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# Investigation of the technology of conductive yarns manufacturing

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## **Abstract.**

The paper is devoted to development of technology of electrically conductive yarn production. This technology allows manufacturing conductive yarns of copper wire and polyester filament yarns. Method of the predicting of the conductive yarn breaking force was developed on the base of analysing of load-elongation curves of each strand of the yarn. Also the method of the predicting of the conductive yarn diameter was offered. Investigation shows that conductive yarns can be integrated into the textiles structure using sewing or embroidery equipment. Application of developed conductive yarn is wearable electronics creating with wide range of functions, for example, for specific health issue monitoring, navigation tools or communication gadgets.

## **1. Introduction**

One of the most prospective textile research fields is the development of electrically conductive yarns for integration into the textiles structure since conductive yarns use is the base of smart textile and wearable electronics creation [1, 2] . It is known that the integration of smart functionality into clothing and other textile products will radically change the culture surrounding these products, fundamentally altering people's relationships with them and the way they use them. Smart functionality will also have an impact on the way products are designed and the materials developed [3]. The aim of the research is development of the technology for production of conductive yarns with predetermined properties.

## **2. Materials and methods**

The developed technology allows manufacturing of conductive yarns of copper wire and polyester filament yarns. Diameter of the wire is 50  $\mu\text{m}$ , the range of conductive yarns linear density is from 40 till 72 tex. Tables 1, 2 show the properties of filament yarns and wire used in the production of electrically conductive yarn.

In accordance to the technology conductive yarn is produced on twisting machines with hollow spindles (figure 1). Copper wire 1 is fed to twisting zone together with one of the filament yarn 2 (core strand). The second filament yarn 3 (covering strand) is being twisted with them while rewinding from package which is fixed on hollow spindles. Further conductive yarn is wound on the bobbin 4.

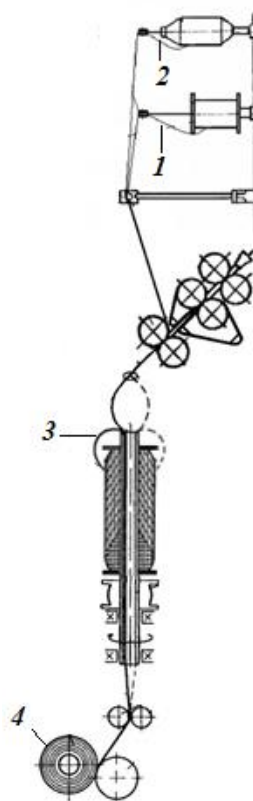


**Table 1.** Properties of polyester filament yarns

Properties	Value	
Linear density, tex	11,3	27
Density, g/cm <sup>3</sup>	1,38	1,38
Breaking force, cN	706,4	1444
Coefficient of variation of breaking force, %	4,0	4,5
Elongation, %	12,3	15,8
Coefficient of variation of elongation, %	6,0	8
Breaking tenacity, cN/tex	62,51	53,48




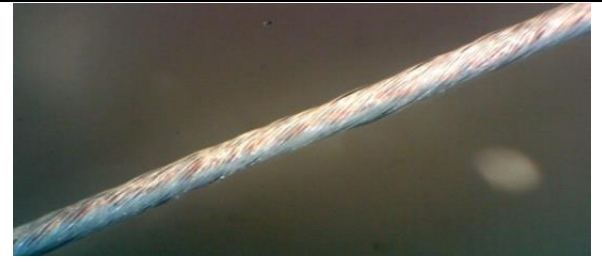

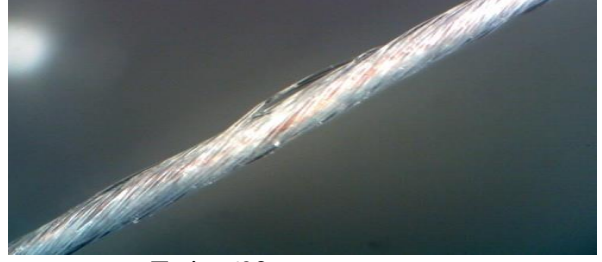
**Table 2.** Properties of copper wire

Properties	Value
Density, g/cm <sup>3</sup>	8,93
Linear density, tex	18,0
Diameter, mm	0,05
Breaking force, cN	45–50
Elongation, %	14 – 16
Coefficient of variation of breaking force, %	5,0
Coefficient of variation of elongation, %	3,0
Bending endurance, cycles	11500
Point of maximum load, kg/mm <sup>2</sup>	20 – 35
Electrical resistivity, Ohm·m	$1,69 \cdot 10^{-8}$

**Figure 1.** Scheme of production of conductive yarn

During researches we determined the impact of linear density of filament polyester yarns and twist of conductive yarn on its structure. It was desirable to obtain the most even covering of wire by polyester filament yarns. Table 3 presents photographs of line sections of different variants of conductive yarns.

**Table 3.** Line segments of different variants of conductive yarn

Variant 1 Core filament yarn 11,3 tex Covering filament yarn 11,3 tex	
	
Twist 455 turns per meter	Twist 692 turns per meter
Variant 2 Core filament yarn 27 tex Covering filament yarn 11,3 tex	
	
Twist 455 turns per meter	Twist 692 turns per meter
Variant 3 Core filament yarn 27 tex Covering filament yarn 27 tex	
	
Twist 455 turns per meter	Twist 692 turns per meter

The photographs (table 3) shows that filament polyester yarn 11,3 tex cannot provide full covering of copper wire. At the same time, we can note that choosing correct twist value leads to full covering of copper wire by filaments of polyester yarn 27 tex. For all variants of yarns we obtained uncovered places on the copper wire if the twist was chosen less than optimal value.

### 3. Predicting of the conductive yarn breaking force

The method of predicting of the conductive yarns breaking force was developed on the base of analysis of each yarns strand load-elongation curves. Prediction of breaking force is an important task for developing of the new type of yarn. The total strength of filament yarns and copper wire (variant 2 in the table 3) was about 2200 cN. However, observed value of breaking force of conductive yarns was 1567 cN, i.e. deviation of calculated values from actual testing results was about 40 %. This fact can be explained by difference of the breaking elongation of the conductive yarn strands.

We can provide more precise calculation on the basis of the analysis of the load-elongation curves of each of the conductive yarn strands. As a result of these curves approximation we obtained the following dependences of the applied load (cN) to strands from elongation (%):

- for core polyester yarn 27 tex:

$$P_{F1} = \frac{1000 \cdot \varepsilon}{4,845 + 1,905 \cdot \varepsilon - 0,0975 \cdot \varepsilon^2}; \quad (1)$$

- for covering polyester yarn 11,3 tex:

$$P_{F2} = \frac{1000 \cdot \varepsilon}{13,16 + 2,734 \cdot \varepsilon - 0,196 \cdot \varepsilon^2}. \quad (2)$$

The significance of the coefficients of the regression models was estimated using the t-test. The part of breaking force of copper wire in total breaking force of combined conductive yarn is very small. So, stretching process was considered using the following straight-line correlation:

$$P_C = 3,33 \cdot \varepsilon. \quad (3)$$

Load-elongation curves of conductive yarn strands are shown at Fig. 2.

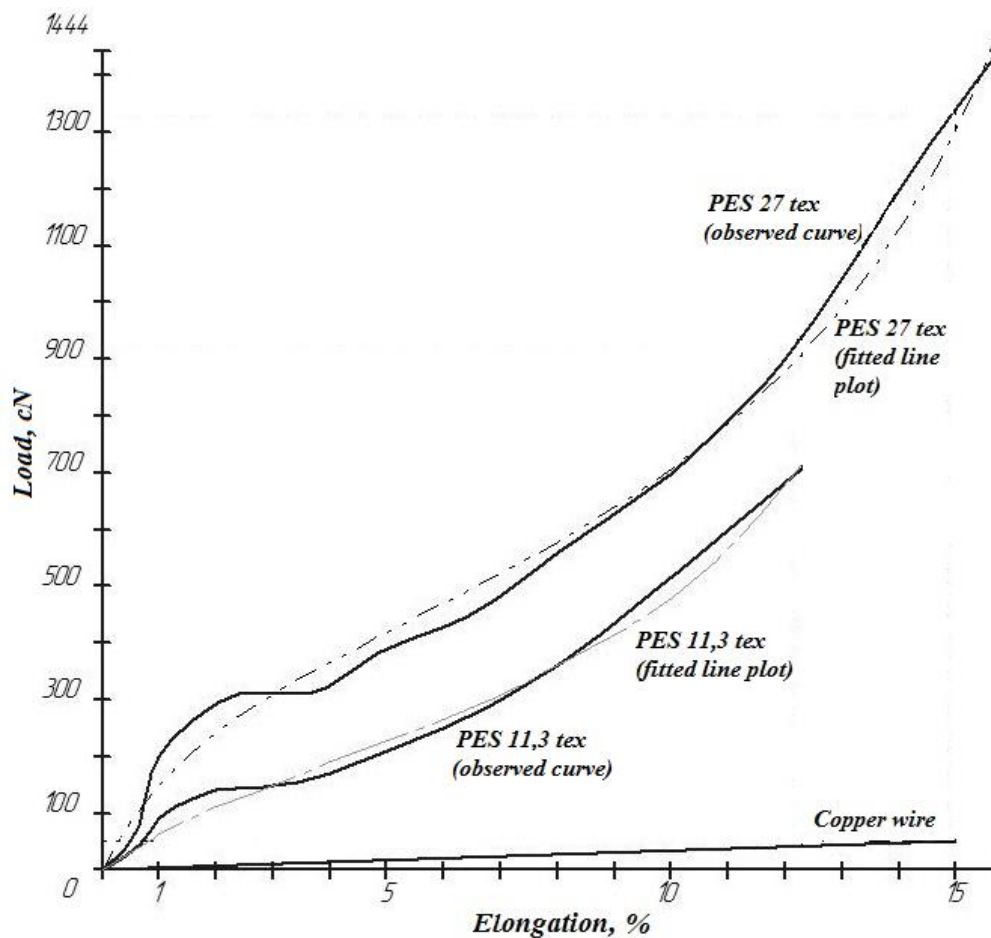
If we analyze the load-elongation curves of the strands of developed conductive yarn we can pay attention to the moment when the polyester filament yarn 11,3 tex breaks. It happens when its elongation rises to 12,28 %. We can consider that in this time the elongations of other strands are the same. We can see on presented graphs that the elongation corresponds to the following calculated values of load applied to the conductive yarn strands:

- to polyester filament yarn 27 tex – 907,2 cN;
- to polyester filament yarn 11,3 tex – 715,1 cN;
- to copper wire – 40,9 cN.

So, at the moment of covering yarn break (PES 11,3 tex) the load applied to the conductive yarn is equal to the sum of the loads applied to all its strands, i.e. 1663,2 cN.

After covering strand break this applied load is redistributed between two unbroken strands (PES yarn 27 tex and copper wire). However, their total breaking force is 1494 cN. This value is significantly less than actual load value. Therefore, covering strand break leads to simultaneous break of the rest strands and we can say that predicted value of breaking force of investigated conductive yarn is 1663,2 cN.

This value is 6,1 % higher than breaking force which we determined as a result of conductive yarn testing (1567 cN). Obtained deviation can be explained by the error in approximation the real load-elongation curves of the yarn strands, as well as by the effect of the properties variation of filament yarns 11,3 tex and 27 tex. At the same time, it can be concluded that the proposed approach can be used for the development of new types of electrically conductive yarns with the structure investigated in this paper.



**Figure 2.** Load-elongation curves (observer and predicted) of the of conductive yarn strands

#### 4. Predicting of the conductive yarn diameter

In some cases for designing of the textile materials structure it is necessary to predict the diameter of the yarns which will be used in their manufacturing. Predicting of the yarn diameter is also very important because this parameter must be used for determining of the setting of the yarn further processing.

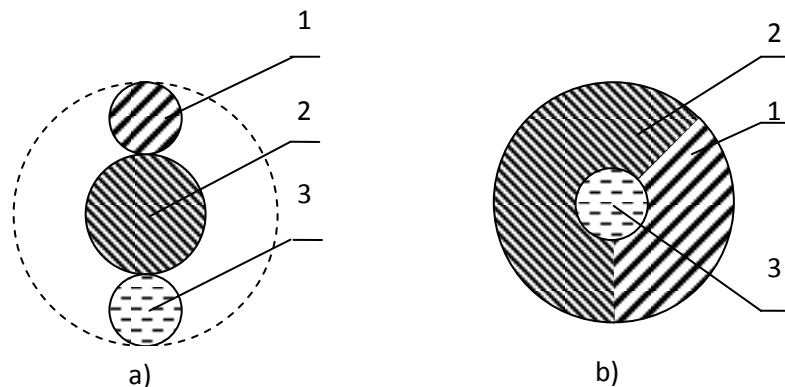
For predicting of the conductive yarn diameter we offered a simplified method taking into account the fact that its individual strands (polyester filament yarns) are differently deformed in its structure.

We can consider that the copper wire in the process of conductive yarn manufacturing retains a circular cross-sectional shape, while the cross-sections of polyester filaments are deformed taking a more complex shape.

Suppose that all three strands in the structure of the conductive yarn can be represented in the form of cylinders enclosed inside the cylindrical shape yarn (Figure 3 a). In this case this yarn diameter can be calculated as follows:

$$D_{CY1} = 0.0357 \left( \sqrt{\frac{T_C}{\gamma_C}} + \sqrt{\frac{T_{F1}}{\gamma_{F1}}} + \sqrt{\frac{T_{F2}}{\gamma_{F2}} \cdot K} \right), \quad (4)$$

where  $T_C$  – linear density of copper wire, tex;  $\gamma_C$  – density of copper,  $\text{g/cm}^3$ ;  $T_{F1}$  – linear density of core filament yarn, tex;  $\gamma_{F1}$  – density of core filament yarn,  $\text{g/cm}^3$ ;  $T_{F2}$  – linear density of covering filament yarn, tex;  $\gamma_{F2}$  – density of covering filament yarn,  $\text{g/cm}^3$ ,  $K$  – fore-run coefficient.



**Figure 3.** Scheme of the cross-section of an electrically conductive yarn  
1 – polyester filament yarn 11,3 tex; 2 – polyester filament yarn 27 tex; 3 –copper wire

If we use this formula (4) for variant 2 of conductive yarn (table 3) taking into account  $K = 1,05$  we obtain the following result:

$$D_{CY1} = 0,0357 \left( \sqrt{\frac{27}{1,38}} + \sqrt{\frac{18}{8,93}} + \sqrt{\frac{11,3}{1,38} \cdot 1,05} \right) = 0,313 \text{ mm.}$$

Also we can consider that the yarn strands during the twisting process are maximally deformed in such way that the section of this yarn gets a circle shape (Figure 2 b). For this yarn structure the diameter can be calculated using the following formula:

$$D_{CY2} = 0.0357 \sqrt{\frac{T_C}{\gamma_C} + \frac{T_{F1}}{\gamma_{F1}} + \frac{T_{F2}}{\gamma_{F2}} \cdot K}. \quad (5)$$

In this case calculated value of yarn diameter is significantly less in comparison with value which was obtained using formula (4):

$$D_{CY2} = 0,0357 \sqrt{\frac{27}{1,38} + \frac{18}{8,93} + \frac{11,3}{1,38} \cdot 1,05} = 0,196 \text{ mm.}$$

It can be assumed that the real structure of the electrically conductive yarn occupies an intermediate position between the two considered structures which are described by the formulas (4) and (5). Then the average diameter of the yarn can be calculated by the following formula:

$$D_{CY} = \frac{D_{CY1} + D_{CY2}}{2} = \frac{0,313 + 0,196}{2} = 0,2545 \text{ mm.}$$

Therefore, the calculated diameter of conductive yarn 60 tex was 0,254 mm. This value was almost the same as measured diameter (the average value was 0,250 mm). The deviation of calculation and measurement data was 1,6 %. This accuracy is quite acceptable for engineering calculations. Thereby, the methods can be recommended for the conductive yarns diameter predicting.

Investigation shows that conductive yarns can be integrated into the textiles structure using sewing or embroidery equipment [4]. While interacting of conductive yarns with tools of the equipment the

structure of the polyester covering remains fixed. Copper wire is not damaged and its properties are not changed. As a result of conductive yarns samples processing we recommended to use the needles with increased eye and to impregnate the yarn by lubricants.

Application of developed conductive yarn is wearable electronics creating with wide range of functions, for example, for specific health issue monitoring, navigation tools or communication gadgets.

### **5. Conclusions:**

1. Investigated technology allows producing conductive yarns with copper wire covered by polyester filament yarns. The range of conductive yarns linear density is from 40 till 72 tex.
2. Methods of the prediction of conductive yarns braking force and diameter are developed. Predicting of the yarn properties can be used for determining of the setting of its processing.
3. Conductive yarns can be used for creation of different kinds of wearable electronics.

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