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THE MANUFACTURING OF TEXTILE PRODUCTS WITH INCORPORATED ELECTRODES

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Abstract:

One of the main causes of disabling deficits is neurological affections. Many times, the evolution of the condition leads to a diminution of the patient's life quality. Functional electrical stimulation (FES) is part of the neurological rehabilitation process that comprises all the actions one can take in order to increase a patient's integration and autonomy degree from a social and financial point of view. FES is a method based on substituting the commands that are usually transmitted by the nervous system with an electric impulse. The use of such a method on different body areas required the development of some adequate devices, starting with the stimulator itself and finishing with the way in which the stimulus is conveyed to the effectors. Textile materials that incorporate sensors and, mainly, the clothing products that have such components in their structure, have a high applicability potential; they can be used for preventing illnesses and for the rehabilitation of seniors, of people who are confined to bed, sportsmen, people who suffer from long-term illnesses, disabled people, thus diminishing the time one spends in the hospital. A possible solution for manufacturing incorporated textile electrodes consists in the insertion of some electro-conductive yarns onto textile surfaces by using a variety of technologies. The project approaches the use of knitting, a widespread textile technology. The incorporated knitted electrodes were accomplished by applying the knitting technology on single circular small diameter machines. Thus, we were able to obtain a variety of knitted articles as two-dimensional or three-dimensional tubular knitted fabric. Their dimensions, structures, and parameters correspond to the typo-dimensions of the human body and to the purpose for which the clothing product was designed. The knitted versions were tested by using a Microstim2v2 (PW = 300 μs, 40 Hz) neurostimulator for which the current intensity was adjusted to approx. 30 mA.

Keywords:

Textile electrodes; electro-conductive textiles; functional electrical stimulation; rehabilitation; conductive knitted fabric; wearable electronics.

1. Introduction

The functional electrical stimulation (FES) is a rehabilitation technique aiming to restore complex limb movements like walking and hand grasping in disabled people due to a central nervous lesion [1,6]. Newly proposed hybrid FES-exoskeleton systems [11,12] may bring better rehabilitation results by inducing cortical reorganization and finesse in following hand exercises trajectories. In skin surface FES, electrodes placed over the nerve are connected by leads to a stimulator unit and may be triggered with a foot switch (e.g. correcting a drop foot in stroke patients). It uses disposable electrodes and sometimes requires the employment of electro-gel under the electrodes. It is important to provide an optimal and proper current density under the electrical stimulation electrodes in order to produce the required movement around a joint by the targeted muscle contraction [7-9]. Furthermore, they should provide optimal performance in inducing the required muscle contraction with the least pain and not cause skin burns or irritation. For neuromuscular stimulation, optimal performance is effective muscle activation at the desired location. The main disadvantages related to the conventional electrodes used up-to-date are: use of disposable electrodes; use of electro-gel that can cause skin irritation; need for every day/exercise session positioning of the electrodes; high price; safety is not always guaranteed; the conditions are not always optimal for a maximum effect. Some researchers are investigating the possibility to produce textile electro-conductive electrodes [3, 10, 13]. A textile composite electrode shown in [13] has been sewed on the textile product and its resistivity has been investigated. We aim to a real textile integration of the electrodes. Therefore, this paper deals with knitted electrodes within socks and tights, and their test against existing gel/silicon electrodes. The main envisaged advantage is seen in terms of: easiest positioning of the electrodes; functional textile customization to fit the patient; easy handling; fully reusable textile electrodes, fully integrated in durable, easy care functional textiles.

2. Specific elements regarding electrostimulation

European studies show that the population is confronted with more and more health problems caused by various disabilities, especially of locomotor nature. For example, musculoskeletal disorders can cause back pains. Such pains are often the result of stress and physical/psychical burdens. They are one of the most commonly spread health problems worldwide, entailing enormous social and economical costs. Contemporary accomplishments in microelectronics should allow the inclusion of monitoring/recovery sensors in our natural work environment and in everyday life, as well as in/on our bodies. Thus, functional and/or intelligent textile materials are key elements for increasing life quality. Fabrics that incorporate sensors and, above all, clothing products that contain such components can have an extremely important practical applicability and a high relevance when it comes to monitoring and preventing medical conditions, and rehabilitation in the case of seniors; also, they can prove to be useful for patients confined to bed, sportsmen, people suffering from long-term illnesses (diabetes, cardiovascular diseases, and so on), people with disabilities, by diminishing the hospitalization period. The FES is a method that includes various approaches of a range of disabling deficits. Generally, it is based on the substitution of commands usually generated by the nervous system as a consequence of an electric impulse. Depending on the body area where the electric impulse—which represents the stimulator itself—is applied and on the way in which the stimulus is conveyed to the effectors, adapted customized techniques have been developed. Thus, the stimulus can be released by means of embedded or surface electrodes.

Classical surface electrodes are atraumatic; however, they are placed at a considerable distance from the target area (compared to embedded electrodes). As a consequence, the stimulus is conveyed in a weak and inaccurate manner, requires higher magnitude currents, and its capacity of generating accurate movements is therefore diminished. The requirements that must be met by this particular type of electrodes in order to allow their long-lasting use within FES monitoring systems can be synthesized as following:

- low impedance;
- assuring a uniform distribution of electricity on product surface;
- easy to apply/detach on/from skin;
- flexibility in order to maintain an adequate contact with skin even on curved surfaces;
- applying such products must not lead to skin irritation if used for a longer amount of time.

Surface electrodes that are embedded in the apparel product have their advantages; they are easy to position and can be reused for long periods of time (increased endurance), if they meet the following necessary requirements:

- a correct contact with the stimulation areas;
- assuring the existence of a surface that would compensate for the lack of precision in positioning, which is inevitable when using systems integrated in apparel products;
- making sure that the positioning of electrodes is maintained while moving the stimulated limb;
- using a conductive gel so as to make sure that the electric signal is adequately conveyed from electrode to teguments.

Neurological pathology is a frequent cause of some disabilities, especially when it comes to locomotor deficiencies that constitute one of the most important beneficiaries of the technologies based on functional electrical stimulation. Walking disorders that can be ameliorated by applying this method frequently occur in pathologies that affect the central motor neuron. Cerebral pathology [the cerebrovascular accident (CVA) first and foremost, but also a range of traumas and tumors], medullary pathology (traumatic, contagious, autoimmune) lead to relatively specific and similar disorders associated with CVA, multiple sclerosis, traumatic medullary pathology, where the motor deficit (followed by spasticity) is essential. Depending on the distribution and the magnitude of the deficiency, FES can either completely substitute or only support to a certain extent the movement generated by the activation of the natural stimulating chain. Extrapyramidal disorders (Parkinson-type disorders) are not characterized by a locomotor deficit in the sense of the diminution of the contraction force, but by a decrease in swiftness and in the ability of initiating it. Therefore, FES can play the role of a rhythm generator that improves the overall quality of movement by providing an activation element. The electrodes embedded in clothing structures that are incorporated in stimulating equipments (neurostimulators, neuroprosthesis, electrostimulation devices) used nowadays have their limits (a lot of time is wasted when assembling and disassembling the electrodes, when searching for the best positions to apply them or when testing them by sitting down). Sometimes, the limiting factors mentioned above can hinder the wide-scale use of this particular method of rehabilitation by disabled people.

Here are some examples of such stimulation equipments belonging to this category:

- ❖ Devices of functional electrical stimulation for "*foot drop"* (Figure 1; examples: ODFSIII, ODFS PACE, ODFS PACE XL, WalkAide), that constitute an alternative to ankle orthoses. "*Foot drop"* occurs when the patient cannot lift the tip of their feet from the ground while walking, which leads to foot dragging (the so-called "mowing walk"). It is AFO. While the patient walks, the device sends a stimulus to the external popliteal sciatic nerve in order to induce the contraction of the anterior tibial muscle the moment when the foot is lifted from the ground. That particular moment is detected with the help of a switch placed under the heel (communicating with the neurostimulator by wireless technology (ODFS PACE XL) or through a wire (ODFS PACE).
- ❖ The Bioness L300 Plus system addresses problems related to *foot drop* or weakness of the femoral area (hip), Figure 2. Another neurostimulator that can be used when walking in order to stimulate the activation of two muscular groups (anterior tibial muscle and ischium-leg muscle), when the knee is flexed at the beginning of the leg flight phase that occurs while the foot is lifted from the ground, is O2CHSII (www.odstockmedical.com).
- ❖ The Bioness H200 system is a medical device that uses electric stimulation at a low level so as to activate various hand and forearm groups of muscles to allow hand gripping, like in Figure 3.

Figure 1. Functional electric stimulation device (14 - http://www.wcbl.com/productspotlight/electrical-stimulation-orthotics/; "http://www.odstockmedical.com" www.odstockmedical.com)

Figure 2. Correction of *drop foot* and insufficient knee flexing (activation of ischiumleg muscles) or of support problems that may occur when the foot is back on the ground (15 - activation of quadriceps muscles - www.wcbl.com/product-spotlight/electricalstimulation-orthotics/)

Figure 3. Bioness H200 system (16 - http://www.wcbl.com/product-spotlight/electricalstimulation-orthotics/)

The electrostimulation process requires the use of various types of electrodes that are placed on skin in the area where the tissue must be activated. Electrodes are used in pairs, generating a difference of electric potential between tissues, within a pair, thus achieving electrostimulation.

3. Functional textiles with embedded electrodes

Contemporary clothing that embeds electrostimulation electrodes has its limits, as mentioned above; this is the reason why there are many research activities that aim at creating a range of functional textiles with embedded electrodes with the purpose of stimulating muscles during therapy sessions. These electrodes must be elastic, fit the shape of the body area that must be stimulated (e.g., legs and hands), and not create discomfort or pressure. Textile materials used to manufacture electrostimulation electrodes must assure a proper electrical conductivity; an important parameter is the resistance of the textile surface. Such textile electrodes that fit the stimulated area lead to the diminution of electrode-skin contact resistance. The development of innovative textile materials that should incorporate electrostimulation electrodes so as to be used by patients during FES-based recovery sessions can be achieved by applying various textile technologies (knitting, sewing, embroidering). Such innovative products focus on obtaining a complex of advantages, such as:

- Innovative solutions of integrating electrodes within textile materials;
- Easy and accurate positioning on body areas that must be stimulated (deviations of 2–3 mm in surface electrostimulation are not crucial; they are compensated by controlling the neuroprosthesis);
- Textile electrodes will be reusable and will stay functional even after many washing–wearing cycles;
- Within the electrostimulation areas, the textile product will assure a controlled compression, which would eliminate the need of a skin–electrode interface gel;
- The obtained products that will form efficient equipments for FES-based daily treatments can be easily manipulated by patients and are also fit for ambulatory use;
- The possibility of acquiring additional functionalities, based on subsequent development of chips and perception and monitoring elements;
- Apparel products with embedded electrodes will be easy to use by patients (easy to put on/take off, an easy connection to the ES equipment);
- The use of accessible fabrication technologies that offer the possibility of customizing the clothing products with embedded electrodes;
- The ability of adapting the design of functional textile products that incorporate textile material - electrodes systems, in conformity with the targeted neuromotor disability;
- The use of common technical (neurostimulating) equipment for electrotherapy;
- The ability of customizing the textile products for each and every patient, depending on their anthropometrical dimensions and on the stimulation area(s) imposed by the neuromotor disability.

The knitting technique is one of the textile technologies that embed textile electrodes within the clothing structure in conformity with their required purpose. By applying the knitting technique in order to obtain embedded electrodes, one uses various types of electroconductive yarns that must meet specific requirements: good elastic behavior, good machinability and mechanical properties that fit the used technology, and the ability to maintain their piezostivity properties.

4. Functional textiles with knitted electrodes for rehabilitation of walking

The CVA caused by stroke, brain injury, or cerebral paralysis is one of the main causes of long-term motor disability worldwide and in more than 85% of these cases, functional deficits (e.g. drop foot, impaired upper limb control) in motor control occur [1, 11]. The electrodes are placed typically over the common peroneal nerve as it passes over the head of the fibula and the motor point of tibialis anterior. A foot switch controls the stimulation delivery in accordance with the walking speed. The heel rise on the affected side is detected and the stimulation starts producing required dorsiflexion and eversion of the foot, and it is stopped when the heel strikes the ground. Figure 4 shows the placement of a pair of surface gel-electrodes that elicit foot dorsiflexion and eversion during the test phase (stimulation on) with an ODFSIII neurostimulator. Figure 5 presents the abnormal walking (foot inversion during the swing phase) due to post-stroke impairment, and the corrected walking (Figure 6) by stimulating the peroneal nerve during the swing phase.

Improving the functionality and design of clothes aiming to address the disabled people by improving their quality of life is a desire of many of the actual researches. One idea is to produce knitted electrodes within socks and tights. It is easier for a patient experiencing the drop foot problem to perform the set-up of a FES system, which improves his/her walking. By applying the knitting technology, we accomplished a tubular jersey containing two knitted electrodes and an electroconductive yarn acquired from the market (Shieldex® 117/17 dtex 2-ply HC+B); the electrodes were placed as following: one textile electrode will cover the head of fibula bone and another is closed to the tibia bone, but placed over the tibial muscle. The obtained jersey can be found as an integrated part of socks or stockings. The obtained knitted products, including knitted electrodes, have a bi or tridimensional tubular form, correlated to the specific dimension of the envisaged body part. The whole knitted article has a single jersey structure (Figure 7), and in the area of the knitted electrodes, the electroconductive yarn is in plated relation with the ground yarn (Figure 8).

The knitted electrode was done on a small circular knitting machine, by SANGIACOMO, used for socks, tights, ortesis, and other knitted underwear articles and has performant electronic equipment, that assure: optimal conditions for knitting nude and covered elastic yarns, a precise and reproductible settings of technological parameters, and a wide range of posibilities for obtaining different patterns and technological operations.

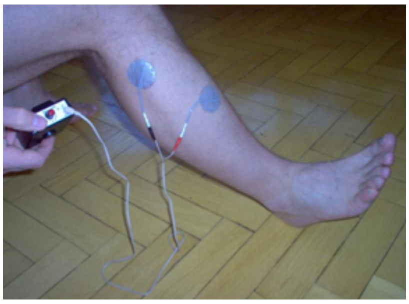

Figure 4. Induced dorsiflexion by means of surface gel-electrodes electrical stimulation over the peroneal nerve.

Figure 5. Impaired walking due to post-stroke sequelae

Figure 6. Improved walking by means of FES

Figure 7. Single jersey structure

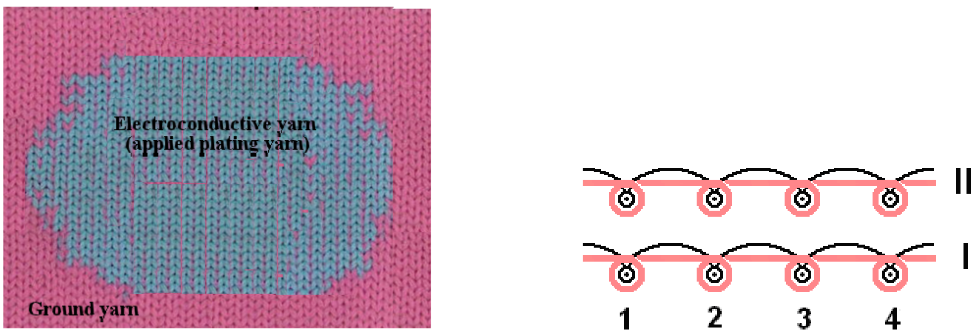

Figure 8. Plated jersey structure

The used conductive yarn has a resistivity of 115 Ω/m. These conductive yarns can be used to heat some textile fabrics, but in our case, it is of importance to only create an electrical charge distribution under the electrode instead of producing heat. The electrical stimulator produces constant current under 100 mA which, with proper electrodes, is enough to elicit the required muscle contraction and therefore a functional movement around a joint. The first step was to test the conductive yarn for different applied currents and to measure the produced heat. The conductive yarn has been supplied with current from a programmable power supply DC source INSTEK PSP-405 (range: 0–40 V and 4 A) and the temperature has been measured with an infrared thermographic camera Fluke Ti125. The infrared thermographic camera was placed approximately 50 cm away from the heated samples and the examinations were carried out at 20 ± 2°C. Figure 9 shows the thermographic image while supplying the conductive yarn (placed on a dummy lower limb) with about 170 mA. Figure 10 shows that for currents less than 100 mA, the temperature at the yarn surface will be lower than 30°C. The knitted electrode would not produce heat and it will only distribute electric charge over the skin.

Finally, we performed the test with the knitted electrodes (Figures 11 and 12). Only few grams of conductive gel have been used for the first test to ensure a better contact skin electrode. A Microstim MS2v2 exercise stimulator (40 Hz, 350 μs) has been used. At about 50 mA current, the required dorsiflexion has been produced similarly with the existing gel disposable electrodes.

5. Conclusions

A FES system that helps stroke people to walk better and therefore improve their quality of life or helping them in rehabilitation requires reliable electrodes for stimulation. Actual used electrodes are disposable ones, with conductive gel, which has to be replaced quite often. We proved that knitted electrodes might be a viable solution with benefits in terms of ease of positioning and reliability. Further performances are still being tested.

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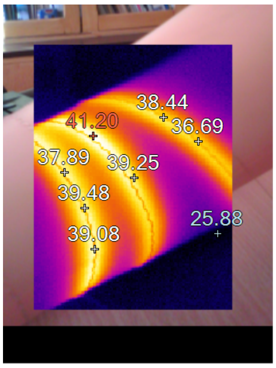

Figure 9. Thermographic image of the conductive yarn (170 mA)

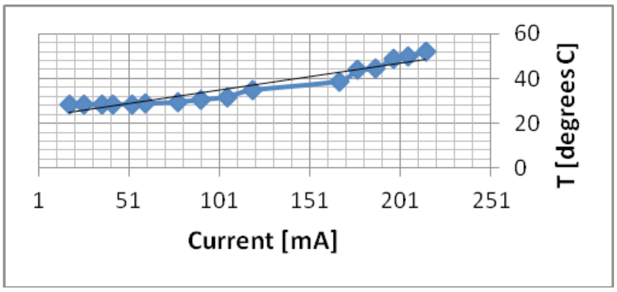

Figure 10. The diagram current–temperature for the conductive yarn

Figure 11. Functional textile with knitted electrodes

Figure 12. Tests performed with the knitted electrodes

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