

# Investigation of the electrical characteristics of electrically conducting yarns and fabrics

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**Abstract.** Electro-conductive textile materials and products are used presently giving solutions to the problems, related to static electricity, electromagnetic shielding and electromagnetic radiation. Thus a study of their electro-physical characteristics, character of conductivity, possibility of forecasting of electric parameters etc has a substantial value. This work shows the possibility of production electro-conducting textile materials with stable anti-static properties by introduction of electro-conducting yarn into the structure of fabrics. The results of the research, directed to the study of the electro-physical characteristics of electro-conducting yarn and fabrics, are influenced by the frequent washing of polyester fabrics containing the different amounts of electro-conducting filaments in the composition. This article reviews the results of the related research, of the electrical characteristics of the yarn and fabric, of the effect of multiple water treatments on the electrical properties of polyester fabrics, containing in their composition different amounts of electrically conductive yarns.

## 1. Introduction

It is known that synthetic fibers and materials accumulate the static electricity in the course of their processing and further operation, in other words, they are electrified greatly. The static-charge accumulation is one of essential disadvantages of synthetic fibers. It complicates significantly their processing and at operation of such materials the spark, which occurs at the electrostatic discharge, can lead to fires, explosions and other undesirable phenomena in the appropriate environments. Moreover, the static electricity has an adverse effect on health of the human beings [1]. For that matter, a lot of studies on the static electricity neutralization and provision of the stable antistatic properties of the materials have been performed and published.

The hydrophobic property and relatively high electric resistance of the synthetic materials causes the static-charge accumulation. For this reason, the most of the methods designed to reduce the static characteristic assume electric resistance reduction of the materials in one way or another.

## 2. Target setting and tasks

The electrically conductive fiber Nitron (ECFN) with the following characteristics was used to manufacture the conductive yarns.

Its linear density was 0.53-0.54 tex; unit tenacity - 17-18 cN/tex; breaking elongation - 30-31%; specific electrical resistance -  $2 \cdot 10^{-5} \text{ Ohm} \cdot \text{m}$ ; metal content on fiber - 16.8% [3].

The medium-fibrous cotton fiber with the following indicators was used as the second yarn component: linear density was 0.16-0.17 tex; unit tenacity - 25-29 cN/tex; breaking elongation - 4-5%.



The mixtures with the certain compositions were prepared from the above fibers and then processed in the yarn with the required parameters.

The electrical resistance of the yarn samples was measured at direct current in accordance with the procedure described in [4] as well as in the ultrahigh frequency range at wavelength  $\lambda = 0.03$  m (at frequency of 10 GHz) based on the method developed by the Central Scientific-Research Institute of Radio Engineering (Moscow) by means of measurement of the radio wave transmission coefficient. The physical and mechanical properties of yarns were determined in accordance with GOST 1119-80. The electric resistance variation coefficient was calculated on the basis of the results of 100 measurements. The results of electrical resistance measurement of mixed yarns with various compositions are given in Table 1.

**Table 1.** Electrophysical characteristics of yarn depending on its composition

Ratio of components in yarn, ECFN/cotton, %	Electrical resistance per unit length, $R_p$		Variation coefficient of $R_p$ at direct current, $K_v$ , %
	at direct current $I_g R_p$ ( $R_p$ , kOhm/m)	at $\lambda = 3$ cm ( $R_p$ , kOhm/m)	
10/90	2.2	120	30.4
20/80	1.6	48	26.5
30/70	1.3	41	20.2
40/60	1.2	35	18.2
50/80	1.2	35	15.3
60/40	1.3	33	14.5
80/20	1.2	35	13.0

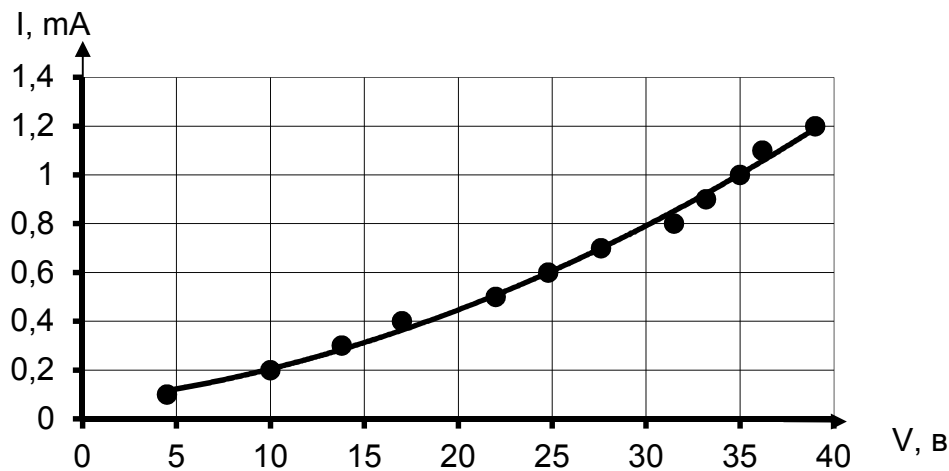
Data presented in Table 1 indicate that addition of such conductive fiber as ECFN in the yarn causes significant reduction of its electrical resistance, especially, at ECFN content of 20-25%.

More monotonic decrease of electric resistance is observed at further increase of ECFN portion. When ECFN content in the yarn exceeds 35-40%, the electrical resistance ceases practically to change. Such behavior of the electric resistance change in the yarn is associated obviously with implementation of various electrically conductive structures in it.

In case of small ECFN additives in the yarn the conditions for direct contact between the conductive fibers have not been achieved. There are high-resistance gaps along the yarn. In general, we obtain a high-resistance, hardly reproducible electrically conductive structure with highly non-uniform electrical properties, which is confirmed by significant values of the electrical resistance variation coefficients ( $K_v$ ) in this area. It is possible to explain the conduction mechanism in this system on the basis of the current flow theory [4], according to which the electric current can flow in the system by means of electrons passage through the potential energy wells, which are dielectric gaps existing between the conductive particles. Passage of electrons can be of activation behavior or carried out with the use of the tunnel effect. When ECFN content in the mixture exceeds 30%, the volume is filled up gradually with the conductive fibers and direct contacts between them are implemented. Under these conditions the reach-through ohmic conductivity exists on the fairly long sections of the yarn and we obtain a more uniform conductive structure with relatively low values of  $K_v$ .

### 3. Experimental researches

To define the electrical conductivity behavior of the yarn its current-voltage characteristic has been studied. The obtained results are shown in Figure 1.



**Figure 1.** Current-voltage characteristic of the conductive yarn

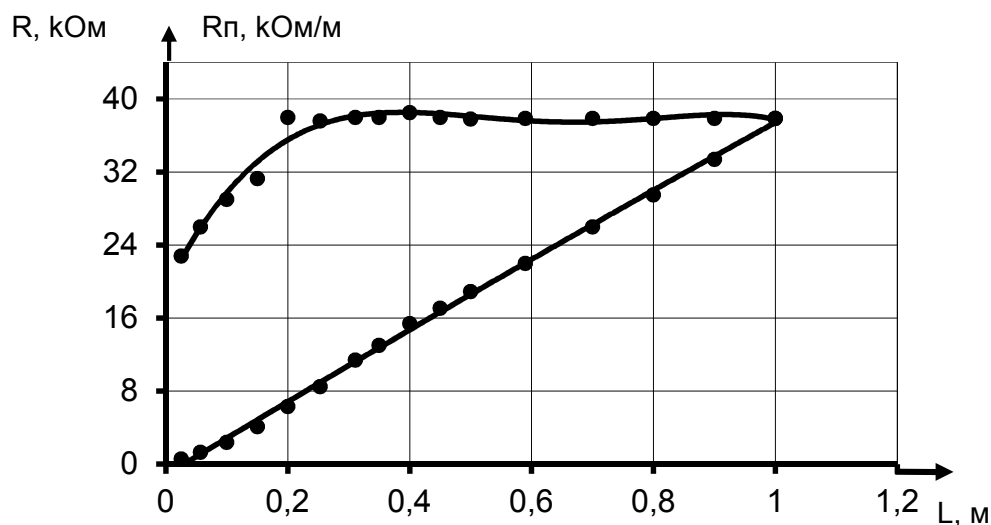
### 3.1. Analysis of the current-voltage characteristic

It is seen from Figure 1 that the current value increases non-linearly with the voltage increase. This current-voltage characteristic is observed usually in the semiconductors. It is known that, when electrical current flows through the direct contact between the conductive particles (so-called ohmic conductivity), the direct proportionality is observed between the current and voltage. However, our findings have confirmed the activation behavior of the yarn conductivity, when passage of electric current through the sample is provided with the use of the thermal electron emission or tunneling effect.

It should be noted that the distance equal to 0.1m has been provided between the electrodes when studying the current-voltage characteristic of the yarn. The study of lengths of the yarn sections, where the activation behavior of conductivity is implemented, has been of significant interest. In other words, it is determination of length of the yarn sections, which contain the potential wells caused by imperfect contacts between the electrically conductive fibers. For this purpose, dependence of the electrical resistance of the yarn ( $R$ ,  $R_n$ ) on its length has been studied. The obtained data are shown in Figure 2.

The obtained results indicate that the electrical resistance of the yarn changes not identically depending on its length. On the short sections of the yarn with length up to 0.2 m we obtain non-linear dependence of the electrical resistance ( $R$ ), but at increase of the distance over 0.2 m the direct proportionality between the resistance and yarn length is observed.

It is known that the electrical resistance of the yarn produced from the mixture of electrically conductive and ordinary fibers is determined by presence of high-resistance sections caused by imperfections in the electrically conductive structure. A number of researchers [5-6] suggest that in such systems the conductivity is realized mainly by means of emission of electrons through the gaps between the conductive particles or as a result of the tunneling effect. The electrical current can flow as well via the direct contact between the conductive fibers. For the ordinary metallic conductors the electrical resistance per unit length  $-R_n$  does not depend on the length of the section, where it is measured. It indicates the direct proportionality existing between the electrical resistance of the conductor and its length.



**Figure 2.** Dependence of the electrical resistance of the yarn ( $R$ ) on its length ( $L$ )

### 3.2. Analysis of the electrical resistance of the yarn

In this case at the yarn length up to 0.2 m rather dramatic increase in its resistance per unit length is observed. It is possible to explain by the fact that the yarn consists of low-resistance and high-resistance sections, which are caused by defects in the conductive structure. The electrical conductivity of the yarn is determined by resistance of such high-resistance sections.

These data are sufficient to come to a conclusion that the length of these high-resistance sections does not exceed 0.2 m. At increase of the yarn length over 0.2 m we have observed constancy of the electric resistance per unit length.

The obtained results can be used in the practice of application of the electrically conductive yarn for manufacturing of various materials with the specified electrophysical characteristics. If the sample sizes exceed 0.2 m, it is possible to predict electrical properties of the material by means of elementary calculations.

It should be noted that these conclusions apply only to the specific yarn having been studied because the realized conductive structure, dimensions of high-resistance sections, electrical resistance of these sections depend on several factors, main of which are as follows: method used to increase electrical conductivity of the fibers; electrical resistance of the conductive fiber; composition of mixture of the conductive fibers and ordinary ones; linear density of the yarn; yarn twist value, etc.

The electrically conductive yarns can be used to manufacture the electromagnetic emission screens and erectable antennas of the space vehicles, as well as the passive anti-radar elements. The fabrics containing the conductive fiber can be used successfully to manufacture special clothes protecting against the electromagnetic emission as well as high-intensity electric fields. Addition of the conductive fibers in small amounts to the ordinary fibers while manufacturing the various products makes possible to get the stable antistatic effect [7].

The hydrophobic property and relatively high electric resistance of the synthetic materials causes the static-charge accumulation. For this reason, the most of the methods designed to reduce the static characteristic assume electric resistance reduction of the materials in one way or another [8].

For example, the synthetic fibers during their forming or processing are treated with the special hydrophilic antistatic products called as “finishing agents” in the production practice. However, disadvantage of this method is that the obtained antistatic effect disappears after the first wash.

Addition of the special conductive fibers and threads in the yarn, fabrics, knitted or nonwoven fabrics is more effective. The practice has shown that addition of 1 - 5% of the conductive fibers or threads results to the stable antistatic effect remaining after 100 washes and more, which is sufficient under the operation conditions.

The results of researches aimed to study influence of multiple water treatments on the electrophysical properties of the polyester fabrics, which contain various amounts of the electrically conductive threads in their composition, have been considered herein.

The samples of the polyester fabrics with plain weave were prepared. The polyester threads with linear density of 7.5x2 and 9x3 tex were used, respectively, as the warp and weft. The warpwise density of the fabric was 600±3 ends/dm, and the filling wise density was 160 ends/dm.

The yarn with the following properties was used as the conductive component of the fabrics:

- Composition - 60% of cotton, 40% of electrically conductive fiber (ECFN);
- Linear density - 50 tex;
- Specific tensile strength – 9 g/tex;
- Breaking elongation - 14%;
- Electrical resistance per unit length - 18-20 kOhm/m.

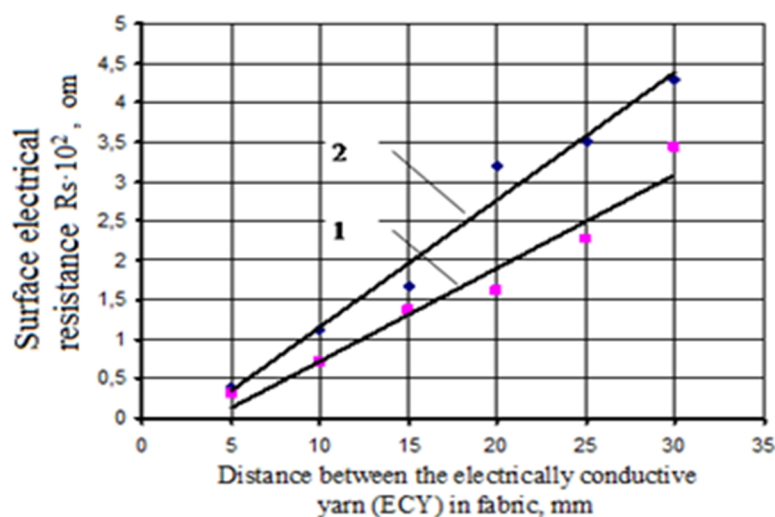
The specific surface resistivity and electrostatic potential of the samples were studied. The specific surface resistivity was measured by means of the 4-electrode potentiometric method; the electrostatic potential value was evaluated on the “Rotary Static Tester” of RS-101D model according to the “B Method” of JIS L-1094 “Testing method for electrostatic propensity of woven and knitted fabrics”.

The samples were washed under the following conditions:

- 5% soap solution,  $t = 400^{\circ}\text{C}$ , time = 30 min., module 50.

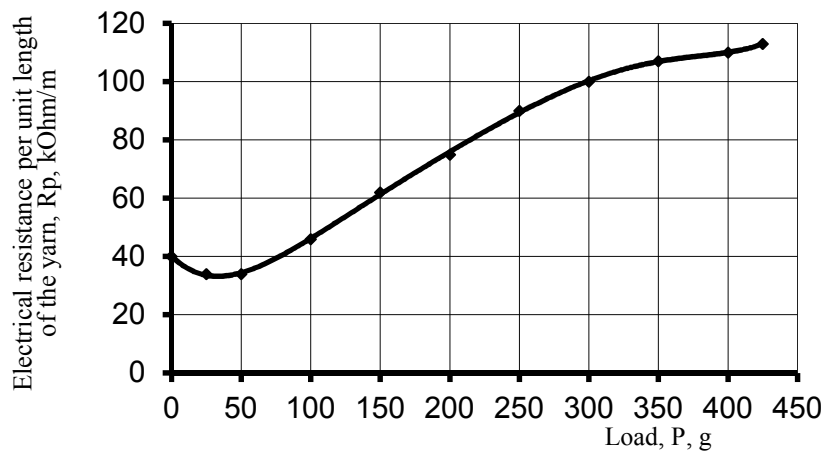
The antistatic fabric samples were made by insertion of the electrically conductive yarn in the polyester fabric structure in the warp-wise and filling-wise directions at the different distances from each other. The distances between the electrically conductive yarns were taken as follows: Sample No. 1 - 5 mm, No. 2 - 10 mm, No. 3 - 15 mm, No. 4 - 20 mm, No. 5- 25 mm, No. 6- 30 mm.

Six samples of the fabrics with different content of the electrically conductive yarn were prepared. Dependence of the specific surface resistivity of the fabrics ( $R_s$ ) on the distance between the electrically conductive yarns (ECY) is shown in Figure 3.



**Figure 3.** Dependence of the surface resistivity of the fabric ( $R_s$ ) on the distance between ECY  
1 - in the filling-wise direction; 2 - in the warp-wise direction

It is seen from Figure 3 that increase of the distance between the electrically conductive yarns in the fabric leads to linear increase of its  $R_s$ . At that, it has been established that in all cases the values  $R_s$  measured in the filling-wise direction are typically lower than the values  $R_s$  measured in the warp-wise direction. It is possible to explain by the fact that the warp yarn tension is higher than the weft yarn tension and it leads to some imperfection in the electrically conductive structure of the yarn and to increase in its electrical resistance. This assumption is confirmed by the study results of the dependence of the electrical resistance per unit length of the yarn on the breaking load value ( $P$ ) (Figure 4) [9].



**Figure 4.** Dependence of the electric resistance per unit length of the yarn ( $R_p$ ) on the load ( $P$ )

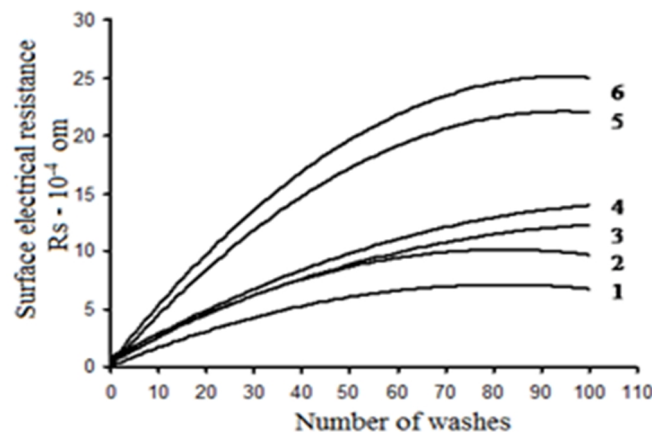
It is seen from Figure 4 that the uniaxial deformation influences not identically on the electrical resistance of the yarn. Load up to 50 g leads to some decrease in the electrical resistance, but in case of its further increase the electrical resistance begins to increase as well and at  $P$  close to the breaking load ( $P$ ) it reaches the value, which exceeds its original value by almost three times.

It is clear that at small values of ( $P$ ) some orientation and approach of fibers in the yarn has happened, which causes the electrical resistance reduction. At the load values of 100 g and more it seems that the yarn structure is subject to significant changes due to movement of the fibers in relation to each other. In this case the contacts between the conductive fibers have been broken and the electrical resistance of the yarn increases.

It is known that the electrostatic properties of materials are characterized indirectly by the value of their electrical resistance. Materials, which specific surface resistivity is less than  $10^7$  Ohm, do not accumulate practically the static electricity and the less is  $R_s$ , the higher is drainage rate of the static electricity. We have selected the surface resistivity  $R_s$  and electrostatic potential value  $V$  in order to characterize the antistatic properties of the fabrics.

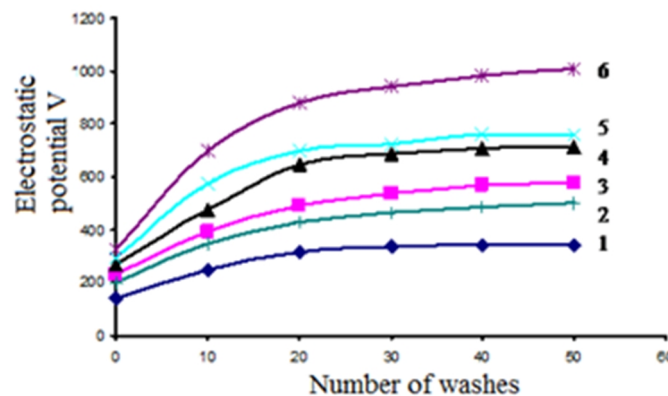
### 3.3. Dependence of the electrical resistance on the number of washes

The study of stability of the electro-physical properties of the antistatic fabrics to multiple washes has been of significant interest. This indicator is quite important and determines the terms and conditions of operation of the antistatic products. Dependence of  $R_s$  on the number of washes is shown in Figure 5.



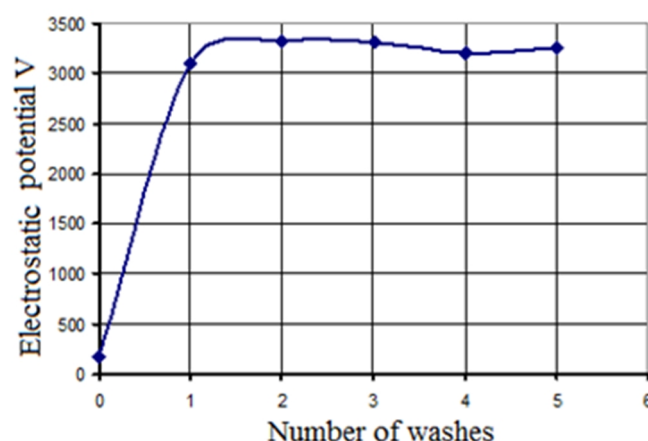
**Figure 5.** Dependence of  $R_s$  on the number of washes  
Samples No. 1-6

It is seen from Figure 5., that even after the 100th wash the value  $R_s$  of the samples does not exceed  $30 \cdot 10^4$  Ohm. It proves indirectly that the studied materials have sufficiently stable antistatic properties. This conclusion is confirmed as well by the data in Figure 6, where dependence of the electrostatic potential on the number of washes is shown. The electrostatic potential of the samples (samples No. 1-6) after 40-50 washes ceases practically to change and its values are within the range of 150-700 V. At that, all tested samples have been negatively charged.



**Figure 6.** Dependence of the electrostatic potential (V) on the number of washes

Dependence of the electrostatic potential of the ordinary polyester fabric (without ECY) on the number of washes is shown for comparison in Figure 7.



**Figure 7.** Dependence of the electrostatic potential (V) on the number of washes

The electrostatic potential of the unwashed sample is 175 V, but after the first wash it increases up to 3300 V and the material begins to be electrified greatly (Figure 7). This is explained by removal of the antistatic agents applied to the polyester fiber during its production.

Thus, insert of the certain amount of the conductive yarn in the polyester fabric structure makes possible to get the stable antistatic properties of these fabrics. The most efficient is to use the samples 2-3 as the antistatic materials.

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