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New Tendencies of Wearable Electronics Application in Smart Clothing

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Introduction

Currently an expanded interest in the structural and functional capabilities of textiles especially in the field of technical textiles can be observed. Thus a lot of measurement devices that can measure physiological parameters (vital signs) of the body are developed [1,2]. Measurements of body movements with on-body sensors is gaining more and more importance. The sensors can provide on-line monitoring data, when a warning alarm is detected.

It is possible to construct knitted fabric sensors that increase or decrease resistance when stretched [3]. The ‘Sensor Jacket’ can be the example of the use of such sensor. It contains 11 stretch sensors placed on the surface of the garment. Each time the jacket is worn, it has to be calibrated by the wearer because the users movements under clothing and body shape influence the sensor readings [4].

The same sensor is used in the ‘Sensor Sleeve’. It detects strain by measuring resistance change in a strip of stretched fabric by interweaving carbon fibres with elastomeric yarn using a knitting process [5]. Current fabric sensors that reduce resistance when stretched show an initial rise in resistance due to current path increase. This effect needs to be eliminated for above mentioned types of sensors in the applications such as sensor jacket. The sensors that have been created to increase resistance under stretch, start to show a reduction in resistance when stretched beyond 160%, work will be undertaken to increase this usable period and the linearity of the resistance change during it.

The Respibelt, developed by M. Catrysse et al., is intended for the monitoring of electrocardiogram and respiration rate of children in a hospital environment. The Respibelt is made of a stainless steel yarn knitted in a Lycra containing belt providing an adjustable stretch. However, it is applied with pre-strain of 50% to avoid the strong non-linearities at low strain levels [6].

C. Mattmann presented new method to define the elongation distribution of a garment where the skeleton movement is measured with markers placed on the skin or the garment [7].

The other research shows electro-mechanical properties of stainless steel knitted fabric made from multi-filament yarn under uniaxial extension. It was defined that the contacting resistance in knitted fabric was much larger than the filament resistance itself. The sensitivity of the knitted fabric sensor mainly depends on the contacting resistance and the structure of the fabric. Based on the experimental results, it was found that the contacting resistance at the overlapped points decreased with loading [8].

This paper presents experimental development of textile stretch sensor. The aim of this research was to develop optimal structure of textile sensor for continuous recording of deformation changes.

Sample preparation and test methods

To reach the goal two tasks were set: 1) to find an optimal structure of textile sensor which would be able to measure low value strains like 5-20%; 2) such structure has to be characterized by low residual deformation. Four samples of textile stretch sensor were developed (Fig.1).

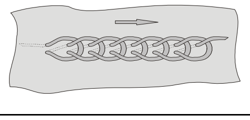
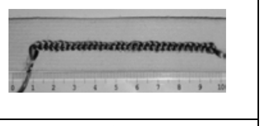
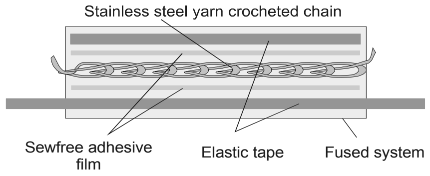
<table>
<tr><td>I sample</td><td>II sample</td></tr>
<tr><td></td><td></td></tr>
<tr><td>III sample (pressure of 2.0 atm.)</td><td>IV sample (pressure of 2.5 atm.)</td></tr>
<tr><td colspan="2">
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Fig. 1. The schemes of developed samples of textile sensors

Table 1. The characteristics of *Bekintex* stainless steel threads

Code	Type	Diameter of fibre (µm)	Tex (g/1000m) +10%	Breaking load (N) minimum	Breaking load (N) average	Torsion per meter	Ohm/m
B1	VN 12/1x275/100Z	12	235	20	37	80-120	30±6.70%
B2	VN 12/4x275/100S	12	1010	80	163	90-110	7±14.30%

The first attempt to make sample of textile sensor was done by using stainless steel yarn embroidered by chain stitch on interlock fabric. The basis of others samples was elastic tape of 3 cm width. II sample was done using stainless steel yarn embroidered by chain stitch on elastic tape. The structure of III and IV samples was the system made of stainless steel yarn crocheted chain, two layers of adhesive film and two layers of elastic tape, fusing the whole system at the pressure of 2.0 atmospheres for III and 2.5 atmospheres for IV sample.

The samples of textile stretch sensors were developed using *Bekintex* stainless steel threads (Table 1).

Meantime to obtain good fused structure, proper adhesive must be selected. For that purpose *Sewfree* adhesive of *Bemis* company was chosen which is a soft, highly elastic, polyurethane adhesive film designed for apparel applications where stretch and recovery are required (softening point 120°C, service temperature from -40°C up to 90°C). This film is also very suitable to use in clothing applications because of excellent wash and good dry clean properties.

The principle of dynamic data recording was done on the basis of sensors electrical resistance changes versus its extension. Based on this principle textile stretch sensor was made of two layers of elastic tape and one stainless steel yarn crocheted chain between them. This whole system is fused using two layers of adhesive film from both sides of crocheted chain. Load is applied to the basic layer of elastic tape. And during tension contact resistance of crocheted chain is measured (Fig.2).

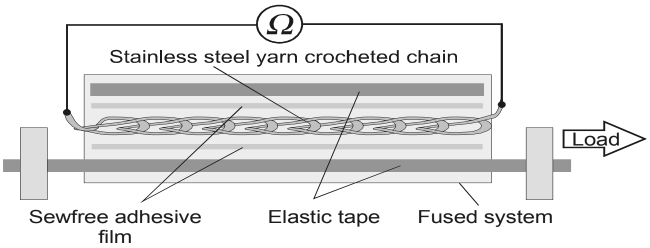

Fig. 2. The scheme of developed textile sensor

The resistance values were obtained on testing base of manual extension. Samples were fixed in two clamps. The resistance was measured at each step of 2 mm. UT33B digital multimeter was used for resistance measurements. The residual deformation values were obtained with *Zwick* standard tensile testing machine. 20 loading-unloading circles were made for each type of samples and they were stretched up to 20%.

Results and discussion

The test results of I sample were not satisfactory (Fig. 3) because of big residual deformation. It can be explained by the high value (up to 7%) of residual deformation of basic interlock fabric (Fig. 4). Seven extension tests were made and the sample was stretched up to 20%.

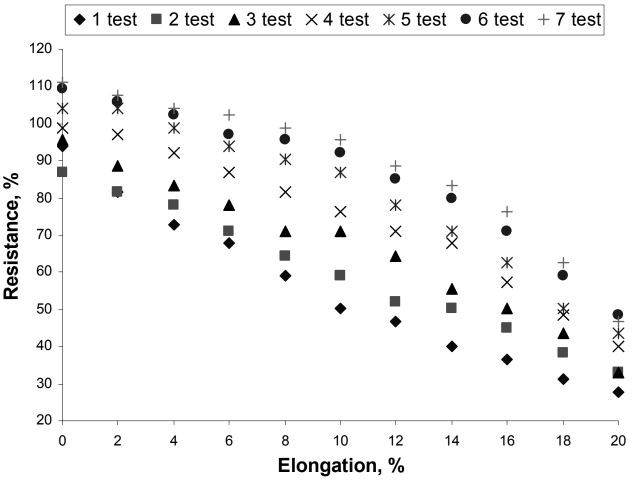

Fig. 3. Resistance changes versus its extension of I sample

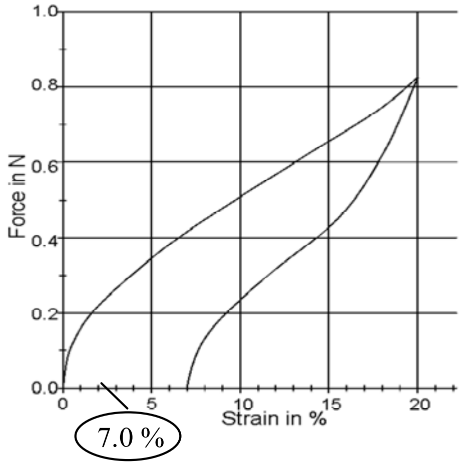

Fig. 4. The hysteresis of interlock fabric (residual deformation 7%)

The results of II sample also were not satisfactory (Fig. 5), but they proved that strong non-linearity was observed up to 50% of elongation.

The results of III sample obtained by fusing the whole system at the pressure of 2.0 atmospheres can be described by liner dependency, but still residual deformation comparing the first extension test with the 15-th is very high (Fig. 6). The relationship between resistance changes R and elongation ε of III sample can be described by the following function:

$$R = a\varepsilon^3 - b\varepsilon^2 + c\varepsilon + d \qquad (1)$$

with sufficient accuracy (coefficient of determination for all tests varies in the range of $r^2 = 0.99$-0.97).

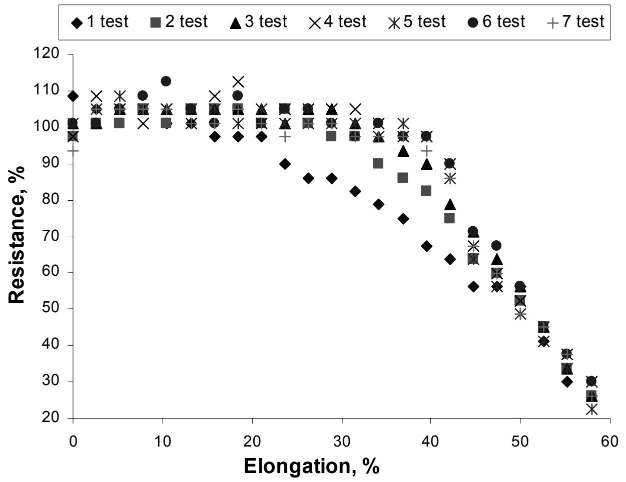

Fig. 5. Resistance changes versus its extension of II sample

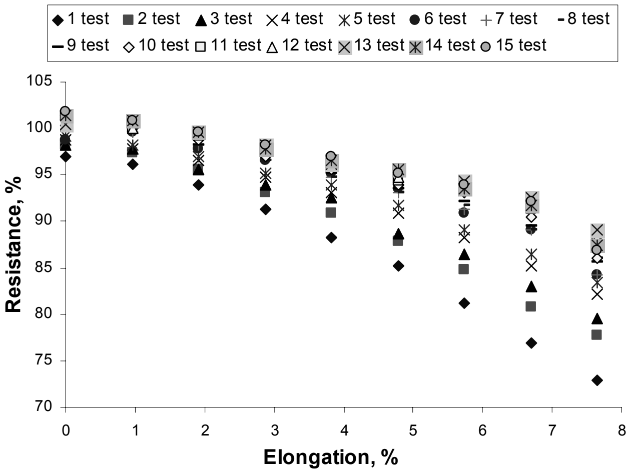

Fig. 6. Resistance changes of the III sample versus its extension (pressure of 2.0 atmospheres)

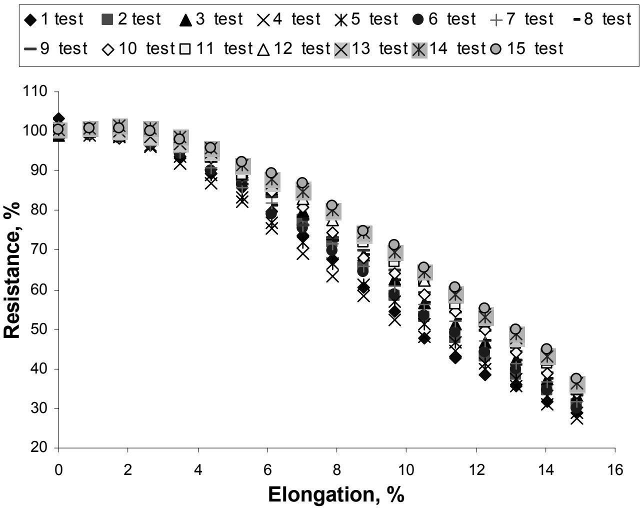

Fig. 7. Resistance changes of the IV sample versus its extension (pressure of 2.5 atmospheres)

Meantime the same sample structure fused at the pressure of 2.5 atmospheres showed much better results (Fig. 7).

The scatter of the resistance values compared to that of the previous sensor decreases by 12-15%. The relationship between resistance changes and elongation of IV sample can be described by the same function (1) with even higher accuracy (coefficient of determination for all tests is $r^2=0.99$).

The scatter of the resistance values is predicated on the residual deformation of the sample structure. So the other part of this research was to investigate the IV sample in regard to derivative components of developed sensor and to traverse the influence of circle testing.

Hysteresis plotted with standard tensile testing machine showed (Table 2) how residual deformation depends on pressure parameters and the structure of sample: type A - one layer of original elastic tape; type B - one layer of pressed elastic tape; type C - two fused layers (both fixed in the clamps); type D - two fused layers (one fixed in the clamps); type E - the fused system with the chain (one layer fixed in the clamps).

Table 2. Residual deformation average values of loading-unloading circle tests

Code / Circle nr.	Type A	Type B	Type C	Type D	Type E
	Residual deformation, %				
(1)	1.92	2.83	1.58	1.66	1.87
2	0.23	0.39	0.33	0.18	0.20
3	0.20	0.28	0.30	0.16	0.20
4	0.14	0.22	0.27	0.15	0.18
5	0.15	0.22	0.24	0.14	0.18
6	0.15	0.22	0.24	0.17	0.16
7	0.16	0.24	0.21	0.08	0.17
8	0.15	0.23	0.22	0.14	0.15
9	0.15	0.21	0.21	0.14	0.15
10	0.14	0.24	0.21	0.15	0.17
11	0.10	0.23	0.20	0.15	0.15
12	0.13	0.30	0.20	0.13	0.16
13	0.13	0.21	0.22	0.16	0.17
14	0.12	0.19	0.19	0.15	0.16
15	0.12	0.17	0.20	0.14	0.16
16	0.13	0.19	0.22	0.15	0.16
17	0.11	0.19	0.20	0.17	0.15
18	0.13	0.19	0.20	0.14	0.18
19	0.12	0.18	0.21	0.17	0.17
20	0.14	0.21	0.22	0.13	0.16
Average (5-20 circles)	0.13	0.22	0.21	0.14	0.16

The results showed the increase of 69% of residual deformation pertinent to pressing. The residual deformation of two fused layers of elastic tape both fixed in the clamps was also high (up to 0.3%). It was decreased in two, when one layer of fused system was fixed in the clamps. In average it was only 0.14%. And stainless steel yarn crocheted chain increased the residual deformation till 0.16%. That can be explained by the residual deformation of the chain.

Circle testing results of residual deformation for all types of investigated systems show that the system need to be cyclic stretched for five circles to get balance.

Conclusions

It was established that the system made of stainless steel yarn crocheted chain, two layers of adhesive film and two layers of elastic tape is characterized as an optimal structure. On the basis of this system dynamic anthropometric data in the range of 4% - 16% elongation can be calculated.

The results of this experiment show that residual deformation of analyzed system can be affected by fusing pressure parameters. Investigations have shown that the increase of ½ atmosphere of fusing pressure decreases the scatter of resistance values by 12-15%. However the remaining scatter of residual deformation forces to search for the new structure of sensors that would enable wider scale of dynamic measurements collection. Circle testing results show that only after five circles the system can be balanced.

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The aim of this research was to develop optimal structure of textile sensor for continuous recording of deformation changes. The principle of measurements is based on the sensor's electrical resistance changes versus its extension. Four samples of textile stretch sensors were developed. It was established that the system made of stainless steel yarn crocheted chain, two layers of adhesive film and two layers of elastic tape is characterized as an optimal structure. On the basis of this system dynamic anthropometric data in the range of 4 % – 16 % elongation can be obtained with sufficient accuracy. The same method can also be used to measure human respiration rate. Ill 7, bibl. 8 (in English; Summaries in English, Russian and Lithuanian).

Е. Страздене, П. Блажевич, А. Вегис, К. Дапкунене. Новые тенденции применения носимых элементов электроники в интеллектуальной одежде // Электроника и электротехника. – Каунас: Технология, 2007. – № 1(73). – С. 21–24.

Цель исследования – создать датчик для непрерывной регистрации деформационных изменений. Принцип измерения основан на изменении электрического сопротивления датчика при его удлинении. Исследовались четыре прототипа текстильного датчика деформации. Определено, что система, состоящая из шва цепного стежка нити нержавеющей стали, двух слоёв липкой плёнки и двух слоёв эластичной тесьмы, является оптимальной. Используя такую систему можно с достаточной точностью фиксировать динамические антропологические измерения при удлинении от 4 % до 16 %. Этот метод можно также использовать для измерения частоты дыхания. Ил. 7, библ. 8 (на английском языке, рефераты на английском, русском и литовском яз.).

E. Strazdienė, P. Blaževič, A. Vegys, K. Dapkūnienė. Naujos elektronikos elementų taikymo intelektualiojoje aprangoje tendencijos // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 1(73). – P. 21–24.

Tyrimo tikslas – sukurti tekstilinį jutiklį deformaciniams pokyčiams nepertraukiamai registruoti. Matavimų principas pagrįstas jutiklio elektrinės varžos pokyčiu dėl jo pailgėjimo. Nagrinėti keturi tekstilinių deformacijų jutiklių prototipai. Nustatyta, kad sistema, sudaryta iš nerūdijančiojo plieno siūlo grandininio dygsnio siūlės, dviejų sluoksnių lipnios plėvelės ir dviejų sluoksnių tamprios juostos, laikytina optimalia. Naudojant šią sistemą galima pakankamai tiksliai fiksuoti dinaminius antropometrinius matmenis, esant pailgėjimui nuo 4 % iki 16 %. Šis metodas gali būti panaudotas ir žmogaus kvėpavimo dažniui matuoti. Il. 7, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).