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YARN PROPERTY PREDICTION

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Annotatsiya. Maqolada takomillashtirilgan tavsiya etilgan formula yordamida ipning nisbiy uzilish kuchini bashorat qilish usuli taklif etilgan. Kvadratik notekislikdan foydalanish hamda ipning uzilishiga qarshilik ko‘rsatmaydigan tolalar uzunligini hisoblash usulidan foydalanish asoslangan.

Tayanch so‘zlar: ip, xossalar, prognozlash, tola, uzilish kuchi, buram, tola uzunligi, kvadratik notekislik, ishqalanish kuchi.

Аннотация. В статье предложен метод прогнозирования относительной разрывной нагрузки пряжи с помощью усовершенствованной рекомендуемой формулы. Обосновано использование квадратической неровноты, а также использования метода расчета длины волокон, не оказывающих сопротивления при разрыве пряжи.

Ключевые слова: пряжа, свойства, прогнозирование, волокно, разрывная сила, крутка, длина волокна, квадратическая неровнота, сила трения.

Abstract. The article proposes a method for predicting the relative breaking load of yarn using an improved recommended formula. The use of quadratic unevenness is substantiated, as well as the use of a method for calculating the length of fibers that do not provide resistance when the yarn breaks.

Keywords: yarn, properties, prediction, fiber, breaking force, twist, fiber length, quadratic unevenness, friction force.

INTRODUCTION.

It is theoretically impossible to accurately predict the breaking strength of the thread. There are many reasons for this, and first of all, it is unjustified that the breaking force of the fibers, which break down sequentially, is recorded using a force gauge - dynamometer. The complexity of the posed problem has also been studied in applied research [1]. For this reason, formulas based on the processing of results by statistical methods were recommended, with relatively little experience in applied research [2].

The characteristics and properties of yarn depend heavily on the properties of the fibers. In cotton yarn spinning, the linear density of the fiber serves as the basis for determining the required linear density of the yarn. To achieve a well-formed yarn structure, the fibers must be evenly distributed throughout its cross-sectional layers [3]. K. I. Koritskiy [4], having analyzed all research in this direction, recommended dividing them into three groups. He also recommended three formulas for calculating the relative breaking load of yarns obtained by various spinning systems and methods [5]. In his research, he based his work on

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the results of statistical analysis of extensive data. In some of his analyses, he used the breaking strength of the yarn itself.

The problems of calculating yarn breaking strength are discussed in the works of N.M.Belitsyn, V.M.Kuzmin, K.I.Koritskiy, B.P.Pozdnyakov, V.E.Zotykov, I.V.Budnikov, P.P.Trikov, A.N.Solovyov, I.M.Rakh [6; 7]. An analysis of the theoretical and empirical formulas proposed by these authors is available in numerous literature sources and scientific publications [8]. The strength of textile threads and yarn has been extensively studied in the works of V. E. Morton [9], J. W. S. Hearle [10], K. I. Koritsky [5], V. P. Shcherbakov [11, 12], and others.

It should be noted that in the studies discussed, the analysis of yarn strength was based on the assumption of its ideal structure. When deriving certain formulas, constant coefficients are introduced to account for the uneven arrangement of fibers within the yarn, their dimensions, and the technological conditions.

METHODOLOGY.

As a result of implementing the HVI (High Volume Instrument) system for measuring cotton fiber properties, the Count Strength Product (CSP) indicator was introduced to characterize yarn strength. According to SITRA recommendations, formulas are provided for calculating the relative breaking load or the breaking length of the yarn [13]. The formula for determining the breaking length of the yarn is presented as follows::

$$R_{km} = \frac{LeaCSP}{150} (1)$$

Accordingly, the relative breaking length of yarn for the carded spinning system is:

$$R_{km} = 1{,}1\sqrt{\frac{L \cdot R_T}{M}} + 4{,}0 - 13\frac{N_e}{150} (2)$$

For the combing spinning system is:

$$R_{km} = 1{,}1\sqrt{\frac{L \cdot R_T}{M}} + 4{,}0 - 13\frac{N_e}{150} + \left(1 + \frac{Y}{100}\right) (3)$$

From the formulas provided, it is evident that according to the recommendations of SITRA, the relative breaking strength (or breaking length) of yarn is based on the upper half mean length of the fiber, the relative breaking strength of the fiber, micronaire, and the yarn count in the English system.

The issue of calculating breaking strength, which is one of the fundamental properties of yarn, based on raw material data, is addressed in the works of many researchers, including [14]. This indicator is referred to by the terms "single yarn

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breaking strength," "relative breaking load or breaking length," and in some cases, simply as "strength."

Based on many years of research and experimentation, A.N. Solovyov proposed the following formula for calculating the relative breaking load of cotton fiber yarn [15]:

$$R_y = \frac{P_f}{T_f}\left(1 - 0{,}0375 \cdot H_0 - \frac{2{,}65}{\sqrt{\frac{T_y}{T_f}}}\left(1 - \frac{5}{L_f}\right) \cdot \eta \cdot k\right) \quad [\text{cN/tex}] \quad (4)$$

where: R_f - Relative breaking load of the yarn, cN/tex;P_f - Breaking load of the fiber, cN; T_f - Linear density of the fiber, tex;H_0 - Specific unevenness of the yarn (for the combed system, H_0 = 3.5 - 4.0; for the carded system, H_0 = 4.5 - 5.0); T_y – Linear density of the yarn, tex; L_f - Staple length of the fiber, mm; η - Coefficient dependent on the condition of the equipment (Excellent - η = 1.1; Good - η= 1.0; Satisfactory - η = 0.9);k - Twist correction factor, dependent on the difference between the actual and critical twist coefficients.

RESULTS AND DISCUSSION.

When deriving the formula, A.N. Solovyov initially recommended taking unevenness into account. It is known from mathematical statistics that the minimum value of the breaking strength (R) differs slightly from the mean value according to the law of normal distribution. This difference is:

$$P = \bar{P} - 3\sigma \quad (5)$$

where $\bar{P}$ - *average tensile strength;* σ- *mean square deviation.*

Provided the experimental results conform to a normal distribution pattern, the following relationship exists between the values of the quadratic unevenness (C) and the linear unevenness (H), based on Sommer's formula:

$$\frac{C}{H} = \sqrt{\frac{\pi}{2}} \approx 1{,}25 \quad (6)$$

If we consider that the formula for linear unevenness is:

$$H = \frac{\sigma \cdot 100}{\bar{P}} \quad (7)$$

Then

$$\sigma = \frac{1{,}25 \cdot H \cdot \bar{P}}{100} \quad (8)$$

Substituting this expression into formula (2), we obtain:

$$P = \bar{P}(1 - 0{,}0375 \cdot H) \quad (9)$$

The breaking strength of yarn is simultaneously influenced not only by the breaking coefficient (k_0) but also by the yarn twist. The twist in the yarn creates a

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tangential force. This force is proportional to the yarn diameter d, and the number of twists K.

$$U = C \cdot K \cdot d \quad (10)$$

where C is a constant coefficient (introduced by A.N. Solovyov).

The normal component of the tangential force, Q, generates a friction force within the fiber.

$$T_0 = f \cdot Q \quad (11)$$

Given that

$$Q = U \cdot \cos\beta \quad (12)$$

we obtain

$$T_0 = f \cdot C \cdot K \cdot d \cdot \cos\beta \quad (13)$$

where f - coefficient of friction; β - angle (Figure 1.)

If the twist in the yarn is replaced

$$K = \frac{1}{\pi \cdot d \cdot ctg\beta} \cdot \quad (14)$$

Then the following formula is derived:

$$T_0 = \frac{C \cdot d \cdot \cos\beta \cdot f}{\pi \cdot d \cdot ctg\beta} = \frac{C \cdot f}{\pi} \cdot \sin\beta \quad (15).$$

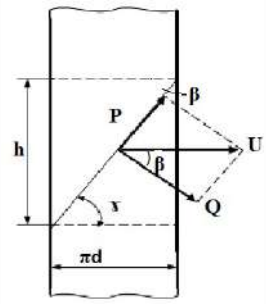


Figure 1. Fiber Disposition Along a Helical Path

Considering that the first factor in formula (15) may be a constant, the expression $\frac{C \cdot f}{\pi} = C_1$ simplifies to:

$$T_0 = C_1 \cdot \sin\beta \quad (16)$$

This expression demonstrated that the friction force, the coefficient of friction, and the sine of the twist angle are directly proportional. Based on the test results, it was noted that the breaking strength of yarn spun from the same fiber is proportional to *sin* β.

Accordingly,

$$P = C \cdot k_0 \cdot n \cdot p_0 \cdot \sin\beta \quad (17)$$

where: P_0 - fiber breaking strength; k_0 - coefficient of simultaneous fiber breakage;

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n - number of fibers in the cross-section of the yarn; C - constant coefficient; β - twist angle.

Taking into account the coefficient k, which accounts for bundle breakage, and when the breaking force is replaced by the breaking length (9), the formula is written as:

$$R_y = R_0(1 - 0{,}0375 \cdot H) \cdot k \quad (18)$$

where: R_0 - is the breaking length of the fiber; k - is the coefficient accounting for the breakage of the twisted fiber bundle.

If we substitute into this formula the value representing the total unevenness H:

$$H = H_0 + \sqrt{\frac{5000 \cdot N}{N_0}} \quad (19)$$

then it will be:

$$R_y = R_0(1 - 0{,}0375 \cdot H_0 - 0{,}0375 \cdot b \cdot \sqrt{N}) \cdot k \quad (20)$$

The coefficient b in this formula, which increases with the yarn count, is called the unevenness growth coefficient. In the studies of A.N. Solovyov, it was proposed to be calculated using the expression:

$$b = \sqrt{\frac{5000}{N_0}} \quad (21)$$

If we relate this expression to the expression for total unevenness:

$$R_y = R_0(1 - 0{,}0375 \cdot H_0 - 0{,}0375 \cdot \sqrt{\frac{5000}{N_0}} \cdot \sqrt{N}) \cdot k \quad (22)$$

If we substitute $0{,}0375 \cdot 70{,}711 = 2{,}65$ and replace the count with the linear density, formula (22) takes the following form:

$$R_y = R_0(1 - 0{,}0375 \cdot H_0 - \frac{2{,}65}{\sqrt{\frac{T_y}{T_f}}}) \cdot k \quad (23)$$

As the fiber length increases, the value of coefficient k also approaches *1,0*. At a certain minimum fiber length, l_0, where it is impossible to form a twisted fiber bundle, $k = 0$. This relationship is expressed by the formula:

$$k = (1 - \frac{l_0}{l}) \quad (24)$$

Based on the relationship between breaking strength and fiber length, A.N. Solovyov proposed that l_0 should be 5 mm.

In practice, the tangential force generated by the helical arrangement of fibers creates resistance to fiber breakage. The number of helical turns (or twists) formed by a fiber within the yarn depends on its length. Consequently, fibers aligned along the helix are more likely to contribute to friction generation. Using

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the method for calculating the length of one helical turn, we can express the formula for determining the length of fibers not participating in breakage as follows:

$$l_0 = 2 \cdot \sqrt{\left(\frac{1000}{K}\right)^2 + (\pi \cdot d_y)^2} \qquad (25)$$

where: K - is the number of twists per 1 meter of yarn, turns/m; d_y - is the yarn diameter, mm.

The yarn diameter is calculated using the formula by Yu.K. Barkhotkin [16]:

$$d = 0{,}057 \cdot \sqrt[6]{\frac{T_y}{K}} \cdot \sqrt{T_y} \qquad (26)$$

where: T_y - is the linear density of the yarn, tex; K - is the number of twists per 1 meter of yarn, turns/m.

A graphical interpretation of the pattern of change in the value of l_0 - the length of fibers not participating in the break - obtained from the calculations is shown in Figure 2.

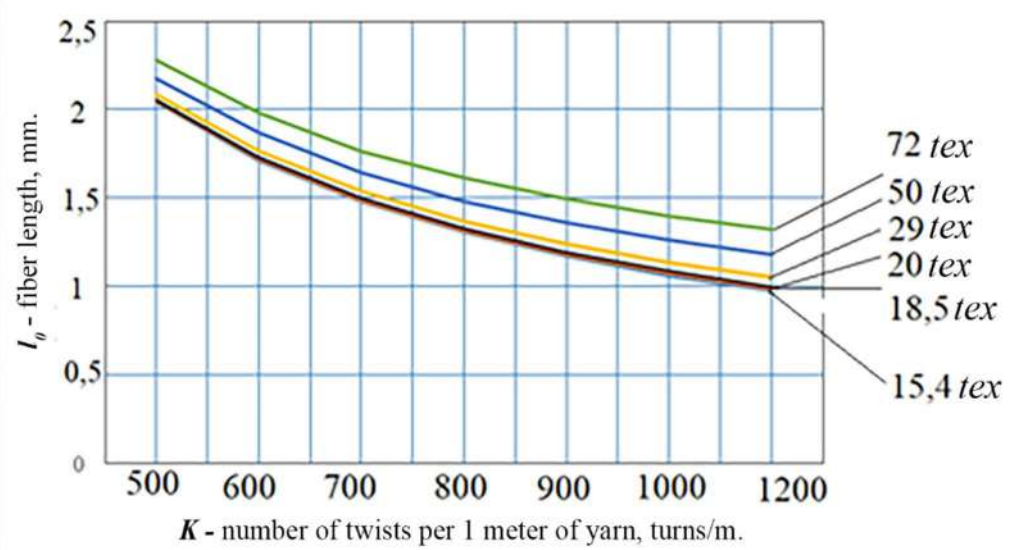


Figure 2. Fiber Length within a Single Yarn Twist

The graph (fig. 2.) showed that the linear density of the yarn increases from 15,4 tex to 100 tex as l_0 increases by 18 - 54%, and decreases by a factor of 1,6 - 2,1 as the number of twists in the yarn increases within the range of 500 - 1000 turns/m.

Taking into account fiber arrangement and alignment, as well as orientation, we recommend considering its double value in the formula (Table 1).

Table 1

Length (l_0) of fibers not participating in yarn breakage, mm

Linear density of yarn, tex	Number of twists in yarn, turns/m						
	500	600	700	800	900	1000	1100
15,4	4,077	3,420	2,952	2,604	2,334	2,119	1,945

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18,5	4,098	3,443	2,978	2,632	2,364	2,151	1,978
20	4,108	3,455	2,991	2,646	2,379	2,167	1,995
29	4,176	3,531	3,074	2,735	2,474	2,268	2,100
50	4,356	3,730	3,290	2,965	2,717	2,522	2,365
72	4,565	3,957	3,534	3,222	2,986	2,800	2,650
100	4,847	4,262	3,855	3,558	3,331	3,154	3,011

When the quadratic unevenness is used in place of the linear unevenness in the previously stated formula for calculating the relative breaking load of yarn, formula (9) takes the following form:

$$P = \overline{P}(1 - 0{,}03C) \qquad (27)$$

Formula (2.34) is also modified accordingly.

Thus, the modified form of A.N. Solovyov's formula appears as follows:

$$R_y = \frac{P_f}{T_f}\left(1 - 0{,}03 \cdot C - \frac{2{,}12}{\sqrt{\frac{T_y}{T_f}}}\right) \cdot \left(1 - \frac{l_0}{l_{sht}}\right) \cdot k \cdot \eta \qquad (28)$$

Where: R_y - relative breaking load of yarn, cN/tex; P_f - breaking load of fiber, cN; T_f - linear density of fiber, tex; C - quadratic unevenness of yarn; T_y - linear density of yarn, tex; l_0 - length of fibers not participating in yarn breakage, mm; l_{sht} - staple length of fiber, mm; k - twist correction determined by the difference between the actual twist coefficient α_T and the critical twist coefficient α_{Tcr}; η - coefficient accounting for equipment condition (excellent - 1,1; normal – 1,0; satisfactory – 0,95).

For a comparative analysis of the relative breaking load of yarn, the calculation results based on the given formulas, standards, and recommendations were studied, along with the results achieved in practice at industrial enterprises. Figures 3 and 4 present a histogram showing the relative breaking loads of cotton fiber yarn, calculated using the current and recommended formulas.

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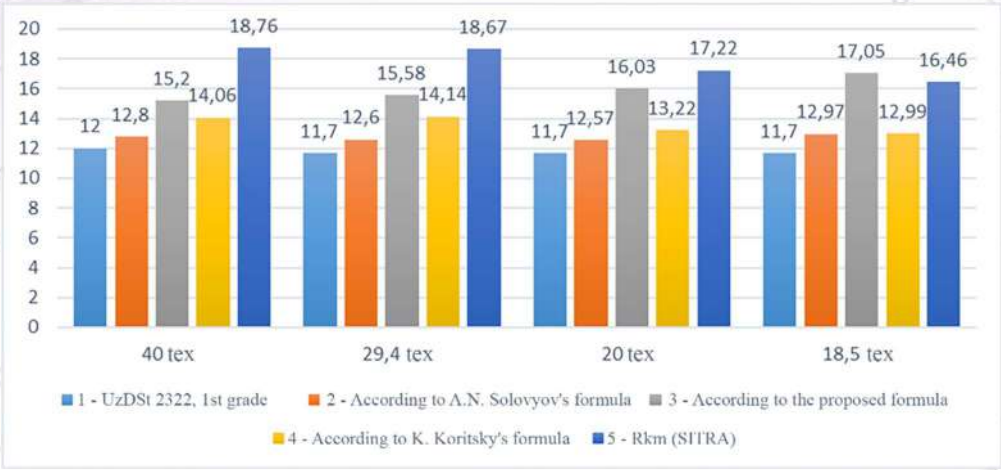


Figure 3. Calculated Relative Breaking Load Indicators of Yarn (for ring-spun yarn)

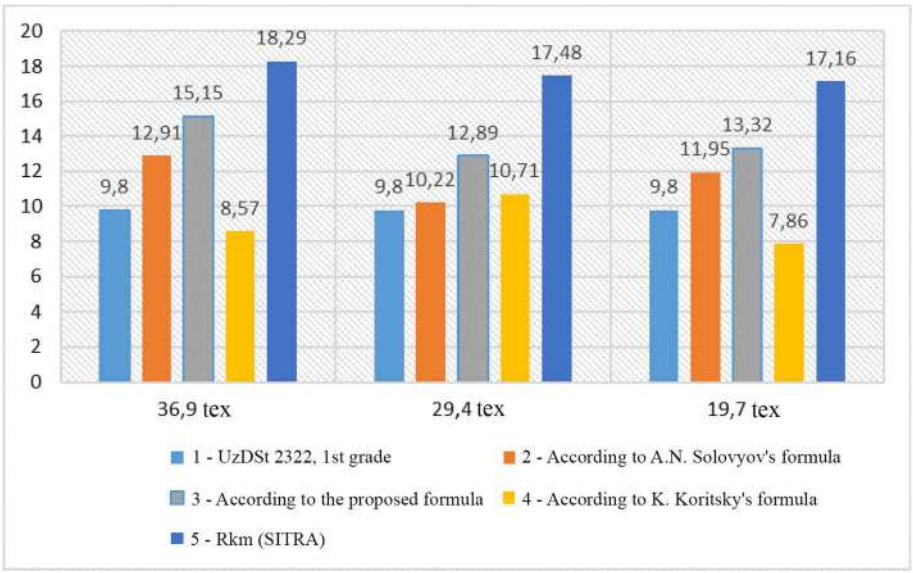


Figure 4. Calculated Relative Breaking Load Indicators of Yarn (for rotor spun yarn)

These histograms demonstrate that the calculation of the relative breaking load of yarn using the proposed formula yields results closely aligned with those obtained by modern computational methods.

CONCLUSION.

In research conducted to study yarn properties and calculate breaking strength, the factors accounting for yarn structure, irregular fiber arrangement, dimensions, and technological conditions vary, and coefficients with constant values are included in different formulas.

Based on research, a modified formula for determining the relative breaking load of yarn was proposed as an evolution of A.N. Solovyov's original formula. This modification involves replacing the linear unevenness of the yarn with the quadratic unevenness and incorporating a method for calculating the length of

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fibers that do not contribute to breakage resistance. It has been established that the results align with modern requirements.

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