Development of special fabrics protecting from electromagnetic radiation

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Abstract. The influence of electromagnetic radiation (EMR) on a person is connected with the existence of electromagnetic field - a special form of matter which conducts the effect of electrically charged particles. The causes of electromagnetic field formation are defined by the fact that the occurrence of electric field changing in time is the reason of magnetic field formation and magnetic field occurrence is the cause of vortex electric fields; both fields change in time and excite each other. Electromagnetic waves formed during these processes exist irrespective of a source of their initiation. Continuous impact of electromagnetic radiation on a person negatively affects various organs of human body. EMR leads to headaches, fatigue of the organism, disorders of the body. The maximum influence of EMR occurs on "blood and eyes, the incidence of cancer and cataract increases, the number of people suffering from skin diseases increases". An important area today is the creation of fabrics protecting from electromagnetic radiation.

1. Introduction

At present, with development and improvement of technology for the production of polymeric materials, in particular chemical fibers, intensive research is being carried out to impart special properties to these materials: heat resistance, high strength, electrical conductivity, etc. One of the representatives of such materials is electrically conductive fibers. They have unique properties: high electrical conductivity characteristic for metal, lightness, elasticity and other valuable characteristics inherent in textile materials.

Electroconductive fibers and materials obtained on their basis are used in various branches of the national economy. One of the widest areas of application of electrically conductive fibers is the production of antistatic non-electrifying materials. Fabrics with low electrical resistance are also used to create special clothing that protects from the effects of an electric field and shields electromagnetic waves. On the basis of electrically conductive fibers, lightweight and flexible woven electric heaters for various purposes are produced [1].

Electroconductive fibers are mainly produced and widely used in highly developed countries such as the USA, England, Japan, Germany, France, etc. In 1990, our Republic also developed the technology of production and created a unique in the CIS pilot production line for the production of electrically conductive fiber nitron (ECFN). ECFN was used mainly to create special radio engineering materials and products for the protection of special equipment.

An important area today is the creation of protective fabrics from electromagnetic radiation. It is necessary to face many problems, since there are no established methods for designing such fabrics; their properties have not been studied sufficiently yet, the requirements not clearly defined.

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Today, protective (shielding) properties are achieved either by applying special preparations to the fabric (at the stage of finishing) or by applying metal coatings to the surface of fabric; as a result, protective properties of the product have no permanence to severe conditions of operation-maintenance.

2. Statement of the problem, aims and objectives

The purpose of this work is the development and introduction into production of new special fabrics for protecting a person from electromagnetic radiation, greatly weakening electric and electromagnetic fields, and to offer a technology for their production.

The choice of cotton fiber for the production of mixed electro-conductive yarns is due, firstly, to the availability of rich source of raw material, and secondly to the high hygienic properties of cotton fiber, given that the materials created will be used to fabricate special clothes shielding electrical fields. The mixture of certain compositions has been prepared from the above fibers; they have been processed into yarns on an express spinning installation. Electrical resistance of the yarn samples was measured at a direct current in accordance with the procedure described in [2], and in the microwave range at a wavelength of λ = 0.03 m (at a frequency of 10 GHz), according to the method developed by the Radio Engineering Research Institute (Moscow), by measuring the coefficient of radio wave passing. Physical and mechanical properties of yarns have been determined in accordance with the State standards - 1119-80. The coefficient of electrical resistance variation has been calculated basing on results of 100 measurements [3].

To determine the dependence of the properties of mixed yarns on its composition, yarn samples with a linear density of 50±2 tex with different content of components have been obtained and investigated. Twist number is 500 twist/m. The dependence of physical and mechanical characteristics of mixed yarn on its composition is shown in Table 1.

Table 1 shows that an increase in amount of electroconductive fiber in yarn composition causes a slight decrease in its tensile strength and an increase in elongation.

Below are the results of strength calculation of mixed yarn, depending on its composition. In calculations, it is assumed that the yarn rupture occurs only due to the rupture of elementary fibers of the electroconductive nitron fibers (ECFN) and cotton fibers entering the yarn.

In calculations, the following formula for calculating the cross-sectional area of fiber is used [3].

$$F = \frac{1000T}{\rho}, \text{ mkm}^2$$

where: F – is the fiber cross-sectional area, mkm^2;
ρ - is the density of fiber, g/cm^3;
T – is the linear density of fiber, tex.

Table 1. Dependence of physical-mechanical characteristics of mixed yarn on its composition.

Ratio of components in yarn, ECFN /cotton, **%**	Breaking load, cN	Specific breaking load, cN/Tex	Breaking elongation, %	Uneven breaking load, %	Uneven tensile elongation, %
10/90	625	12,5	10,8	7,2	16,8
20/80	560	11,2	11,5	8,1	16,0
30/70	525	10,5	12,1	8,4	14,8
40/60	450	9,0	14,0	9,0	14,2
50/50	430	8,6	15,5	9,2	13,8
60/40	422	8,4	15,6	10,2	13.1
80/20	405	8,1	16,2	11,8	9,2

In calculations the following data are used:
The linear density of yarn - 50 tex;
Breaking load of ECFN -9,2 cN;
Density of ECFN -1,73 g/cm^3;
ECFN cross-sectional area – 312 mkm^2;
Breaking load of cotton fiber - 4,0 cN;
Density of cotton fiber -1,52 g/cm^3;
Cotton fiber cross-sectional area - 105,3 mkm^2

The data presented in table 1 show that breaking load of yarn decreases at increase in ECFN amount. This is explained by the fact that an increase in breaking load due to increase in ECFN amount cannot compensate its decrease due to reduction of cotton fibers in yarn.
These data, though being approximate (displacements of fiber relative to each other at rupture are not considered), give the chance to judge regularities of strength change in mixed yarn depending on its composition [4].
Study of the effect of yarn composition on its electric properties is of essential interest (table 2).

Table 2. Electrical-physical characteristics of yarn depending on its composition.

Ratio of components in yarn, ECFN /cotton**, %**	Electrical resistance per unit length, Rp		Variation coefficient of Rp at direct current, K_v, %
	at direct current lgRp (Rp, kOhm/m)	at λ = 3 cm (Rp, 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 2 indicate that the introduction of ECFN to yarn composition causes sharp decrease in its electric resistance, especially at ECFN amount up to 20-25%.

3. Experimental researches

3.1. Study of physical-mechanical properties of electroconductive fabrics
To obtain experimental samples of electroconductive fabrics a conductive yarn has been used. Its characteristics are:

Composition - 60% of cotton, 40% of electroconductive fiber (ECFN);
Linear density - 50±2 tex;
Specific tensile strength – 9 g/tex
Breaking elongation - 14%;
Electrical resistance per unit length measured at λ=- 0,03 m - 35 kOhm/m
Number of twists - 500 twist/m.

A cotton yarn with linear density of 29.4 tex is used as the second component of woven product. Five experimental samples of cotton fabrics of a plain weave with different amounts of electroconductive yarn have been prepared. Electroconductive yarn was introduced into the composition of fabric on a warp and weft at the set distance from each other. Interweaving density is:
on a warp - 180±3, on a weft - 150±3 yarn/dm.

Samples No. 1 and No. 5 consist completely of electroconductive yarn and cotton yarn, respectively. In other cases the distances between electroconductive yarns are the following: sample No. 2 - 2,5 mm; sample No. 3 - 5,0 mm; sample No. 4 - 10,0 mm.

Results of properties research of fabric samples are given in figures 1-3. As seen from figures 1-3 the breaking load, breaking elongation and fabric rigidity increase with an increase in content of electro-conductive yarn. The minimum values of these indicators are observed at pure cotton fabric (sample 5), and the maximum values - at fabric of electroconductive yarns only (sample1). The same regularity could be observed on indicators of surface density and air permeability of fabrics (table 3).

These facts can be explained by the effect of specific properties of the electroconductive Nitron fiber which is a component of conducting yarn and has a greater strength, elongation and rigidity than cotton fiber [5-7].

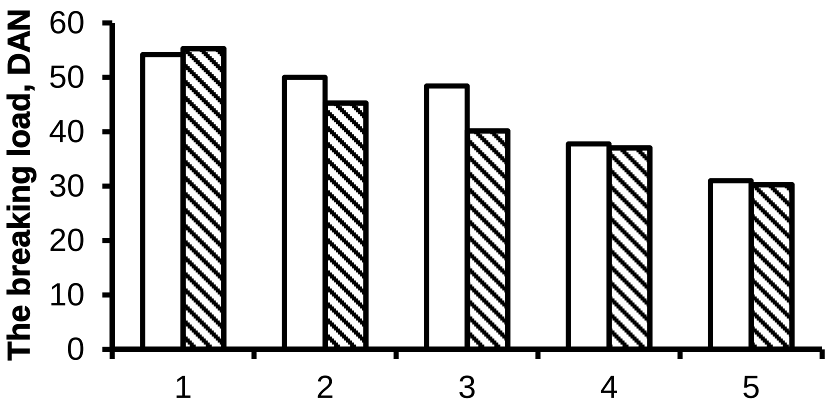

Figure 1. The values of the breaking loads of the samples of conductive fabric

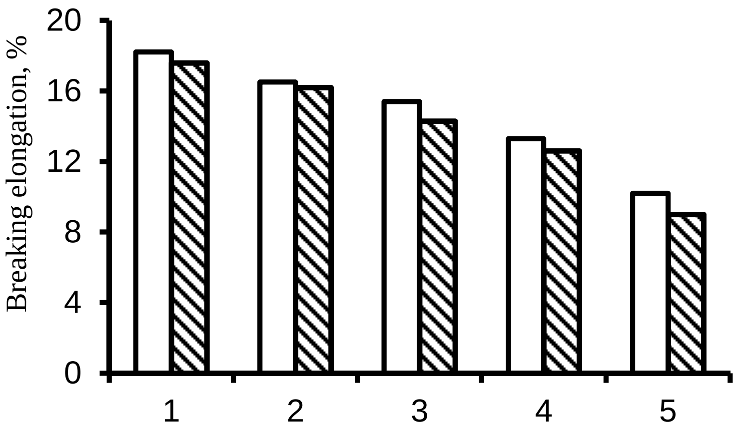

Figure 2. The values of elongation of the samples of conductive fabric

□ - warp; ▧ - weft

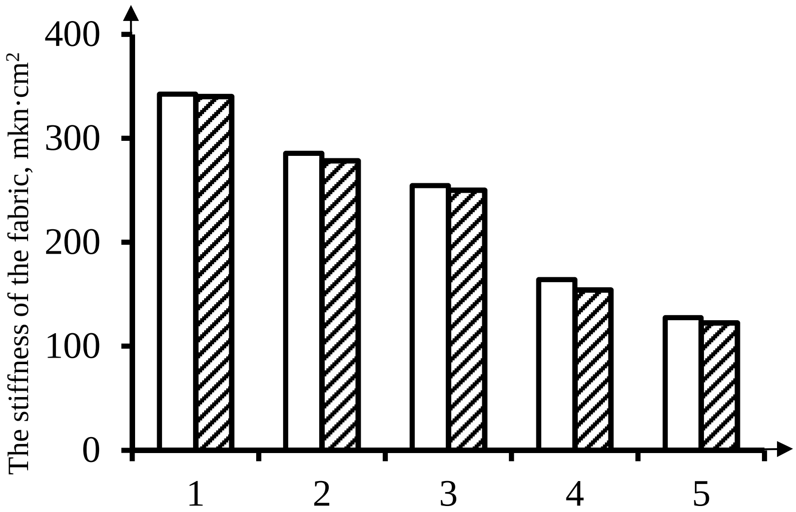

Figure 3. The values of stiffness of the samples of conductive fabric

Table 3.Change of properties of the fabric samples depending on the amount of electroconductive yarn.

Surface density g/m^2	Air permeability dm^3/m^{2}s
180±5	605
148±5	226
140±5	185
135±5	173
125±5	150

Electroconductive yarn is more loose in structure, than the cotton yarn; that explains the reduction in air permeability of fabric samples in the series 1-5. At increase in amount of electroconductive yarn the durability of fabric considerably decreases (figure 3**)**. It is obviously connected with the attrition of thin metal layer applied on elementary synthetic fibers in the course of metallization and formation of microparticles which act further as an abrasive, leading to a rapid destruction of material. The efficiency of materials with semiconducting and conducting yarns, aimed to shield electric fields, is checked by their placement in strong electric fields and determination of electric field strength in the set point before introduction of material (E) and after introduction (Eэ). The shielding factor in dB is determined by a formula:

$$K\text{э} = 20\lg\frac{E}{E\text{э}}$$

To study the shielding effect of developed materials the test unit of the Center of high tensions and big currents of the Institute of Power Engineering (Energy) and Automatic Equipment of the Academy of Sciences of the Republic of Uzbekistan has been used.

En increase in amount of electroconductive yarn leads to a sharp decrease in surface electric resistance of fabric and an increase in its shielding ability (table 4). Surface electric resistance of fabric samples is measured at the wavelength λ=0.03 m. The shielding factor of fabrics in dB is determined at a tension of 80 kV.

Table 4. Electric properties of fabrics.

Surface electrical resistance, Ohm	The shielding factor of electric field, Ke, dB , U=80 kV
34	58,1
152	50,0
296	46,0
630	28,1
$>10^8$	-

It should be noted that according to existing norms, the protective clothes shielding electric fields have to possess the shielding factor no less than 50. Protective clothes or material with shielding factor equal to 50 weaken the electric field strength by 320 times. It means that even at tension of 400 kV/m, field tension inside the clothes won't exceed 1,3 kV/m; that allows the person to stay in electric field without threat to health for rather long period. Naturally at tension decrease the duration of person's stay in electric field considerably increases. Data in the table 5 show that the samples of fabrics No. 2 and No. 3 with electroconductive yarn on a warp and weft located at distance of 2.5 mm and 5 mm, respectively, from each other meet the requirements imposed to materials used for creation of protective clothes shielding electric fields of high tension. Increase in amount of electroconductive yarn in fabric leads to increase in the shielding factor up to 58 and higher (sample1), at the same time the cost of fabric and its weight increases, which is naturally undesirable.

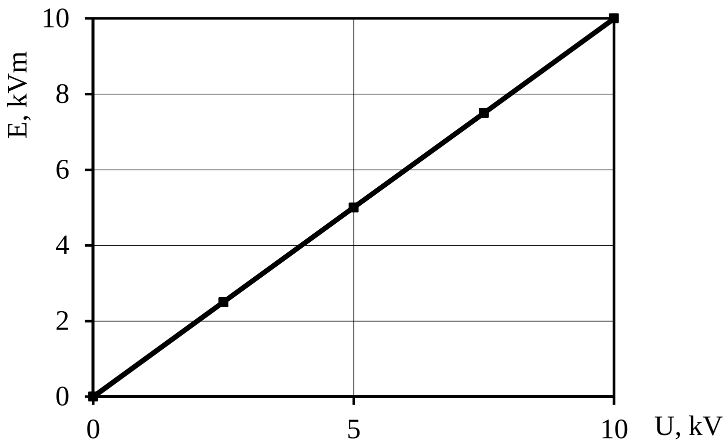

Figure 4. Dependence of electric field on the voltage

Dependence of the shielding ability of materials on tension is of essential interest [8-10]. Dependence of electric field strength on the value of high voltage attached to electrodes without shielding material is given in figure 4. As seen from the figure this dependence has a linear character and at voltage of 10 kV on electrodes the indication of the measuring device reaches the maximum value of -10 kV/m. Quite another picture we observe when shielding the measuring device by electroconductive materials developed in the current study. Results of measurements of electric field strength are given in figure 5 in the same system of electrodes that has been described at data acquisition in figure 4, when shielding the measuring device by electroconductive material.

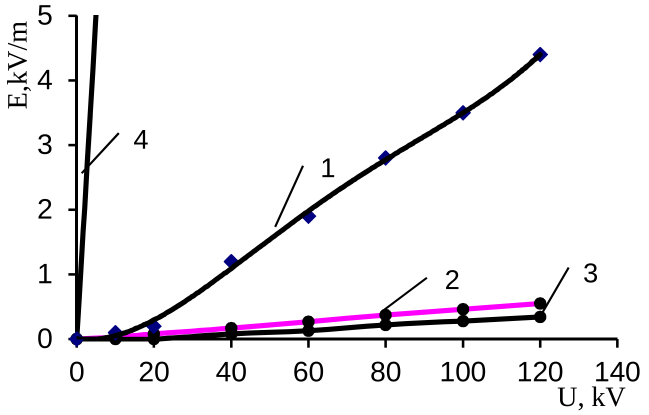

Figure 5. Dependence of electric field on the

In case of material No1 with conductive threads 10 mm apart from each other, both on a warp and weft, (dependence 1), it is established that at tension between electrodes 10 kV/m, the device screened by this material shows the tension 0,1 kV/m only, i.e. even at such sparse arrangement of conductive yarns in fabric as in this option, the shielding factor of electric fields is about 40. It means that this electroconductive fabric reduces the influence of electric fields of alternating voltage of industrial frequency almost by 100 times. However, at further increase in tension electric field inside the screen gradually increases, reaching the value of 2,4 kV/m at tension in interelectrode space of 75 kV/m.
Essential decrease in electric field strength behind the screen is observed when screen material No 2 with more dense arrangement of conductive threads is taken, for example, when these threads in fabric are 5 mm apart from each other (dependence 2, figure 5) So if at tension in interelectrode space of 75 kV/m in a case of conductive threads 10 mm apart the tension of the field is 2,4 kV/m, then reducing this distance to 5 mm, at the same value of field tension in interelectrode space, it equals to 0.03 kV/m behind the screen. Greater decrease in electric field strength happens in case of material No 3, at compaction of conducting threads to 2,5 mm (dependence 3). For comparison in figure 5, the dependence of measured electric field strength on the value of applied tension without the screen is given (dependence 4). Shielding factors of the studied samples of electroconductive fabrics are specified in table 5 at various tensions.
Shielding factor Ke is calculated in dB by the following formula:

$$K э = 20 \lg \frac{E}{E э}$$

where: E – is the electric field strength before the shielding, kV/m.
Ee - is the electric field strength after the shielding, kV/m.

As seen from table 5 electroconductive materials samples No 2 and No 3 possess rather high factors of shielding even at relatively high values of tension. They can be used to create special clothes shielding electric fields of high tension.

Table 5. Shielding factors of various samples of materials, Ke, dB.

Voltage, kV	Without shielding		Sample 1		Sample 2		Sample 3	
	E, kV/m	$K_э$	E, kV/m	$K_э$	E, kV/m	$K_э$	E, kV/m	$K_э$
10	10	0	0,1	40,0	0,03	50,4	0	-
20	20	0	0,2	40,0	0,08	48,0	0	-
40	40	0	1,2	30,5	0,17	47,4	0,08	53,4
60	60	0	1,9	30,0	0,27	46,9	0,13	53,3
80	80	0	2,8	29,1	0,37	46,8	0,22	51,2
100	100	0	3,5	29,1	0,46	46,8	0,28	51,1
120	120	0	4,4	29,0	0,55	46,7	0,34	51,0

The studies carried out on the properties of electroconductive fabrics of various compositions have allowed to establish the following:
- an introduction of electroconductive yarn into the composition of cotton fabric leads to an increase in breaking load, breaking elongation, rigidity, air permeability and surface density of fabric. At the same time some decrease in durability of fabric on attrition is observed. The most rational from the point of view of electric properties is the fabric in which electroconductive yarns are located on a weft and warp 2,5÷5 mm apart from each other. Such fabric can provide the shielding factor of electric field more than 50; that corresponds to the existing standards.

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