ANALYSIS OF YARN TWIST FROM THE POINT OF VIEW OF CURRENT KNOWLEDGE

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Abstract

An analysis of models (presented in available world literature) for the twist of multi-folded threads consisting of two component fibre streams (doubled thread, doubled yarn) is discussed. The possibility of forecasting the twist value of the component streams for an accepted twist value of the multi-folded thread is considered.

Key words: twist, yarn twist, thread twist, twist modelling, multi-folded thread, doubled thread, doubled yarn, siro-spun yarn, folding, fibre streams.

List of more important designations and their units:

- $\mathbf{Q_0}$, Nm - twisting momentum of a multi-folded thread below the contact point of component fibre streams;
- $\mathbf{Q_\infty}$, Nm - twisting momentum of the component yarns of a multi-folded thread above the contact point of component fibre streams;
- $\mathbf{T_0}$, cN - tension of a multi-folded thread below the contact point of component fibre streams;
- $\mathbf{dT_0}$, cN - elementary tension increment of the component fibre streams of a multi-folded thread;
- $\mathbf{T_\infty}$, cN - tension of the component yarns of a multi-folded thread above the contact point of component fibre streams;
- $\mathbf{2\alpha}$, rad - convergence of the angle between component yarns of a multi-folded thread;
- $\mathbf{R_s}$, m - radius of cross-section of the component fibre stream of a multi-folded thread;
- **M**, Nm - bending moment of one of the component fibre streams of a multi-folded thread;
- **dM**, Nm - elementary increment in the bending momentum of the component fibre streams of a multi-folded thread;
- $\mathbf{dQ_0}$, Nm - elementary increment in the twisting momentum of the component fibre streams of a multi-folded thread;
- **E**, Nm^{-2} - Young's modulus, the modulus of the longitudinal elasticity of thin rods;
- **G**, $Nm^{-2}rad$ - Kirchhoff modulus, the modulus of the transversal elasticity of thin rods;
- **A**, m^2 - cross-section area of thin rods, $A = \pi R_s^2$;
- ν, - - Poisson coefficient for thin rods;
- $\mathbf{S}_p$, m^{-1} - twist of the multi-folded thread;
- $\mathbf{S_s}$, m^{-1} - twist of the component stream of a multi-folded thread;
- **V**, N - bending force of the component stream of a multi-folded thread;
- **dV**, N - elementary increment in bending force of the component stream of a multi-folded thread;
- **F**, N - reaction force of the multi-folded thread's components;
- **K**, - - coefficient determining the rigidity of twisting thin rods;
- **B**, - - coefficient determining the rigidity of bending thin rods;
- ρ_s, kg m^{-3} - density of component yarn;
- β_n, rad - angle formed by the axis of the component fibre stream with the direction of the multi-folded thread.

1. Introduction

Yarn twist is one of the most important morphological yarn features which influences yarn properties (such as the breaking strength) and significantly determines its processing. Folding is applied to improve the quality properties of yarn [8]. Yarn folding, which means twisting together some component yarns, causes uniform improvement of the yarn's linear density, improvement in abrasion resistance, a decrease in the rigidity of yarn bending, and a decrease in yarn pilling.

2. Aim of the work

This work was carried out with the aim of analysing methods which have been published up to now for modelling the twist of a multi-folded thread composed of two component yarns (doubled thread, doubled yarn). The analysis presented includes a comparison of different considerations concerning the possibility of forecasting the twist values of component fibre streams such as roving and yarns. The problem of single yarn twisting is comprehensively described in works published until now, but there is a lack of sufficient information related to the twisting of multi-folded threads. This problem is very crucial, as the possibility of forecasting the twist value of component streams of multi-folded threads would allow us to replace expensive industrial experiments by numerical experiments with the use of computers. the models of yarn twisting elaborated by Koechlin, Emmanuel & Plate, and Fraser & Stump [1-4, 9, 12, 15] were taken into consideration in this analysis.

3. Physical models of twist of a multi-folded thread

3.1. Theoretical considerations of multi-folded thread twisting based on the Koechlin eduction

Koechlin was one of the first researchers who initiated considerations of yarn twist. His research works was published at the beginning of the nineteenth century. All further investigations are based on Koechlin's eductions and are named after him in engineering applications. A schematic view of a twisted multi-folded thread in the form of a doubled thread is presented in Figure 1. Two component yarns are twisted around the multi-folded thread axis during folding.

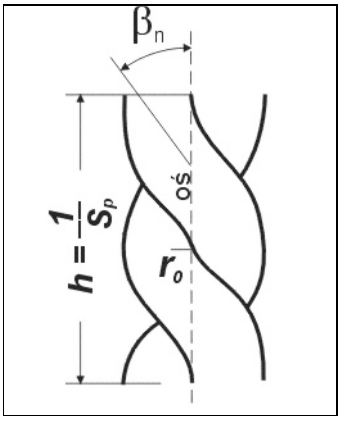

Figure 1. Schema of a twisted multi-folded thread (doubled yarn) accepted for consideration [12, 13]

The following simplified assumptions were accepted as the basis of further considerations:
1. The multi-folded thread (doubled thread) is formed from component yarns of equal linear density, equal twist, and twist direction: $\mathbf{R_s}$ = constant, $\mathbf{S_s}$ = constant, and $\mathbf{Tt_s}$ = constant;
2. Yarn contraction is not taken into account.

On the basis of the thread dimensions presented in Figure 1, equation (1) describing the torsion $\aleph$ was educed. Torsion is determined as the rotation of the multi-folded thread cross-section perpendicular to its axis measured in radians.

$$\aleph = \frac{2\pi}{h} \cdot \frac{x^2 + 6y^2}{\left[\left(x^2 + y^2\right)g_n{}^2 + 1\right]\left(x^2 + 4y^2\right) - x^2 y^2 g_n{}^2} \tag{1}$$

where:

$$x = \frac{r_0}{R_s}; \qquad y = \frac{r_1}{2\pi R_s}; \qquad g_n = \frac{2\pi R_s}{h}; \qquad h = \frac{1}{S_p};$$
$$R_S = \sqrt{\frac{Tt_s}{\pi\rho_s}}; \qquad g_n = \mathrm{tg}\,\beta_n = 2\pi R S_p; \tag{2}$$

x - coefficient dependent on the number of folds and twists of yarn,
g_n - twisting parameter of the multi-folded thread;
h - pitch of the helical line of twist;
r_0 - radius of any of the yarn cross-section layers, $0<r_0<R_s$;
r_1 – radius of the component yarn within the range of one pitch of the twist's helical line.

While twisting the component yarn, the fibres are bent in such a way that their axis forms a three-dimensional curve similar to a helical line with changing pitch (h).

The increase in twist per unit length (Δ**S**) of the component yarn screwed in the multi-folded thread is described by the formula $\Delta S = \aleph/2\pi$, and after insertion of (1) for $\aleph$ equals:

$$\Delta S = \frac{\aleph}{2\pi} = S_p \frac{1}{1 + x^2 g^2{}_n} \tag{3}$$

The twist number per 1 mm length of the component yarn screwed in the multi-folded thread is determined by equation (4):

$$S_{s1} = S_s + (-1)^i S_p \frac{1}{1 + x^2 g_n{}^2} = S_s + (-1)^i S_p \frac{1}{1 + 4\pi^2 x^2 R^2{}_s S_p{}^2} \tag{4}$$

where:
S_{s1} - twist of the singular yarn after screwing it into the multi-folded thread, per mm;
S_s - twist of the singular yarn before screwing it into the multi-folded thread, per mm; and
i - coefficient – exponent of (-1), i = 1 for opposite twists and i = 2 for consistent twists.

Equation (4) allows us to state that the twist **S_s** of the component yarn depends on its radius and the pre-set twist value **S_p** of the multi-folded thread, its direction and the pitch of the helical line.

3.2. Considerations of Emmanuel & Plate

Emmanuel & Plate considered the twist problem of Siro Spun yarn [1, 2, 9]. This yarn is composed from two rovings twisted together.

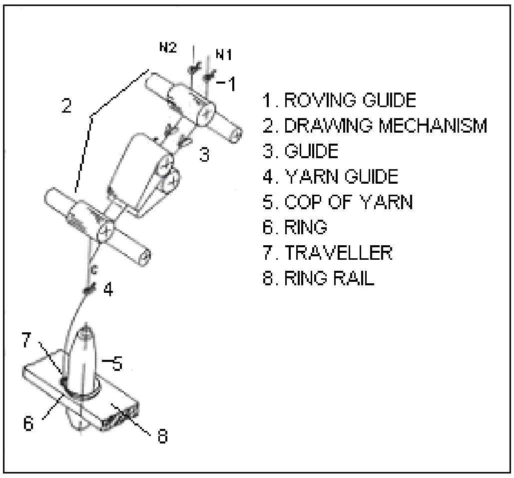

Figure 2. Schema of the twisting-and-spinning mechanism of a ring spinning frame [4]

The process of Siro Spun yarn formation is presented in Figure 2 [4]. Two rovings, N_1 and N_2, are guided through a modified drawing apparatus (2) mounted on a ring spinning frame [6]. The rovings are inserted into the drawing apparatus by guides (1). The guides (3) and dividers, which are inserted before the middle and front roller, serves to run the two fibre streams separately through the drawing rollers' grips. The fibre streams are twisted in one yarn and coiled onto the cop (5) by means of the traveller (7) which rotates guiding by the ring (6).

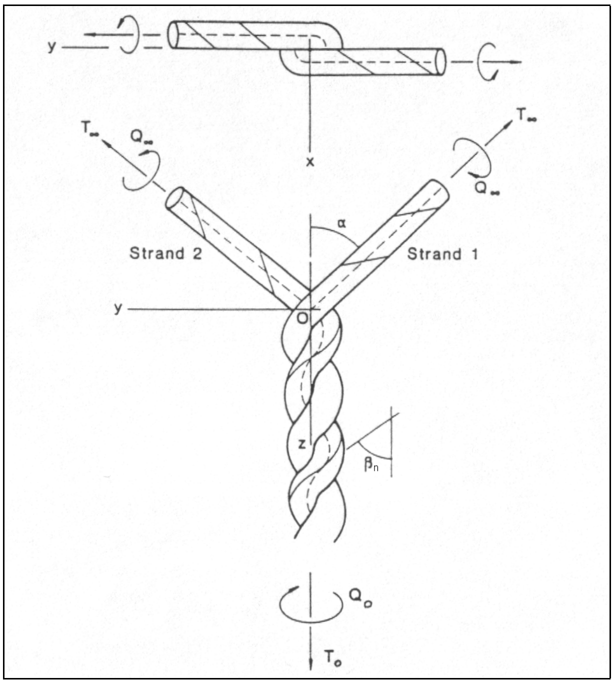

Figure 3. Schema of a twisted multi-folded thread accepted for consideration, and presented in the Cartesian co-ordinate system [3]

The following simplified assumptions were accepted in these considerations;

- the multi-folded thread consists of two rovings of ideal circular cross-section shapes: **R** = constant, the rovings' cross-sections will not be deformed in their plane as a result of twisting;
- the components of the multi-folded thread have an assumed constant bending rigidity; and
- yarn contraction was not taken into account.

A schema of a multi-folded thread composed from two rovings is presented in Figure 3. The directions of tensions $\mathbf{T_0}$ and $\mathbf{T_\infty}$ and of the twisting momenta $\mathbf{Q_0}$ and $\mathbf{Q_\infty}$ are visible in this figure. The whole system is in static equilibrium.

Dependencies describing the tensions $\mathbf{T_0}$ and $\mathbf{T_\infty}$, and the twisting momenta $\mathbf{Q_0}$ and $\mathbf{Q_\infty}$ of the multi-folded thread below and above the rovings' contact point (point O visible in Figure 3) are presented below:

$$T_0 = 2T_\infty \cos\alpha \quad (5)$$

$$Q_0 = 2aT_\infty \sin\alpha + 2Q_\infty \cos\alpha \quad (6)$$

$$T_\infty = \frac{T_0}{2\cos\beta_n} \quad (7)$$

$$Q_\infty = \frac{Q_0 - T_0 tan\beta_n}{2\cos\beta_n} \quad (8)$$

Emmanuel & Plate stated [9] that the following relation can be elaborated for the process of manufacturing Siro Spun fibres:

$$S_s = \frac{S_p}{1 + 4\pi^2 R_s^{\ 2} S_p^{\ 2}} \tag{9}$$

The dependency cited above allows us to state that the twist $\mathbf{S_s}$ of rovings depends on the roving's radius and the pre-set twist value of the multi-folded thread. By comparison of equations (9) and (4), it is visible that the twist direction (Z/Z, S/S or Z/S, S/Z) of folding was not considered in the latter considerations, which allows us to make the statement that equation (4) is more universal.

3. 3. Considerations of Fraser & Stump

The considerations of Fraser & Stump were based on Emmanuel's, Lappage's, and Plate's investigations [1, 2, 9] and on using the theory of the bending and twisting of thin rods. Their model considered the material properties **E**, **G**, and ν of the component streams.

Fraser & Stump analysed the twist of a multi-folded thread of the Z direction which was composed of two twisted-together component fibre streams of the S direction.

The following simplified assumptions were accepted in these considerations:
1. circular shape of the yarns' cross-section $\mathbf{R_s}$ = constant, the roving's cross-section will not be deformed in its plane as a result of twisting;
2. the yarn is not stretchable (no elongation occurs during twisting);
3. friction between the component streams was not considered; and
4. yarn contraction was not taken into account.

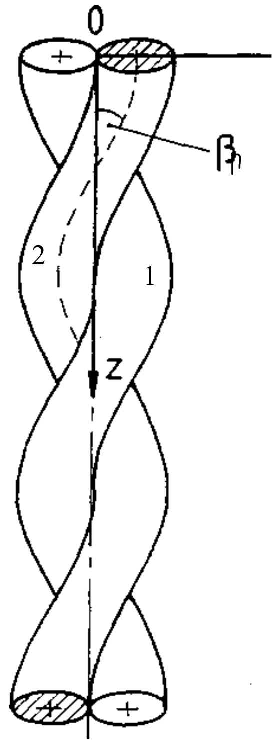

Figure 4. Schema of two thin rods

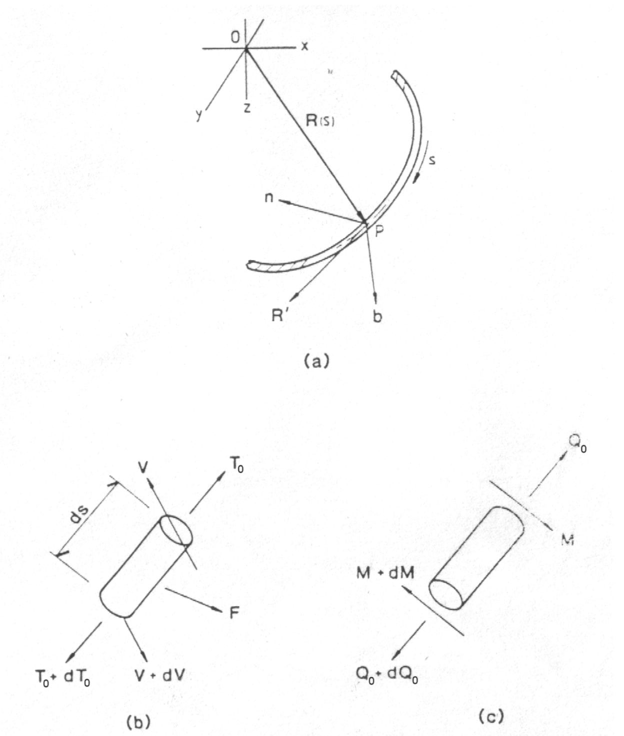

Figure 5. Schematic drawings presenting: twisted together, and presented a) Position of the radius vector R', the normal in the Cartesian co-ordinate system [4] main vector n, and the bi-normal vector b; b) forces acting on an element of the component fibre stream; c) momenta acting on an element of the component fibre stream [3, 4]

A schematic diagram of two twisted-together thin rods presented in Cartesian co-ordinates is shown in Figure 4. The radius vector **R(s)** of the material point **P**, positioned on the component yarn axis which describes its position in relation to the pre-set initial 0-point of the co-ordinate system **0xyz**, is clearly visibly in Figure 5a. The directions of the tangential vector **R'**, the main normal vector **n**, and the bi-normal vector **b** are presented in this figure on the basis of Frenet's trihedron, which is formed by three mutual perpendicular planes connected with every point **P** of the three-dimensional curve.

Figure 5b. presents the forces acting on the elementary segment **ds** of the component fibre stream. The designations are as follows:
V – bending force of the component fibre stream of a multi-folded thread,
dV – elementary increment in bending force of the component fibre stream of a multi-folded thread,
T_0 – tension of the component fibre stream of a multi-folded thread,
dT_0 – elementary increment in component tension of the fibre stream, and
F – force of the reaction of component fibre streams.

Figure 5c. presents the momenta acting on an elementary segment **ds** of the component fibre stream. The designations are as follows:
M – bending momentum of the multi-folded thread,
dM – elementary increment of the bending momentum of a component fibre stream,
Q_0 – twisting momentum of roving, and
dQ_0 –elementary increment of the bending momentum of a component fibre stream.

Considerations aimed at determining the dependencies between the twist of component yarns and the twist of the multi-folded thread were based [3, 4] on a description of bending and twisting rigidity of thin rods which were educed by Timoshenko & Young [10]:

$$K = \frac{1}{2} GAR_s{}^2 \text{ i } B = \frac{1}{4} EAR_s{}^2 \tag{10}$$

Accepting ν as the Poissone coefficient, we can formulate:

$$G = \frac{E}{2(1+\nu)} \text{ i } K = \frac{B}{1+\nu} \tag{11}$$

By inserting the coefficient κ into the equations, and transforming equations (10) and (11), we obtain:

$\kappa = K/B = 1/(1 + \nu)$

Emmanuel & Plate [1] educed equation (9) under the condition that twisting of the rovings is uninterrupted in the rovings' contact point (point 0 in Figure 3). This means that the twist of roving after screwing it into the multi-folded thread $S_{s1} = 0$ (according to equation 12).

$$S_{s1} = \frac{1}{2\kappa \cos 2\beta_n} \left(Q_0 \cos \beta_n - T_0 \sin \beta_n - 4 \cos \beta_n \sin^3 \beta \right) - \cos \beta_n \sin \beta_n \tag{12}$$

Elaborating the theory of thin rods, it was assumed that twisting is interrupted in the rods' contact point, and that a correction should be inserted into equation (9). By taking into account the considerations cited above, the bending momentum of the multi-folded thread below the contact point of the rovings is:

$$Q_0 = T_0 tan\beta_n + 4\kappa \sin \beta_n \cos 2\beta_n \tag{13}$$

This latter result was substituted as **Q_0** into equation (8), resulting in equation (14):

$$Q_\infty = \kappa \cos \beta_n \sin \beta_n + (2-\kappa) \frac{\sin^3 \beta_n}{\cos \beta_n} \tag{14}$$

This allows us to enduce the roving's twist above the contact point:

$$S_s = \frac{Q_\infty}{2\pi\kappa R_s} = \frac{1}{2\pi R_s} \left[\cos \beta_n \sin \beta_n + \frac{(2-\kappa)}{\kappa} \frac{\sin^3 \beta_n}{\cos \beta_n} \right] \tag{15}$$

Fraser & Stump educed the dependency of the twist of multi-folded threads on the basis of Figure 4:

$$S_p = \frac{tan\beta_n}{2\pi R_s} \qquad (16)$$

which results in:

$$\sin\beta_n = \frac{2\pi R_s S_p}{\sqrt{1+4\pi^2 R_s{}^2 S_p{}^2}}; \qquad \cos\beta_n = \frac{1}{\sqrt{1+4\pi^2 R_s{}^2 S_p{}^2}} \qquad (17)$$

On the basis of equations (16) and (17), the consideration result was obtained in the form of equation (18):

$$S_s = \frac{S_p}{1+4\pi^2 R_s{}^2 S_p{}^2}\left[1+\frac{(2-\kappa)}{\kappa}4\pi^2 R_s{}^2 S_p{}^2\right] \qquad (18)$$

From this relation, it results that the twist $\mathbf{S_s}$ of the component fibre streams depends on the roving radius $\mathbf{R_s}$, the pre-set twist value $\mathbf{S_p}$ of the multi-folded thread, and the coefficient κ which characterises the material parameters of the component fibre streams. By comparing equation (18) with equations (4) and (9), and by accepting a pre-set value of ν for cotton $\nu = 0.3$ [12], it could be stated that a calculation which considers the material parameters of the component fibre streams causes an increase in the twist value $\mathbf{S_s}$.

When carrying out their investigations, Fraser & Stump also analysed the problem of the 'degree of twist unbalance' of multi-folded threads. This problem was also considered by Frydrych [5], who stated that the level of the twisting momentum of multi-folded threads determines the twist equilibrium characteristic as well as the processing properties of yarns.

4. Summary

Analyses of twist of multi-folded threads were carried out by many researchers [1-4, 8, 12, 13]. All of them accepted many simplifying assumptions related to the physical models considered. These assumptions reflected the real object in various degrees. As a result of these simplifications, the models under consideration could be analysed more easily. The main problem of all these considerations was the influence of the twist value of multi-folded threads on the twist value of component yarns.

The researchers cited in [12, 13] carried out their works on the basis of the twist structure of a multi-folded thread consisting of two yarns (doubled thread, doubled yarn), whereas the researchers cited in [1-4, 9] analysed the twist of Siro Spun yarns manufactured from two rovings connected together in the operation of ring spinning.

In their publications Fraser & Stump demonstrated [3, 4] that the bending and twisting momenta, as well as the tension which occurs as a result of yarn twisting, can be described on the basis of the theory of twisting and bending thin rods connected together. The material parameters of yarns were taken into consideration only within the model presented by Fraser & Stump, and it should be emphasised that this caused an increase in the twist value $\mathbf{S_s}$.

The research work presented above concerns an analysis of the considerations carried out until now of the influence of the pre-set value of the twist of a multi-folded thread on the twist value of the component yarns. The next phase of our work will be a consideration of the twist equilibrium of a multi-folded thread composed of N yarns; this consideration will also include an examination of yarn contraction. The investigation planned is also aimed at developing and verifying an algorithm and computer programme for modelling the twist of multi-folded threads.

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