Printed Load Cells on Clothing Made of Fire-Protective Fabric

A V Lozitskaya¹, A P Kondratov³, V A Baranov³ and E P Cherkasov³

¹Moscow Polytechnic University, Moscow, Russia
E-mail: a.p.kondratov@mospolytech.ru

Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

The paper represents the trial results of nonwoven fabric stencil-screen printed gauge indicators that can be made on other two types of fabric. They can be applied either for specific producing of pilot and test pilots' uniform or for airport emergency and fire officers clothing. The research being carried out, volt-ampere characteristics of conductive belt layer and electrical resistance scale effected by distortion were identified. It was also revealed that aramid fiber fabric sensors were to be applicable for creep stress measurement at temperatures of 20–200°C.

Keywords: printed electronics, polymer strain gauge sensor, elongation, printed sensors for flexible elements, fire-protective printed gauge, temperature gauge

1. Introduction

It should be noted that flex strain and temperature gauge indicators are the essential members of cutting-edge multifunctional uniform of test pilots, pilots, airport emergency service and fire officers. Besides this, flex strain and temperature gauges are widely used in aviation robotic equipment and luggage handling units. Therefore [1], artificial intelligence and robotics industrial sector have a high priority as the areas for these kinds of indicators. The supreme task of the devices and the clothing with special gauges is a real time monitoring of human movements, strains, stresses and the temperatures of the fabric [1–4]. The strain gauges are to be extremely flexible, tensile and adaptable to the fabric used [2]. One must emphasize that strain-tension gages seem to be one of the most significant ones among all available devices on the market due to their cost-effective and functional properties [1]. They are not widely used as sensor substrates of nonwoven fabrics [5–7]. It is essential that strain properties related to the structure and fiber mixture [5, 6, 8] and bonding were scrutinized without electrical properties of conductive belt. In addition, wearable electronics was not taken into account as well.

The experts [9] believe that the gages’ performance (the variation of electrical resistance under strain condition) is specific on nonwoven fabrics, nonconvertible damage on the first cycle of strain including marginal and major forces can occur. The changes of pseudo-unbroken layers of carbon nanotubes are demonstrated on the example of applying filtering through nonwoven fabric consisted of nanotubes, cyclic stretching following as well. The net structure of the fabric keeps the operating conditions of the gages under relatively intensive and considerable elongations.

To sum up, this paper deals with a simple and economically-effective approach to make printed gauge indicators with the distortion versatility by means of screen printing for two types of fabric at special clothing production.

2. Subjects and methods

Nonwoven sheets and two types of fabrics are chosen as a gauge indicator substrate. They are:
- Polypropylene fiber sheets which are called spanbond (density 60g/sm)
Needled fabric made of polypropylene fibers

Cotton fiber non-combustible fabric for clothing inner layer branded Frol 280a (Fig.1). It contains non-combustible infiltration agent of quintavalent polycondensate comprising phosphonium and nitrogen-containing compounds branded AFLAMMIT ®SAP. Flame resistant fabric for clothing outer layer made of aramid fiber mixture branded FlamFort W280 (Fig.2).

Figure 1. Cotton fiber structure implied for fire-proof clothing inner layer: 1 — cellulose fibers; 2 — antipyrene particles.

Figure 2. The wrath in scene of fire-proof polyaramid fabric implied for outer clothing layer: 1 — polymethaaramid fibers; 2 — polyparaaramid fibers.

Fabric and nonwoven gauge indicators shaped as 10mm stripes were produced by printing plate stencil with net ruling 120 lpi. Electrically conducting stencil films Sun Chemical containing graphite dispersion and amorphous carbon were applied for gauge indicators’ samples.

The samples were laboratory prepared at the temperature of 22±2°C being under conditioning and relative humidity of 45–50% [11].

The electrical resistance circuit with gauges’ stress and strains in 50–100 Hz dc-and-alternating current network is attached to the article.

The stress-and-strains characteristics were identified in accordance with State All-Union Standard 15902.3-79. The gage resistance to increased air temperatures by means of sample exposure in temperature-cabinet for 20 minutes under RH 90–95% with consequent resistance following the methodology was noted [11].

3. Results and discussion

The initial and processed by printing gauge indicators on fabric samples were put to the mechanical tests on stress and strains. On examining the sheets, a strong effect in stress and distortion of electrically-conductive film was not detected.

The fabric distortion up to relative elongation 30–40% longwise and against the grain occurs. It takes place under mitigating stress caused by fibers weaving. (Fig. 2).

Electric and mechanical properties of flex gauge indicators are determined by homogeneity and layer printing composition on offsets. The surface texture is repeated. The samples of gauge indicators were manufactured on nonwoven polypropylene sheet, they were produced for comparison and determining the effect of surface texture on electric conductivity of the flex gauge indicators. The samples are varied greatly by microstructure and surface homogeneity.

On Figure 4 volt-ampere characteristics of printed resistors are shown, the alternating current frequency is 100 kHz on the different density nonwoven fabrics substrates. It could be seen that electric resistance of the print on the thin and uneven thermal bonded sheet Spanbond exceeds twice the resistance of the same size needled nonwoven material. (2)

Volt-ampere characteristics of all samples with woven substrates are determined by linear characteristics, which makes them possible to be used as stable elements of electronic circuits formed by polygraph and combined methods. The printing on one type bonding sheets was implemented to obtain fire-p roof gauge resistors, the ones having similar structure and homogeneity.

| Direction of strength tests | Longwise | Across |
|-----------------------------|----------|--------|
| Parameters                  | No composition | With composition | No composition | With composition |
| Relative elongation, %      | 57       | 60     | 44       | 45       |
| Strength limit, MPa         | 21,8     | 22     | 13,7     | 14      |
3

Figure 3. Technical diagram of aramid fabric strain, applied for outer clothing layer. 1 — longwise 2 — against the grain.

Figure 4. Relation of electric voltage to electric power on printed resistors, produced on non-woven sheets with the density of 1 — 60g / cm² and 2 to 60g / cm².

Figure 5. Relation of electrical resistance of printed on fire proof cotton fiber resistor to strain distortion (ε).

$$\Omega = 2E - 15e^2 + 0.48e + 48 \quad (R^2 = 1)$$

Table 2. Electrical resistance of gauge indicator prints to D.C (direct current)

| The direction of the trial | Longwise | Against the grain |
|---------------------------|----------|-------------------|
| Temperature, °C           | 20       | 50                |
| Electrical resistance, Ω  | 550      | 600               |

4. Conclusion

Overall, the possibility to obtain the tension and distortion gages by means of screen printing on nonwoven fabric and other two types of fabrics are shown in this article. This technology can be used for producing the uniform for test pilots and pilots as well as for emergency service and fire officers. In addition, the stability of electrical characteristics in the range of 20–200 °C was established. Besides that, the benefit of this type of printed sensors is the prospect to place them at any part of clothing as well as the variation of the voltage form and the voltage limits measured in composition with industrial production.

References

[1] Nag A, Menzies B and Mukhopadhyay S C 2018 Sensors and Actuators A 276 226–36
[2] Cao J, Qin L, Liu J, Ren Q, Foo C, Wang H, Lee HP and Zhu J 2018 Ext. Mechanics Lett. 21 9–16
[3] White E L, Case J C and Kramer R K 2017 Sensors and Actuators A 253 188–97
[4] Nehir S O, Keskin A, KheaD and Onal C D 2015 Sensors and Actuators A 236 349–56
[5] Advances in Technical Nonwovens ed. George Kellie 2016 (Woodhead Publishing)
[6] Omrani F et al. 2016 Composites Part B 116471–48
[7] Dal Pra I et al 2005 Biomaterials 26 1987–99
[8] Savel’ev M A, Komarova L Y and Kondratov A P 2016 Izv. Vys. Uchebn. Zaved. Problem poligrafii i izdat. dela 2 44–54
[9] Zaravleva G N, Komarova L Y and Kondratov A P 2015 Izv. Vys. Uchebn. Zaved. Problem Poligrafii i izdat. dela 1 20–6
[10] Syrbu S A, Salikhova A H and Fedorinov A S 2014 Technosphere safety Technologies 5 http://ipb.mos.ru/ttb/2014-5/2014-5.html
[11] Kondratov A P, Nagornova I V and Varepo L G 2019 Journal of Physics: Conference Series 120 012067
[12] Syrbu S A, Salikhova A H and Fedorinov A S Pat. 128235 RF on application no. 2014128235 of 09.07.2014 D06B1/00 flame Retardant for special purpose fabrics of moleskin type based on Aflamite-SAP and silicon dioxide