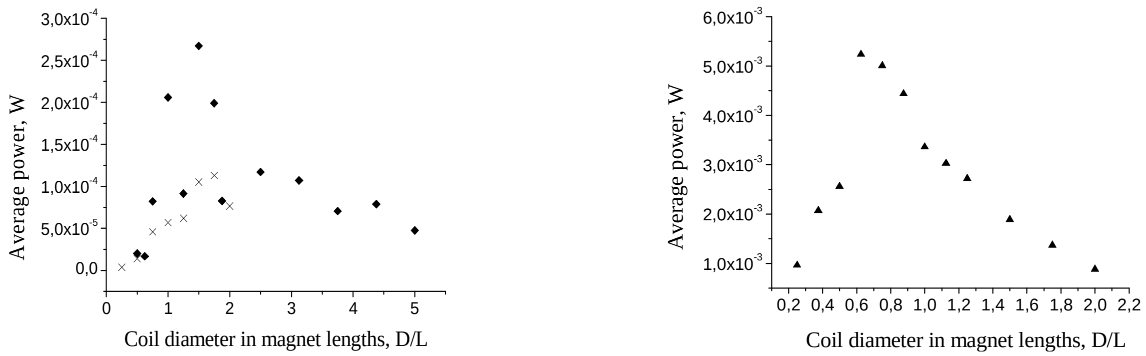
Rechargeable accumulators or batteries almost exclusively provide power for wearable electronics, the energy per unit mass in batteries is limited, that is why there is a trade-off between device power consumption, battery weight and duration of operation. Furthermore, the use of batteries imposes an obligation on the wearer to replace and recharge them periodically. This, in turn, makes hermetic of all integrated systems difficult or even impossible.

Nowadays the examination of alternative sources of energy is one of the most topical and high-demand directions of scientific research. The conducted researches are aimed first of all at creation of new technologies, which would provide compact sizes of power resources with a bigger energy-output ratio, as well as their ecological compatibility and cost effectiveness.

There is a topical research on using garments in the role of autonomous power generators that provide energy for portative electronic devices of the user. At present there are a number of alternative power resources for portable electronic devices such as chemical power elements, fuel elements, thermogenerators, piezoconverters, and converters of kinetic energy into electrical energy.

Human power is an alternative and attractive energy source. In the recent years devices that are suitable for generating microwatt energy from usual human motions arouse growing interest [3, 7]. Energy that is generated during routine and seemingly insignificant human motions can recharge wearable electronics. Earlier on there were proposed a number of devices that produce power using the efforts of their owner. Examples of these devices include hand crank and bicycle generators as well as wind-up flashlights, radios, and cell phone chargers [6]. But most of them have significant drawbacks – they demand special attention from the user, together with performance of sometimes rather unconventional and unnatural for a human being motions, thus limiting the time available to produce power and consequently the amount of useful energy that can be generated.

It is known that there are already discovered and patented smart clothes and other accessories, with integrated power generation systems, such as energy-harvesting shoe, biomechanical energy harvester, energy harvesting backpack [5, 10-12]. The prototype devices also use a piezoelectric crystal, capacitors with variable capacity and moving-magnet and coil system [3, 7]. The main disadvantage is that all these objects are three-dimensional and therefore cannot be integrated into apparel as each item of the apparel consists of two-dimensional parts.



a b

Fig.1. The average power of harvester vs coil diameter in magnet lengths, D/L: „♦” – for magnet No.1 L= 8 mm; „x” - for magnet No.2 L=20 mm, „▲” – for magnet with double magnetic field structure Nr.3 L= 40 mm.

At Riga Technical University a mechanical energy harvester has recently been developed for generating electricity during human walking [2]. Our device has a planar structure. Electrodynamic converter consists of flat, spiral-shaped coils and a rectangular or an arc-shaped magnet, and all elements can be deployed on a variety of clothing items. During the natural human motions the generator elements move in relation to one another and induce the pulses of voltage inside the flat inductor.

The objective of the present investigation is the optimization of the electrodynamic human motion energy harvester with a planar geometry and to integrate a generator into a garment.

EXPERIMENTAL

The data on generator construction, the first findings of the research on the generator optimization, as well as the analysis of a generator location in the smart apparel were published earlier. [2, 9]

Within the framework of the research, a number of experiments were devoted to the optimization of the electromechanical converter and the prototype tests – to walking at a different speed.

Optimization of the Generator

Principle of electromechanical converter operation: a permanent magnet, moving parallel to the plane of the flat coil, without crossing it, creates an alternating magnetic field flux, which is required for the induction of an electromotive force.

Experimentally the no-load voltage and voltage drop on the resistive load were measured. To get the maximal power, the resistance of the load was equal to the resistance of the flat coil.

The power developed by the harvester with a planar structure is strongly dependent on the characteristic sizes of the coil and moving magnet. The dependence of the developed power on the ratio of coil diameter D and the length of the magnet L, D/L is shown in the Figure 1.

Experiments were done using two block-shaped magnets with size 3×5×8 mm (magnet No.1) and 5×10×20 mm (magnet No.2) and one arc-shaped with double magnetic field structure with size 2×15×40 mm (magnet No.3) and the remanence of magnetic field correspondingly 0.37 T, 0.1 T and 0.26 T. The diameter of the flat coils was from 4 mm (8 windings) up to 80 mm (158 windings). The maximum of generated power for both block-shaped magnets were observed at very close D/L ratio: D/L=1.5 for the magnet No.1, D/L=1.75 for the magnet No. 2 and D/L=0.625 for the arc-shaped magnet No. 3.

The performance of the device at maximum power developed was characterized by the following parameters:

the average power (the pulse generated energy divided by the duration of the pulse);

the volume density of the power (the average power divided by the volume of the coil and magnet);

efficiency (the energy generated as the part of magnet motion energy, per cent).

The numerical data of harvesters are shown in Table 1.

TABLE I
THE PERFORMANCE OF FLAT COIL HARVESTERS WITH DIFFERENT MAGNETS

Magnet	Size, , **mm×mm×mm**	Remanence, T	Number of windings
No. 1	3×5×8	0.37	26
No. 2	5×10×20	0.1	72
No. 3	2×15×40	0.26	50
	Average power, mW	**Density of power, mW/cm^3**	**Efficiency, %**
No. 1	0.267	1.82	1.8
No. 2	0.113	0.1	0.4
No. 3	5.24	4.01	

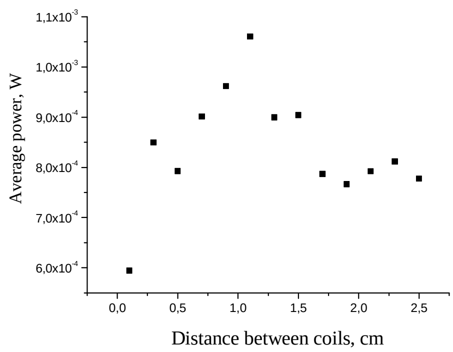


Fig. 2. The average power of harvester vs distance between the coils for coil diameter D=2.5 cm

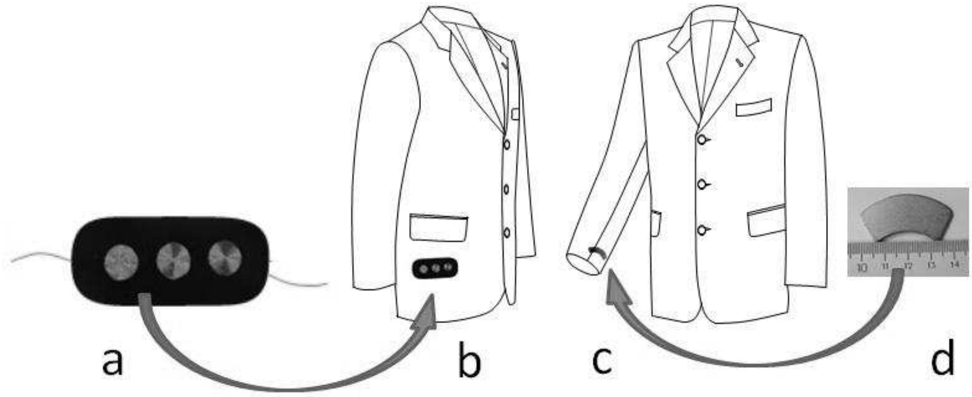


Fig. 3. Jacket with the electrical generator. There is shown in Figure 1.: a - set of flat spiral shaped coils, b - location of the inductive elements, c – location of the magnet, d – permanent magnet

The performance of generator also depends on the distance between edges of the coils, as shown in Fig. 2.

Taking into account that for locating the coils a relatively plain (even by motion) section of garment was needed, there was defined the place for locating the coils on the front part (pocket area) of jacket, the size of which is about 10 centimetres in length. On a section of such length it is possible to locate three coils with diameter 2.5 cm and distance of 1 cm between the coils.

Main Structure of the Generator inside the Prototype

Electrodynamic human motion energy harvesters integrated into the jacket contain two parts:

Set of flat, spiral-shaped coils consists of three groups of coil with identical/same direction of winding turns, which are connected in series with distance between the coils of 1 cm. Each coil group consists of five layers, placed one onto another with insulating layer in between of flat coils with a diameter of 25 mm and the number of windings 50. Planar coils are made of copper wire (diameter 0.22 mm).

The second part of generator is lightweight, small, arc-shaped and strong neodymium (Nd) magnet with double magnetic field structure.

The volume of the generator (coils + magnet): about 4.8 cm^3 and its mass – 45 g.

Generator Location in the Smart Jacket

See Figure 3 for the information on a generator location in the energy generating smart "full energy" jacket.

Placement of the magnet maximally low inside a sleeve and placement of a set of coils on the front part of the jacket (pocket area) assure movement of the magnet at the maximum speed possible during human motion against location of the coils, as well as corresponding maximum possible electromotive force induced by coils.

Location of the generator details and a number of coil layers are found by an experimental approach. All the positions of generator parts inside the garments were optimized during the process of walking in order to achieve exact trajectory of motion of the magnet that would pass through the centres of magnetic coil.

Test of the Prototype – Walking at Different Speed

At the same time, there are two generators integrated into the jacket – on the right and left sides. The prototype was tested by a wearer during the process of walking at different fixed speeds: 3, 4.5 and 6 km/h which correspond to slow, normal and quick walking of a middle-aged man. (See Fig.4.). The power of the generator was registered in two modes: induced electromotive force (as no-load voltage) and maximum power (using the load with resistance, which is equal to the coil resistance) mode.

By means of digital oscilloscope Picoscope 2205, there were fixed voltage pulses, formed by the generator at resistive load. Load resistance was equal to the total resistance of coils – a condition for the development of the maximum power. The voltage generated on the load resistor vs. time during nine full motions of the magnet along the coil is shown in Figure 5.

Having known the meanings of voltage during the movement there was calculated the produced energy, and by dividing it into the time of motion – average power. The numerical data of harvester relevant characteristics – the average and maximum power for the full walk cycle are shown in Table II.

Fig. 4. Test of the prototype

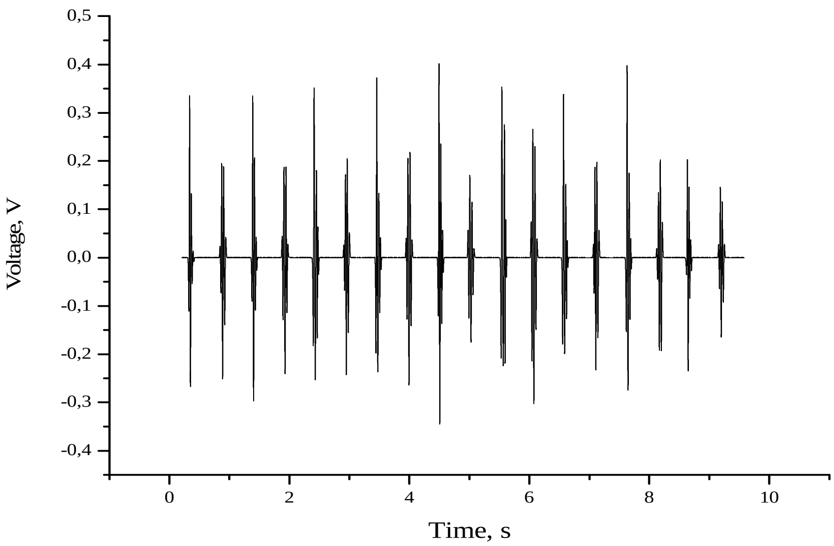


Fig. 5. Generated voltage pulses at the motion speed of 6 km/h. The full motion/walk cycle - the period of double step – is formed for each arm from both forward and reverse movements

TABLE II
PROTOTYPE IN USE – DEVELOPED POWER

Speed of motion	**Steps in 1 min**	**Maximal power, mW**
3 km/h	80	3
4.5 km/h	103	14
6 km/h	115	10
	Mean power (through 1 min of walking), mW	**Mean density of power, W/cm^3**
3 km/h	0.05	7.59E-06
4.5 km/h	0.11	1.59E-05
6 km/h	0.21	4.08E-05
	Average power ± absolute error, W	**Relative error, %**
3 km/h	(3.70±1.66)E-05	45
4.5 km/h	(7.75±1.97)E-05	25.5
6 km/h	(19.9±1.96)E-05	9.9

Repeatability of parameters in successive cycles of movements during walking is not absolute: the movements have some variability.

There was observed some asymmetry of pulses connected with the trajectory of sleeve movement. It was observed that during the movement of sleeve forward the trajectory of magnet is maximally close to the coils, while during movement of sleeve backwards the magnet is further away from them. Presumably it is connected with individual dynamic stereotypes of motion.

Maximal instantaneous power 14 mW is observed at the speed of motion 4.5 km/h, and maximal mean power 0.21 mW at the speed of motion 6 km/h. This is definitely related to the wearer's optimal walking speed, which is an individual parameter, as well.

The estimated statistical error determines the stability of the hand movement during human walking and, as a consequence, defines the stability of generator operation. Maximal relative error 45% is observed at the speed of motion 3 km/h, and minimal relative error 9.9 % at the speed of motion 6 km/h.

On the left side in the induced electromotive force (as no-load voltage) mode, alternatively one after another there are tested generators with 5-layer and 4-layer spiral-shaped inductive elements at the speed of motion 4.5 km/h.

The generated power modified by changing 4-layers to 5-layers coil inductive elements was characterized by the following parameters (see Table III):

-the average power;

-the volume density of the power;

-the volume of the generator;

-the ratio of growth/loss generated power (ΔP) is possible to calculate as the difference between the power of 5 - and 4-layer generators divided by the power of a 4-layer generator or as the difference between the power of 4 - and 5-layer generators divided by the power of a 5-layer generator.

The coefficient of ΔP allows estimating the variation of the generated power by changing 4-layers to 5-layers coil inductive elements. A positive value of ΔP indicates the growth of generated power, while a negative value – the loss of generated power. The coefficient is positive and equal to 0.23; hence, there is a power growth of 5-layer generator relative to the 4-layer generator. Further increase in the number of layers of this type of clothing is not advisable, because it changes the appearance of clothing.

TABLE III
THE CHARACTERISTICS OF HARVESTER WITH DIFFERENT INDUCTIVE ELEMENTS

Inductive element	**The volume of the generator (coils + magnet), cm^3**	**Average power, W**	**Density of power, mW/cm^3**	**ΔP**
4-layers	4.0	2.25E-09	5.63E-10	-0.19
5-layers	4,8	2,7848E-09	5,80E-10	0.23

Additionally the work of generator was tested in case of human unsymmetrical posture (unbalanced walking action) at the speed of 4.5 km/h. The power of the generator was registered at maximum power (using the load with resistance, which is equal to the coil resistance) mode. Human walking is characterized by symmetry of rhythmical and alternative movements of the left and the right sides. By wearing a brief case weighing 6 kg on the left shoulder or in the left hand the effect of unsymmetrical posture is achieved.

Statistical power analysis and generated power which was produced by the right hand motion during the process of walking at different postures are shown in Table IV:

TABLE IV

GENERATOR OPERATING PARAMETERS AT A DIFFERENT MOVEMENT SPEED

Posture/ human motion types		**Average power, W**
normal posture/ natural movement		7.75E-05
unsymmetrical posture/ unbalanced walking action	briefcase in the left hand	9.48E-05
	briefcase on the left shoulder	3.55E-05

The largest, as well as the smallest value of power energy is achieved during testing when subjects stand up with an asymmetrical posture.

From the analysis of the dynamic equilibrium it is known that the right disposition of gravity centre influences the balance and posture. During motion the point of gravity centre of a person is continuously moving against the body, while the body parts (corpus and extremities) change their disposition in the space [1].

In this experiment when a person is carrying a heavy briefcase in the left hand or on the left shoulder an additional displacement of the gravity centre takes place, and for keeping vertical balance and maintaining evenness and smoothness of walking the person has to deviate and to produce permanent compensatory movements with the free right hand.

More specifically, in case when the briefcase is in the left hand, the left shoulder is displaced downwards, femora are displaced to the right, and the common gravity centre of the person and the cargo deviate to the left. In order to return the previous position of the gravity centre and to restore equilibrium the person is forced to deviate to the right, and as a consequence the distance between the right femora and the free right hand is becoming shorter. And the value of electric potential is increasing (See Fig.6.).

In case when the briefcase is on the left shoulder, the common gravity centre of the person and the cargo are displaced to the right, the left shoulder is displaced upwards and the position of the femora displaces to the left. The person has to deviate to the left and to put aside the free right hand in order to return the former disposition of the gravity centre and to restore equilibrium. In that case the distance between the body and the free right hand is growing. And the value of electric potential is reducing. That corresponds with the earlier determined dependence of electric potential on the distance between the coil and the magnet, when the distance between the coil and the magnet is shortened, and electrical potential and power are growing.

RESULTS AND DISCUSSION

Earlier initiated converters of mechanical energy were created as three-dimensional installations. This construction is not suitable for integration into clothing.

The investigated generator can be used as a mobile and ecologically clean source of energy, easy in use, and not changing substantially visual properties of textile structures, its sizes or weight.

Weight of the energy harvester is insignificant in relation to the weight of the product, and it provides the same easiness of motion as garments without an installed energy generator.

The offered generator has several advantages:

Coil of electrodynamic energy harvester is performed as a spiral-shaped with planar geometry, and a small, flat magnet provides minimal volume, weight and occupied space by the harvester. Thanks to these properties the harvester is completely integrated inside the garments without changing its shape or outer appearance.

The generator with the flat coil does not need additional volume for magnet motion as it is located in a different part of garments, one of which is moved against the other during the process of walking, and therefore can be implemented almost in every garment.

Elements of the construction of the energy harvester are not united under one frame and can be located almost in every garment, where the above-mentioned conditions can be executed, along with the choice of the suitable size and number of coils. When compared to other investigations [4] on power density (from 0.8 to 0.07 mW/cm3) of different constructions of harvesters, the supposed power density of the present harvester (up to 1.8 mW/cm3) is higher, as the planar structure and direct use of sleeve movements (without any actuators) do not demand additional space for moving the magnet against the coil. The harvested energy is enough for supporting the work of watches or different installed sensor nodes.

The disadvantage of the present harvester in its first prototype is a rigid magnet inside the sleeve, which preferably could be substituted with flexible/elastic one.

It would be reasonable to investigate the characteristics of using an energy generator in other types of garments and accessories. In Table V several examples of possible places are provided for locating a magnet and coils.

TABLE V

PLACES OF LOCATING A GENERATOR INSIDE APPAREL AND ACCESSORIES

Location of flat spiral shaped coil	**Location of magnet**
Patch-pocket	Sleeve/cuffs
Bag	Side seam trousers
Belt bag	Sleeve/cuffs
Inner seam trousers	Inner seam trousers

There is a need to carry out investigations in the field of protection of generator details against unfavourable impact of laundry process.

It is also necessary to consider the opportunity of integrating the flat coil into apparel as the element of decoration.

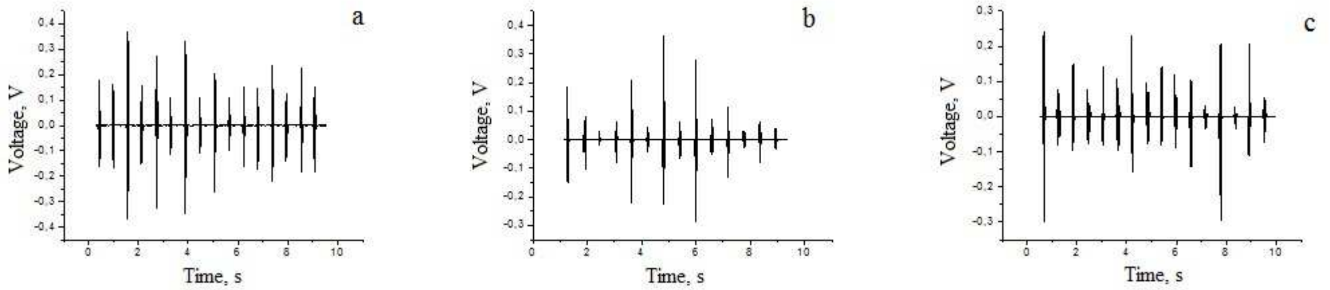


Fig.6. Generated voltage pulses at the motion speed of 4.5 km/h for different posture (balanced and unbalanced walking action), where a – unbalanced walking action: a briefcase in the left hand, b – unbalanced walking action: a briefcase, on the left shoulder c - balanced walking action without any load.

CONCLUSION

The possibility to integrate the electrodynamic human motion energy converter with a flat architecture into the clothes is considered in the paper.

The generated energy can be used for running different integrated sensors and/or can be stored for later usage.

The insertion of the coils is achieved without any deformation of the fabric of jacket; the position of the coils in practice is not visible from the right side of the product.

Due to flat planar geometry form of the coil, motion of elements and parts of garments can be used directly for generator operation.

ACKNOWLEDGEMENT

This work has been supported by the European Social Fund within the project “Establishment of interdisciplinary research groups for a new functional properties of smart textiles development and integrating in innovative products", Nro.2009/0198/1DP/1.1.1.2.0./09/APIA/VIAA/148.

ESF
EIROPAS SOCIĀLAIS FONDS
INVESTING IN YOUR FUTURE
EIROPAS SAVIENĪBA

REFERENCES

[1] Физиология человека. Под редакцией В. М. Покровского, Г. Ф. Коротько Издательство: Медицина 656 стр. Серия: Учебная литература для студентов медицинских вузов ISBN 5-225-04729-7; 2007 г.

[2] J. Blums et al., The Electrodynamic Human Motion Energy Converter with Planar Structure, Advanced Materials Research, Vol. 222, 2011, pp. 36-39.

[3] R. Elfrink, et In: Proceedings of the powermems workshop, Sendai; November 10–11, 2008. p. 249–52.

[4] P.D. Mitcheson et al., “Energy harvesting from human and machine motion for wireless electronic devices” Proceedings of the IEEE, vol.96, No. 9, (2008) p. 1457-1486

[5] L.C. Rome., et al., Generating Electricity While Walking with Loads, Science, Vol. 309 no. 5741, 2005, pp. 1725 - 1728 (2005).

[6] Paradiso JA, Starner T: Energy scavenging for mobile and wireless electronics. IEEE Pervasive Computing 2005, 4:18-27

[7] C.R. Saha et al. Electromagnetic generator for harvesting energy from human motion / Sensors and Actuators A 147 (2008) 248–253

[8] T. Starner, J. Paradiso: Human generated power for mobile electronics. In Low-power electronics design. EditedbyPiguetC. BocaRaton: CRCPress; 2005

[9] G. Terlecka, A. Viļumsone, J. Blūms The Electrodynamic Human Motion Energy Harvester in Smart Clothes // 150 Years of Research and Innovation in Textile Science: Book of Proceedings. Vol.2, Francija, Mulhouse, 8.-10. jūnijs, 2011. - 866.-870. lpp.

[10] Y.Garcha Bionic energy harvester design trials to be conducted with soldiers, http://www.bionic-power.com/

[11] J. Paradiso Energy Harvesting for Mobile Computing http://www.dcu.ie/chemistry/asg/Workshop/EnergyHarvestingforMobileSystems-JParadiso.pdf

[12] A.Schwartz Japanese Company Develops Electricity-Generating Shoes http://cleantechnica.com/2008/10/16/japanese-company-develops-electricity-generating-shoes/

Galina Terlecka, Mg.sc.ing., Doctoral student, Researcher
Since 2009 - Doctoral student. Textile and clothing technology. Institute of Textile Materials Technologies and Design, Riga Technical University, Latvia 2007 – Engineer of Clothing Technology and - 2009 - Master's Degree in materials science, Riga Technical University, Riga. Title of thesis "Identification and 3D Visualisation of Women Body Types".
Since 2007 - Assistant and - 2009 Researcher in scientific work at Riga Technical University, Institute of Textile Materials Technologies and Design.
Main activities and interests: CAD/CAM systems in product design, innovative textiles and technologies.
Riga Technical University, Institute of Textile Materials Technologies and Design,14-121, Āzenes Str., Riga, LV-1048, Latvia, galina.terlecka@rtu.lv

Juris Blums, Dr.phys., Associate Professor
Juris Blums graduated from the University of Latvia in 1992 as physicist, in 1997 obtained Dr.phys. from the University of Latvia, title of thesis “Laser Induced Centres in Silicon”.
J.Blums was a guest scientist at Tallinn Technical University (Estonia, 2000), University of Essen (Germany, 2001-2003) in experimental physics. Since 2003 – asoc. prof. at Riga Technical University, Institute of Technical Physics.
Fields of scientific interests – semiconductor physics, laser-matter interaction, elaboration of energy harvesting and scavenging devices.
Riga Technical University, Institute of Technical Physics, 14/24-322, Azenes Str., Riga, LV-1048, Latvia, phone +37129774351, Contact information: e-mail: blum@latnet.lv , phone +371 29774351, fax. + 371 67089074.
blum@latnet.lv

Ausma Vilumsone, Dr.sc.ing., (1993 RTU) Professor
Head of the Institute of Textile Materials Technologies and Design, Head of the Department of Clothing and Textile Technologies
Development and optimization of garment design technological process, CAD/CAM systems in product design, innovative materials and technologies
Riga Technical University, Institute of Textile Materials, Technologies and Design, Riga Technical University, 14/24-319, Azenes Str., Riga, LV-1048, Latvia, phone +371 67089565,
ausma.vilumsone@rtu.lv

Ilgvars Gornevs Bc.Sc.ing., Master student, Electronics Technician
2010 - Bachelor's Degree, Riga Technical University, Riga. Title of thesis “Power Supply for Portable Electronics”.

Institute of Radioelectronics, Riga Technical University, 12–322, Azenes Str., mylifes@inbox.lv
Riga, LV-1048, Latvia, phone +371 67089245,

GaļinaTerļecka, Juris Blūms, Ausma Viļumsone, Ilgvars Gorņevs. Mehanoelektriskā enerģijas pārveidotāja struktūra un integrēšana apģērbā
Pētījuma mērķis ir optimizēt enerģijas pārveidotāja struktūru, kā arī iestrādāt apģērbā enerģijas pārveidotāju un testēt ģeneratora darbību apģērbā. Pētījumu laikā ir izveidots enerģijas pārveidotājs ar plakanu ģeometriju, kas sastāv no plakaniem, spirālveida indukcijas elementiem un taisnstūra pastāvīgā magnēta vai lokveida magnēta ar dubultu magnētiskā lauka struktūru, kas ir pilnībā integrējams apģērba elementos, kuri kustas viens gar otru, cilvēkam kustoties. Magnētam kustoties gar indukcijas elementu, tajā tiek inducēts elektriskā sprieguma impulss. Lai palielinātu ģeneratora jaudu magnēta kustības trajektorijā, ir izvietotas vairākas virknē savienotas spoles grupas. Izveidotajā prototipā (vīrieša žaketē) pārveidotāja elementi tika integrēti žaketes sānos un piedurknē. Eksperimentāli noteikts, ka enerģijas pārveidotāja darbības efektivitāte ir stipri atkarīga no attiecības starp spoles diametru - D un magnēta garumu – L un no attāluma starp spoles malām. Maksimālā jauda ir novērota pie D/L=0,625 lokveida magnētam ar dubultu magnētiskā lauka struktūru, kad attālums starp spoles malām ir $^1/_2$ D. Optimizējot magnēta un indukcijas elementu izmērus un to izvietojumu prototipā, vidējā attīstītā jauda sastāda 0,2 mW, cilvēkam soļojot ar ātrumu 6 km/h.
Izvēlētā pārveidotāja plakanā ģeometrija ļauj minimizēt pārveidotāja aizņemto tilpumu, samazinot to līdz elementu kopējam tilpumam, kas nodrošina salīdzinājumā ar citiem pārveidotājiem augstāku jaudas blīvumu (ap 1,8 mW/cm^3) un ļauj integrēt pārveidotāja sastāvdaļas apģērba elementos bez to ārējā izskata izmaiņas. Saražotā enerģija ir pietiekami liela, lai nodrošinātu pulksteņu un dažādu sensoru darbību.

Галина Терлецка, Юрис Блумс, Аусма Вилюмсоне, Илгвар Горневс. Структура механоэлектрического преобразователя энергии и его интеграция в одежду
Исследование направлено на оптимизацию структуры преобразователя энергии с плоской геометрией и тестирование интегрированного в одежду генератора. Разработанный преобразователь энергии, состоит из группы плоских, спиральных индуктивных элементов и постоянного прямоугольного магнита или дугообразного магнита с двойной структурой магнитного поля, который полностью интегрирован в части одежды, которые перемещаются относительно друг друга во время движения человека. При движении магнита вдоль индуктивных элементов индуцируется электрический импульс напряжения. Для увеличения мощности генератора на траектории движения магнита находятся последовательно соединенные группы катушек. В экспериментальном образце (мужском пиджаке) элементы генератора размещены на внутренней стороне рукава и на полочке пиджака (область кармана). Опытным путем установлено, что эффективность работы генератора сильно зависит от соотношения между диаметром катушки - D и длиной магнита - L и также зависит от расстояния между краями катушек. Максимальная выходная мощность наблюдается при D/L = 0,625 для дугообразного магнита с двойной структурой магнитного поля, когда расстояние между краями катушки составляет $^1/_2$ D. При оптимизации размеров индуктивных элементов и магнита и их расположения средняя мощность интегрированного генератора составляет 0,2 мВт при скорости человека в 6 км / ч.
Плоская геометрия преобразователя позволяет минимизировать занимаемую площадь и объем, что обеспечивает по сравнению с другими исследователями более высокую плотность мощности (около 1,8 мВт/см^3) и благодаря чему возможно размещение компонентов преобразователя в одежде без изменения формы и внешнего вида одежды. Вырабатываемой энергии достаточно для поддержания работы часов или различных встроенных датчиков.