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Energy Generating Outerwear

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Abstract **– This study investigates whether energy harvesting systems can be integrated or placed in/on clothing. The first part of the study includes general information about smart clothing that is already made with integrated energy systems and different types of energy sources to operate energy harvesting systems. During this study a male jacket prototype with an integrated planar structure electrodynamic converter was made. Experiments were done to verify the harvesting system according to system location, components (it was decided to experiment with 2 and 3 coil connections in series) and textile layer thickness. It was concluded that many factors affect the trajectory of permanent magnets and the amount of generated energy.**

Keywords **– Smart clothing, human motion energy harvester, electrodynamic converter, wearable energy sources.**

I. Introduction

Twenty years ago nobody could imagine that clothing and electronics can be combined. Electronic device size, weight and power required have decreased dramatically because of rapid growth of electronic engineering industry. Therefore the integration of multiple electronical devices in clothing and accessories has become possible and accomplishable. Focus is to assign additional practical functions – health monitoring, communication, location determination, extension of operation time of portable devices.

Effective smart clothing use is studied in health, military industry and in research on fire-resistant clothing. The main purpose is to provide extra safety and protection to certain activities (1).

Harvesting system has to be provided with stable energy source that is easy to produce and easy to gain. The energy source cannot dramatically change the size of clothing, the weight of clothing and the main function of clothing. In most cases rechargeable AA cell batteries are used. The Main problem of using rechargeable batteries is that the owner has to remember to regularly replace or charge them. As an alternative sun panels, thermoelectric elements and mechanic energy converters can also be used.

The research group at Riga Technical University have developed electrodynamic human motion energy converter with planar structure. The electrodynamic converter consists of a flat, spiral-shaped coil and a rectangular magnet that move in respect to one another during human motion. An average power of about 10 μW is generated during the motion of the rectangular magnet over a flat coil. The generator elements are planar and small – so both of them can be easily integrated in different places on clothing, which normally move in respect to one another during human motion. Usually, while walking and running a person makes a lot of equal, periodic motions that can be used as a mechanical energy source for electricity generation.

During this study a male prototype jacket pattern was made, which is provided with pockets and openings where to insert the generator elements. The main challenge was to prevent major changes in apparel size and weight, and to ensure comfortable movement and flexibility. Pockets were placed on the side pocket and the side sleeve, so the generator elements would directly pass each other while the wearer of the jacket walks or runs. After first experiments, a positive amount of energy was generated and it was decided to integrate not only a human motion energy converter, but also an energy accumulation system. Saved energy could be used later to charge portable devices or to operate small capacity sensors (temperature, GPS, health monitoring).

During this study different technical solutions were discovered for “how to” and “where to” better place energy harvesting system. Multiple experiments were performed.

II. Experiments

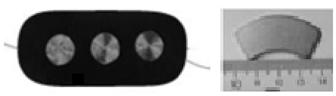
Several requirements had to be considered for the placement of energy harvesting system:

- the size of the system;
- technological processing and manufacturing of apparel;
- system placement terms;
- qualities of the used garment.

Generator consisted of three groups of flat, spiral-shaped coils with identical direction of winding turns that were connected in series; the distance between the coils was 1 cm. Each coil group consisted of five layers that were placed one onto another with an insulating layer in between flat coils (diameter – 25 mm, 50 winding turns). Planar coils were made of copper wire (diameter – 0.22 mm).

The second part of generator was a lightweight, small, arc-shaped and strong neodymium (Nd) magnet with double magnetic field structure (2).

See Fig. 1 for main components of the generator.



a b

Fig. 1. The structure of the electrical generator: a – a set of flat spiral shaped coils; b – a permanent magnet (2).

The placement of systems in the jacket is very important to optimize the performance of the generator. The main rules are:

- generator components have to be placed as closely as possible for the coils and magnet to move as closely as possible while the apparel is in motion;
- integrated system cannot restrict the freedom of movement;
- integrated generator components have to be detachable from the garment due to care restrictions;
- coils have to be placed on the same level as the magnet to generate maximum voltage (2);
- the most effective placement for an average male is on side of the body, approximately 6–8 cm down from the waist and for the magnet – across the coil on sleeve side part, see Fig. 2;
- an outerwear jacket with insulation lining is considered to be the most suitable apparel for integration.

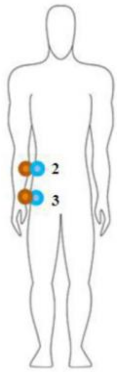


Fig. 2. The placement of generator components: the most effective placement is number 2 (3).

A. Analysis of Coil Placement

To test whether the generated energy could be increased, six, four, three and two coils were connected in series. voltage Impulse was measured for every coil separately while changing the coil position in relation to side seam of the jacket. After the experiment, the results were summed up as percentages and combined in a table. The table provides information about instantaneous power percentage increase/decrease depending on the coil position to the side seam. See Fig. 3 and Table I.

TABLE I

INSTANTANEOUS POWER PERCENTAGE CHANGES

Coil position in relation to the side seam	6th coil	5th coil	4th coil	3rd coil	2nd coil	1st coil
a		−90	−39	100	−31	
b	−78	−14	24	100		
c			−3	100	−48	−93
d	−78	−52	−6	100	−40	−93

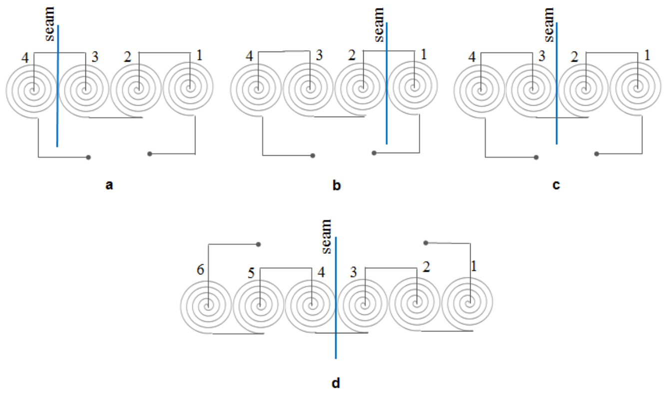


Fig. 3. Position of spiral shaped coils and their quantity in relation to side seam of the jacket. The blue line marks the side seam.

As follows from Table I, the most optimal positions for coils in relation to side seam were b and c. These positions show the highest interaction and the highest level of instantaneous power. It was decided to use three-coil chain connection on the right side and two-coil chain connection on the left side, see Fig. 4.

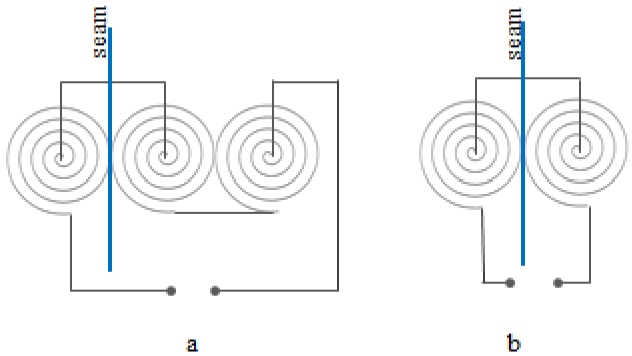


Fig. 4. The optimal position of spiral shaped coils: a – three planar coil chain connection placed on the right side seam; b – two planar coil chain connection placed on the left side seam. The blue line marks the side seam.

B. Technical Description of the Jacket and the Placement of the System

The system was placed in parallel on both sides of the jacket. On the right side seam of the jacket three coils connected in series were placed inside a pocket that was closed with a waterproof zipper and a permanent magnet was inserted in a flap in the sleeve on same side. The flap was closed with a plastic snap button. The same arrangement was placed on the left side of the jacket, with the exception that two planar coils were connected in series. It was very important to use plastic or non-metallic trims because the presence of any sort of metallic particles can interfere with proper performance of the electrical generator. For more detailed placement of the system in the ready-made garment see Fig. 5.

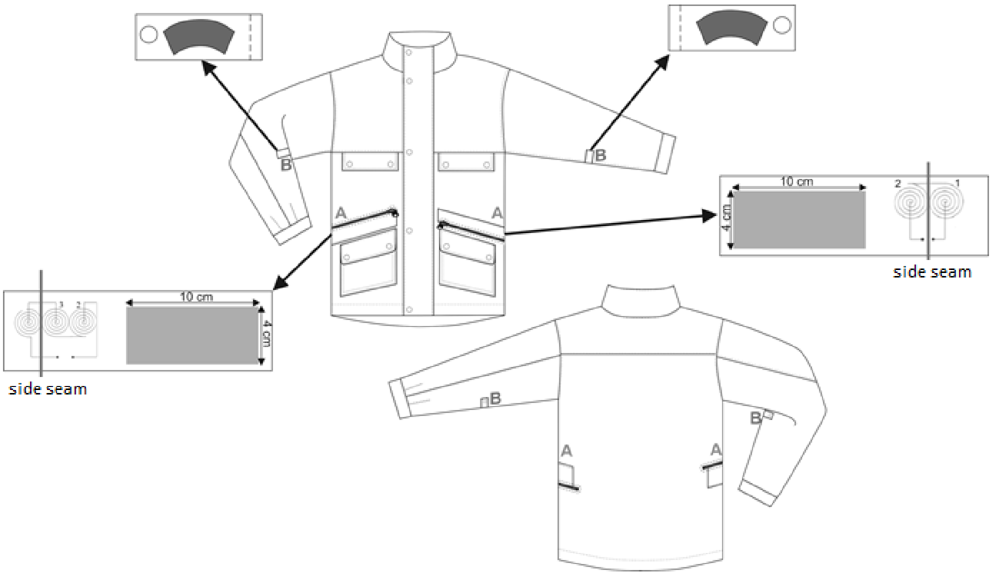


Fig. 5. The technical drawing of the jacket and the placement of the electrical generator: A – planar coil and the possible position of an accumulator, B – placement of the permanent magnet.

C. Adaptation of the System and the Testing of the Ready-made Jacket

The location of the generator components and the number of coil layers were determined experimentally. All positions of generator components 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 (4).

As mentioned before, there were two electrical generators placed in the jacket at the same time – one on the right side and another one on the left side.

Before the start, the test coils were connected to an oscilloscope *Tektronix TDS-2014* to check if the placement is effective enough to generate stable and active voltage pulses. After the test of effectiveness of the placement, the system was adapted to following placement changes – the two-coil connection was moved 2.5 cm away from the side seam, the three-coil connection was moved 4 cm away from the side seam and 1 cm upwards from the original position, see Fig. 6.

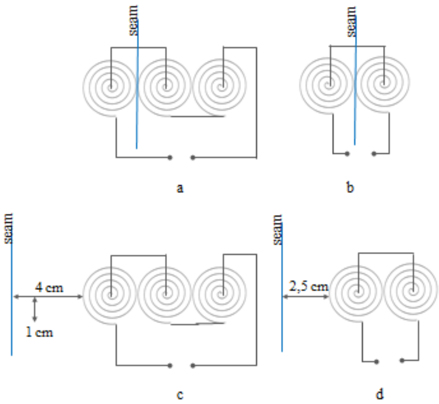


Fig. 6. Optimal placement of planar coil system: a, b – the placement before the test, c and d – the placement after the test.

The placement of system components can change because of several factors:

- every person has an unique posture;
- the prototype jacket pattern is not an exact copy of the sample jacket;
- the lining of the prototype jacket thickness is different;
- a change in lining thickness modifies the trajectory of the permanent magnet.

The prototype jacket was tested using a digital oscilloscope *Picoscope 2205* in two ways – while walking on spot (without advancing) and while walking at an optimal speed (10 walking cycles – one cycle is a hand movement back and forth, returning to the starting position). Furthermore, the electric generator with a 2-coil connection is described as Channel A and the electric generator with 3-coil connection is described as Channel B. Experiments were held with three different linings inserted in prototype jacket: with thin lining (for midseason), with thick lining (for winter season), without any lining (for warmer weather), see Fig. 7.

Fig. 7. The test of the prototype jacket: a – walking on spot, b – walking at an optimal speed.

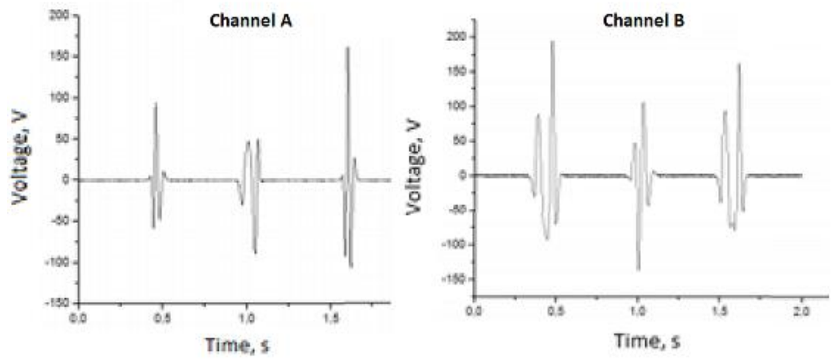


Fig. 8. Generated voltage pulses while walking at an optimal speed

As seen in the graphs, impulses on Channel B had larger amplitude, so they generated more energy, but impulses on Channel A were more stable and constant and had more even results.

Having known the meanings of voltage during the movement the produced energy was calculated, and by dividing it into the time of motion – average power. The collected data is shown in Table II.

TABLE II

AVERAGE ENERGY GENERATED ON THE PROTOTYPE JACKET

Movement type	**Generated energy, mJ**			
	Channel A (2 coils)		**Channel B (3 coils)**	
	Average	Statistical scattering	Average	Statistical scattering
Thin lining				
In movement	21.73	8.31	21.10	4.27
Walking on spot	7.50	2.01	17.21	4.82
Thick lining				
In movement	5.21	2.34	6.32	2.50
Walking on spot	0.49	0.22	0.51	0.66
Without lining				
In movement	1.68	0.98	0.47	0.43
Walking on spot	4.74	1.68	4.28	1.14

As can be seen in the table, the highest amount of energy generated is reached when a thin lining is used. There was no large difference between cases where two or three coils were connected in series. The main issue was that electrical generator placement was changed after the thin lining was inserted. When the lining was changed or removed, the trajectory of permanent magnet was changed and it significantly affected the amount of generated energy. The trajectory of the permanent magnet after the insertion of lining is compared in Fig. 9.

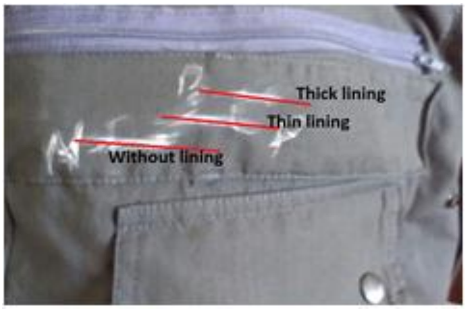


Fig. 9. The impact of textile layer thickness on the trajectory of the permanent magnet.

III. CONCLUSION

The integration of energy harvesting systems into clothing was complicated and was affected by many technical and individual factors, for example: the posture of the person, physical movement, average walking speed, amplitude of hand swing and the thickness of the textile layer.

Average generated energy using a thin lining was 42.83 mJ (21.73 mJ – two-coil generator, 21.10 mJ – three-coil generator). Average generated energy using a thick lining was 11.53 mJ (5.21 mJ – two-coil generator, 6.32 mJ three-coil generator). Average generated energy without lining was 2.15 mJ (1.68 mJ – two-coil generator, 0.47 mJ – three coil generator). The generated energy was enough to power LED diodes or to run simple integrated sensors.

To ensure more stable results, it could be reasonable to use a different form of a permanent magnet. Round type or wider magnet and ellipse form coils could decrease the distribution of generated energy. Every aspect needs to be checked.

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Laima Eglīte, Gaļina Terļecka, Juris Blūms. Enerģiju ģenerējošs virsģērbs
Rīgas Tehniskā universitāte ir izstrādājusi elektromagnētisko enerģijas pārveidotāju (EMP) ar plakanu struktūru, kurš pārveido cilvēka mehānisko kustību enerģiju elektroenerģijā. Elektromagnētiskais enerģijas pārveidotājs sastāv no plakaniem elementiem (spirālveidīga indukcijas elementiem un pastāvīga magnēta), kuri ir paslēpti apģērbā un kopumā nemaina apģērba lietošanas īpašības un ārējo izskatu. Konstrukcijas elementi ievietoti apģērbā tādā veidā, lai tie soļošanas laikā pārvietojas viens attiecībā pret otru kopā ar atbilstošajām apģērba daļām. Pētījuma ietvaros tika meklēti risinājumi valkājamo enerģijas pārveidotāju ievietošanai vīriešu virsjakā, pielāgojot enerģijas pārveidotāja un enerģijas uzkrāšanas sistēmu izvietojuma vietu. Tika izdarītas vairākas pārbaudes. Izpētīta daudzkārtu apģērba pakešu ietekme uz magnēta pārvietošanās trajektoriju un ģenerētās enerģijas daudzumu. EMP darbību ietekmē indivīda ķermeņa un kustības īpatnības, soļošanas ātrums, roku kustību amplitūda. Ņemot vērā lielās rezultātu atšķirības pie dažādām daudzkārtu apģērba paketēm, būtu ieteicams apsvērt domu par jaunu indukcijas elementu formu izveidi vai platāka magnēta izmantošanu, lai samazinātu rezultātu izkliedi.

Лайма Эглите, Галина Терлецка, Юрис Блумс. Верхняя одежда, генерирующая электричество
В настоящем научном исследовании рассмотрено создание встраиваемого в одежду преобразователя энергии движений человека в электрическую энергию, что позволит отказаться от использования внешних источников питания для встраиваемых электронных систем, сделав их независимыми. Рижский технический университет разработал электромагнитный генератор с плоской конструкцией, которая использует энергию механического движения человека для генерирования электричества. Электромагнитный преобразователь энергии состоит из плоских индукционных элементов и плоского постоянного магнита, которые могут быть полностью размещены в элементах одежды таким образом, чтобы они перемещались во время ходьбы один относительно другого и контактировали с соответствующими частями одежды, что не влияют на ее внешний вид и условия её эксплуатации. В рамках данного исследования электромагнитный преобразователь энергии был размещен в прототипе мужской куртки с различными по толщине съемными подкладками. Было проведено тестирование и оценено влияние различных по толщине пакетов одежды на технические характеристики электромагнитного преобразователя энергии движений. Опытным путем установлено, что эффективность работы генератора зависит от толщины пакета одежды.