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# Influence of changes in Yarn Twist on the Dynamics of Yarn Motion During Spinning on a Ring Spinning Machine

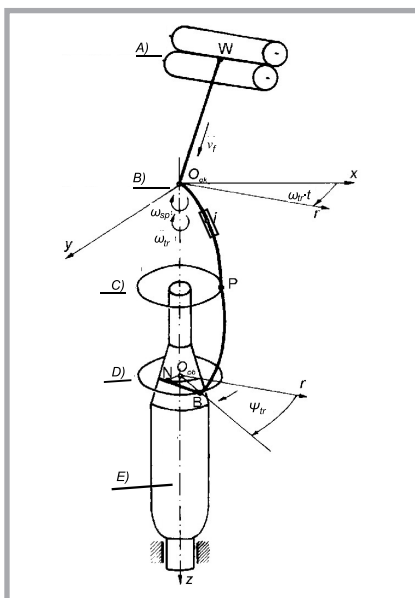
## Abstract

The value of twist is an essential yarn property for a spinner. This paper presents an analysis of the influence of changes in the yarn twist value on yarn tension and the stability of yarn formation conditions, including the balloon shape, while using a ring-spinning machine. In order to carry out this analysis, a computer program was used, which was designed on the basis of a mathematical model developed by the author of the dynamics of the twisting-and-winding unit. The results of numerical calculations are presented in the form of charts.

**Key words:** ring spinning machine, twisting-and-winding unit, yarn twist, yarn motion dynamics, mathematical model, numerical experiment.

## Introduction

The twisting-and-winding unit of a ring-spinning machine presented in Figure 1 is the research object of this article. A previously elaborated physical model of this unit was accepted for consideration [4]. The model includes the following elements and units: the yarn which is transported through the twisting-and-winding unit (with a speed depending on the feeding speed, the assumed value of yarn twist and the spindle speed), the delivery rollers of the drawing apparatus, the guiding eye, the balloon limitation element, the traveller which co-operates with the ring, and the spindle with the bobbin.



**Figure 1.** Scheme of the twisting-and-winding unit accepted for consideration [4]; A) plane of the feeding (delivery) roller; B) plane of the guide eye; C) plane of the balloon limiting element; D) plane of the ring; E) axis of the ring spindle

The yarn transportation speed is determined by the machine's efficiency and the dynamic phenomena [5], which are mirrored by the form and stability of the balloon, among others.

The spinner, which uses the value and direction of twisting the fibre stream, exposes the properties of the spinning material, and at the same time creates new, unique aesthetic and useful properties in the yarn.

In order to follow the trends in modern fashion, which change dynamically, and the client demands connected with them, the technologist must take into consideration the work of the twisting-and-winding unit under conditions of different, assumed and accepted twists of yarn. Sometimes these may be values from the very limits of the technology available for the unit's working conditions. In such a situation, tests with the use of a real object are burdened by risk and not recommended. However, it is reasonable to, carry out numerical experiments with the use of a computer program, which would imitate the occurrence of phenomena and processes which occur or may occur in the object analysed.

In the elaboration presented, thanks to using a stimulator, the isolated influence of the yarn twist on the yarn tension and balloon shape during the transportation of the yarn through the twisting-and-winding unit is shown for a wide range of changes in the yarn twist values. Such a presentation is a novelty in comparison to those hitherto described by available publications [1, 2, 9].

A computer program elaborated on the basis of a mathematical model [4] of

the dynamics of a twisting-and-winding unit was used as a simulator. The model enables the analysis of the dynamic equilibrium of a yarn element, which is especially important as it is placed in the free part of the balloon, as well as the elements which are in direct contact with the traveller, the balloon limitation element, the guiding eye, and the yarn element which is placed on the length of yarn above the guiding eye. Furthermore, the dynamic equilibrium of the traveller motion around the ring, the yarn elasticity, as well as the random and deterministic input function were considered. The modelling process was discussed in [4].

## The aim of the elaboration and research program

The aim of this elaboration is to present the influence of changes in the twist value on the dynamics of yarn motion during spinning, characterised by the following features:

- the time-dependences of yarn tension  $T_y = f(t)$ ;
- the values of average yarn tension  $T_{y,av}$  and the amplitude of yarn tension oscillations  $T_{yA}$ ; and
- the balloon shape and animation of the yarn motions in the balloon.

Correlation and regression analyses were used in order to analyse the dependences between the yarn twist values and the parameters which characterise the yarn tension [3].

Numerical experiments were carried out at assumed, technologically justified parameters [7] of a ring spinning frame, with cotton yarn; the parameters are presented in Table 1. The detailed calcula-

Table 1. Experiment parameters.

Parameter	Symbol	Unit	Value
Linear density of the cotton yarn	$Tt_y$	tex = mg/m	12
Yarn twist	$Tw_y$	rotations per meter	400 - 1370
Twist coefficient	$\alpha_{Tt}$	-	1386 - 4743
	$\alpha_{Nm}$	-	44 - 150
Linear speed of yarn delivery	$v_f$	m/minute	7 - 25
Coefficient of air resistance	$C_r$	-	0,96 [1]
Coefficient of kinetic friction of the pair: yarn – steel	$\mu_y$	-	0,29 [4]
Traveller mass	$m_{tr}$	g	0,052
Spindle rotary speed	$n_{sp}$	r.p.m.	167
Balloon height	$H_{bl}$	m	in relation to the bobbin's base
Minimum bobbin radius	$r_{b,min}$	m	
Maximum bobbin radius	$r_{b,max}$	m	

tions were based on the constructional parameters of the PJ ring spinning frame, produced in Poland.

The simulation was carried out for an object characterised by a deterministic basic input function, determined by the particular construction of the twisting-and-winding unit [4].

At normal working conditions of the spinning frame, change in the twist value  $Tw_y$  is realised only by altering and next setting the feeding speed  $v_f$  of the delivery rollers of the drawing apparatus. The rotary speed  $n_{sp}$  of the spindles is constant at the same time.

In order to present the influence of changes in the twist value, obtained by changing the feeding speed, on the dynamics of yarn motion, numerical experiments were carried out for selected parameters, listed in Table 1.

### Theoretical considerations

Traveller  $B$ , which moves around the raceway of the ring with an angular speed  $\omega_{tr}$ , twists the fibre stream fed with the speed  $v_f$  at the same creating forces which determine the yarn tension value  $T_y$ . The tension is distributed along the whole yarn segment, which is transported through the twisting-and-winding unit [1, 2, 9, 10].

During the manufacturing of yarn, its tension and the shape of the balloon are determined by the working parameters of the unit. The change in these parameters, resulting from the tasks performed, cause a change in the ratio of the forces acting on a rotating yarn segment, as well as in the total yarn tension  $T_y$ . This raises the question of how the twist value changes,

especially over a wide range of values, as well as how it influences the dynamics of yarn motion, characterised by the dependency of yarn tension on time and balloon shape.

In order to find an answer to this question, the forces acting on a rotating elementary yarn segment, which are displayed in Figure 2, and their changes (resulting in the yarn twist value analysed) were calculated, and next a numerical experiment was carried out which showed the influence of twist on the dynamics of yarn motion.

According to Figure 2, it is not only the forces of tensions  $T_y$  and  $(T_y + dT_y)$ , the latter being the reaction of the neighbouring yarn elements, which act on the rotating yarn element 'i', but also the following differential forces: the air resistance  $dF_a$ , the centrifugal force  $dF_{cen}$ , the Coriolis force  $dF_{Cs}$ , and the yarn inertia force  $dF_{y,in}$ .

The forces of air resistance  $F_a$  (and at the same  $dF_a$ ) are proportional to the square of the actual yarn speed, as well as to the longitudinal cross-section area of the yarn element, and the yarn resistance coefficient. According to Figure 3, the vector of the yarn velocity  $v_y$  is the sum of the vector of the rotating speed  $(\omega_{tr} \times r_i)$  of the traveller and the vector of the feeding speed  $v_f$

$$v_y = (\omega_{tr} \times r_i) + v_f \quad (1)$$

where:

$r_i$  – is the radius-vector of the yarn element 'i'.

The rotary speed  $\omega_{tr}$  of the traveller is connected with the assumed rotary spindle speed  $\omega_{sp}$  and the actual bobbin radius  $r_b$  by the equation:

$$\omega_{tr} = (\omega_{sp} \cdot r_b - v_f) / r_b \quad (2)$$

The longitudinal cross-section area  $S_{yi}$  of the elementary yarn segment 'i' of length  $\Delta l_i$  connected with its diameter  $d_{yi}$  equals:

$$S_{yi} = d_{yi} \cdot \Delta l_i \quad (3)$$

Where the yarn diameter is determined by the Pierce [12] equation:

$$d_y = (4 \cdot Tt_y / \pi \rho_y)^{1/2} \quad (4)$$

where:

$\rho_y$  – is the yarn's material density, which is proportional to the twist coefficient  $\alpha_{Tt}$ , described by the Barella dependence [12]:

$$\rho_y = 600 + 85.4 \cdot \alpha_{Tt}, \text{ in kg/m}^3 \quad (5)$$

Considering the changes in the value of the air resistance force  $F_a$ , as

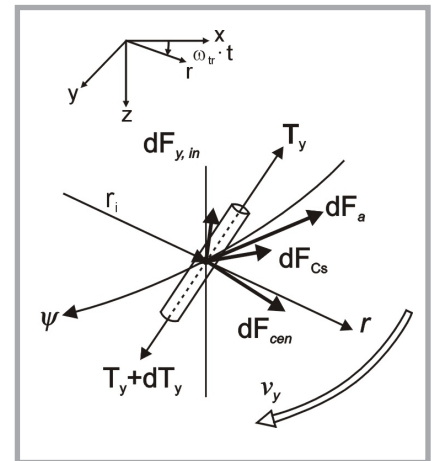


Figure 2. Forces acting on the element 'i' of the yarn segment within the balloon.

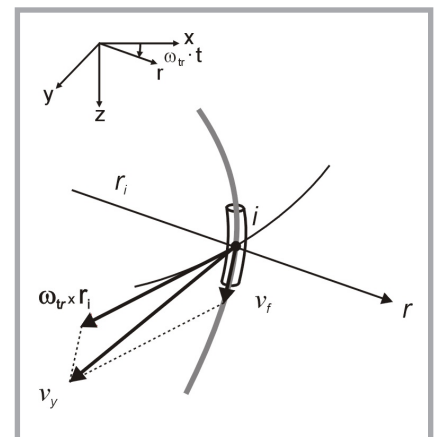


Figure 3. Direction of the speed vector  $v_y = (\omega_{tr} \times r_i) + v_f$  of the elementary 'i' segment of yarn within the balloon, which is the sum of the rotary speed vector  $(\omega_{tr} \times r_i)$  and the yarn feeding speed vector  $v_f$ .

the consequence of changes in the yarn feeding speed, we can state that the yarn speed of its rotary motion ( $\omega_{tr} \times r_i$ ) is significantly greater than its feeding speed  $v_f$ , which may be described by:

$$\omega_{tr} \times r_i \gg v_f \quad (6)$$

Therefore, we may assume that a numerical experiment carried out with separated values of the feeding speed  $v_f$ , as a way of realising the assumed set twist values  $T_{w_y}$ , will not create essential changes in the air resistance force.

On the other hand, while analysing the centrifugal force  $F_{cen}$ , which acts on the yarn element 'i' ( $dF_{cen}$ ), we can state that it is proportional to the mass of the element  $\Delta m_i$ , radius vector  $r_i$ , and yarn feeding speed  $v_f$ . From the previous considerations it can be observed that the feeding speed is significantly smaller than the peripheral speed ( $\omega_{tr} \times r_i$ ), and what is more, the radius of the balloon's curvature  $r_{b,c}$  is much greater than the radius vector  $r_i$ , and hence the following dependency may be given:

$$v_f^2 / r_{b,c} \ll \omega_{tr}^2 \times r_i \quad (7)$$

Thus, a conclusion can be drawn that changes in the feeding speed  $v_f$  do not cause significant alterations in the value of the yarn's centrifugal force.

The subsequent force, whose value will vary with a change in the yarn feeding speed  $v_f$ , is a Coriolis force, described by the dependency:

$$F_{Cr} = \Delta m_i \bullet (2v_f \times \omega_{tr}) \quad (8)$$

Equation (8) proves that the significance of the feeding speed for value  $F_{Cr}$  rises with its increase. However, when the feeding speed is relatively low, characteristic of a ring-spinning frame, it only has a secondary, unimportant influence on the Coriolis force.

The changes in the parameters of the twisting-and-winding unit, as well as differences in yarn parameters, which may be caused by e.g. yarn irregularity, result in disturbances of the yarn segment movement as it is guided through the unit. They were considered while designing the model by including the yarn inertia force  $F_{y,in}$  in its mathematical characteristic in the form of the quotient of the mass of the elementary element of the yarn segment and its acceleration.

The above-presented analysis of forces acting on the yarn element allows to state that the air resistance force  $F_a$  has the greatest importance for the value of yarn tension  $T_y$ , which is in agreement with research results presented in [1, 2, 10].

As was demonstrated, the yarn feeding speed  $v_f$  of a ring-spinning frame is significantly smaller than the yarn's peripheral speed ( $\omega_{tr} \times r_i$ ) in the ascending motion. Therefore, we may predict that a change in the twist value within a very wide range, caused by a change in the yarn feeding speed, would not cause disturbances of the stability of yarn manufacturing conditions.

The quantitative evaluation of the influence of yarn twist on the balloon's shape and yarn tension by measuring the actual values of the real object is very difficult, as the reaction of the twisting-and-winding unit and the yarn is a complex, confounding function of the unit's and yarn parameters as well as their irregularities and imperfections. Thus, a need arises to use a simulator to visualise the isolated influence of changes in yarn twist on the dynamics of yarn motion.

### Presentation of simulation results.

As a result of the simulation investigations carried out, a lot of numerical data and charts were obtained which illustrate changes in the yarn tension and balloon shape as functions of time. Considering the great amount of results obtained and the limited space in this article, only four time dependences of the tension  $T_y = f(t)$  are presented in Figures 4 – 7.

In Figure 4 a time-dependence is presented at the minimum twist value of  $T_{w_y} = 400$  t.p.m. (expressed by rotations per metre), caused by the maximum yarn feeding speed of  $v_f = 25$  m/minute.

For the experiment carried out, the character of changes in the average tension value  $T_{y,av}$  and the yarn tension amplitude  $T_{y,A}$ , which are a result of a change in the twist value ( $\Delta T_{w_y}$ ) within the whole range of values accepted, are graphically presented in Figures 5 and 7 for the cases of winding yarn at the maximum and minimum radii of the bobbin.

Verification of the statistical hypothesis of the correlation significance between  $T_{w_y}$  and  $T_{y,av}$ , as well as between  $T_{w_y}$  and  $T_{y,A}$  at the condition of a constant balloon height and bobbin radius, at a significance level of  $\alpha = 0.05$  and degree of freedom  $n - 2 = 17$ , confirm the hypothesis that within the whole range of investigations carried out, a correlation exists between the features tested.

An example is shown in Figure 6 of the instantaneous shape of the balloon in the planes of yarn and ring rotation together with the time-dependences of yarn tension  $T_y = f(t)$  at the minimum twist value  $T_{w_y} = 400$  t.p.m. and feeding speed of  $v_f = 25$  m/minute.

### Final remarks and conclusions

Considering the influence of the yarn's twist value, within the ranges

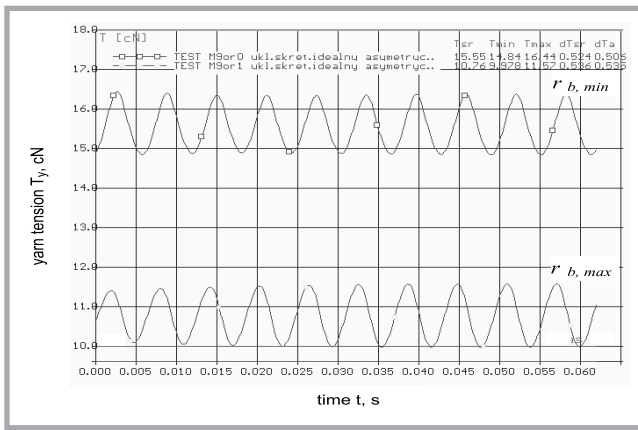
of  $T_{w_y} \in < 400 \text{ t.p.m.} - 1429 \text{ t.p.m.} >$ , and

of  $v_f \in < 7 \text{ m/minute} - 25 \text{ m/minute} >$

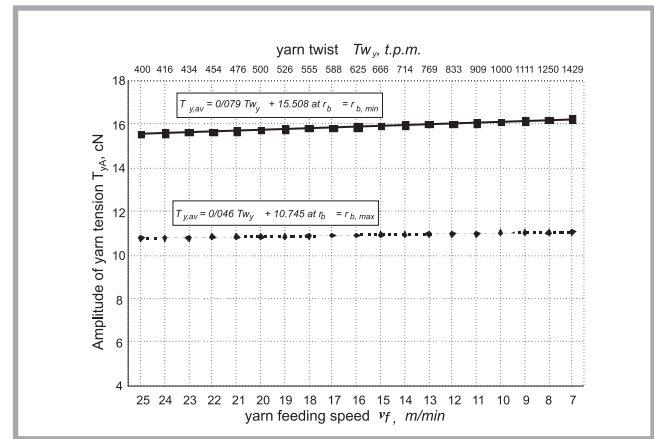
on its average tension, we can state that it is almost insignificant from the point of view of a technologist. This is illustrated in Figure 5, where there is only a very small increase in the yarn's average tension as a function of twist ( $T_{y,av} = f(T_{w_y})$ ). The intensity of these changes is comparable for the radius analysed:  $r_b = r_{b,min}$  and  $r_b = r_{b,max}$ .

The changes in the twist value are mirrored more strongly in the dependency of the yarn tension amplitude on the twist value. As is visible in Figure 7, the increase in twist value  $T_{w_y}$  causes a remarkable decrease in  $T_{y,A}$  with different intensities at various bobbin radii. The maximum, comparable values of the yarn tension amplitude at the particular bobbin radius analysed occurred at a minimum twist value of  $T_{w_y} = 400$  t.p.m., caused by the maximum yarn feeding speed of  $v_f = 25$  m/minute. A further increase in the twist value caused, as a result of an increase in the yarn's rigidity, a decrease in the yarn's sensitivity to irregularities and fewer changes in the working conditions of the unit.

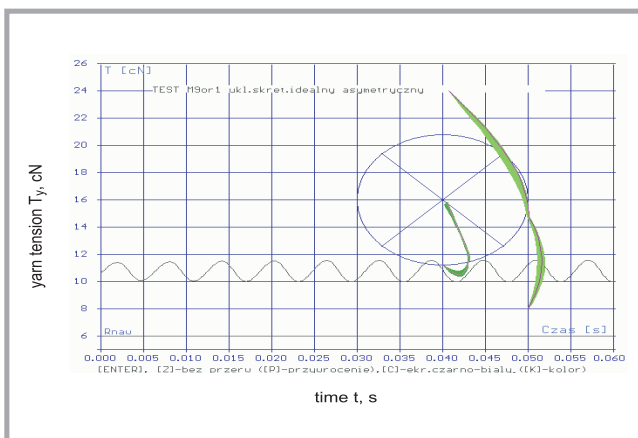
From observation of the time-dependences in Figure 4 and the balloon shape



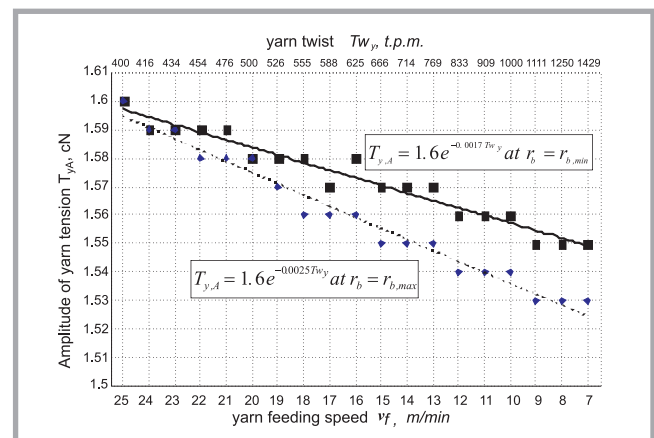
**Figure 4.** Time-dependency of yarn tension  $T_y = f(t)$  at yarn twist  $Tw_y = 400$  t.p.m. and yarn feeding speed  $v_f = 25$  m/minute while winding the yarn at the maximum ( $r_{b,max}$ ) and minimum ( $r_{b,min}$ ).



**Figure 5.** Regression lines  $T_{y,av} = f(Tw_y)$  for average values of simulated yarn tension as a function of yarn twist values at bobbin radius  $r_b = r_{b, min}$  and  $r_b = r_{b, max}$ .



**Figure 6.** Instantaneous shape of the balloon together with the time dependency of yarn tension  $T_y = f(t)$  for yarn with twist  $Tw_y = 400$  t.p.m. at a feeding speed of  $v_f = 25$  m/minute.



**Figure 7.** Regression lines  $T_{y,A} = f(Tw_y)$  for amplitude values of simulated yarn tension as a function of yarn twist values at bobbin radius  $r_b = r_{b, min}$  and  $r_b = r_{b, max}$ .

In Figure 6 it can be concluded that changes in the twist values of yarn, with an assumed linear density  $Tl_y = \text{const}$ , causes a change in its material parameters - primarily its rigidity. Subsequently, the rigidity influences the susceptibility of the yarn to twisting and bending. In this way we have a specific feedback. The change in the twist value causes a change in the yarn's compactness by increasing the packing of the fibres in the yarn core, as well as a change in its hairiness. These subsequently result in a change in the air resistance coefficient, and the friction coefficients of the yarn sliding on the twisting-and-winding elements of the unit. It is well known from engineering praxis that the twisting-and-winding unit, which twists the yarn, is very sensitive to changes in the friction conditions. Therefore, we should assume that while working at actual conditions, the influence of changes in the yarn twist value on its tension and the balloon shape will be more distinct.

## References

- Batra S. K., Ghosh T. K., Zeidman M. I.: *An Integrated Approach to Dynamic Analysis of the Ring Spinning Process, Part I, Textile Research Journal*, 1989, No 6, s. 309-317; *Part II, Textile Research Journal*, 1989, No 7, s. 416-424; *Teil III, Textil Praxis International*, 1992, No 9, s. 791-799; *Part IV, Textile Research Journal*, 1995, No 7, s. 417-423.
- Fraser W.B., Farnell L., Stump D.M.: *The Effect of Slub on the Stability of the Ring-spinning Ballon, The Journal of the Textile Institute*, 1995, Vol.86, No 4.
- Gref J.: *Mathematical Statistic: Models and Exercises, (in Polish)*, PWN, Warsaw.
- Przybył K.: *Simulating the Dynamics of the Twisting-And-Winding System of the Ring Spinning Frame. Fibres and Textile in Eastern Europe*, 2001, Vol.9, No 1, s.16-19
- Przybył K.: *Stability of Working Conditions of the Twisting-and-Winding System of the Ring Spinning frame in Dependence on yarn Material, Fibres and Textile in Eastern Europe*, 2001, Vol. 9, No 4. s. 24-27
- Przybył K.: *Influence of Yarn Surface Properties on the Dynamic of the Twi-*

*sting-and-Winding System of the Ring Spinning Frame, Fibres and Textiles in Eastern Europe*, Vol. 10, April/June 2002, No 2 (37).

- Przybył K.: *Stable Working Conditions of the Twisting-and- Winding System of a Ring Spinning Frame. Fibres and Textile in Eastern Europe*. 2005 Vol. Nr 1 s.35-38
- Rosiak D., Przybył K.: *Considerations about Twist and Properties of Yarns and Multi-Folded Threads, STRUTEX, 11th International Conference, TU Liberec, December 2004. pp.101-108*
- Szneider J., Heitman U., Planck H.: *Development of a ballon control system for the processing of man-made fibres, Melliand International* 2007, No 2, s.97-101
- Tang Z. X., Wang X., Wang L., Fraser W. B.: *The Effect of Yarn Hairiness on Air Drag in Ring Spinning, Textile Research Journal*, Vol 76(7), 559-566, (2006)
- Żurek W., Frydrych I.: *Semantic and technical difficulties into yarn twist determination., (in Polish), Przegląd włókienniczy*, No 2. 1990, pp.35-39
- Żurek W. i inni: *Struktura liniowych wyrobów włókienniczych, WN T, Warszawa Wyd. II, 1989.*

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