D. Radivojevic,
*M. Stamenkovic,
*J. Stepanovic,
*D. Trajkovic

Coherence Analysis of the Charasteristics of Wound Woolen Yarn Deformation

High Technical School of Textile,
Leskovac

***Faculty of Technology,**
Leskovac
Email: natal@ptt.yu

Abstract
In the winding process, on its way from the spinning tube to the bobbin, yarn was exposed to different influences that caused various tensions in different sectors. The increase in the tension force brought about a decrease in the linear density of all the wound yarns. All of this influenced the resulting tension with which the yarn was wound onto the bobbin. After two weeks, the deformation characteristics of these yarns were examined. Also determined were values of the breaking forces and relative elongation at break for all the linear density. On the basis of a F-ε curve, elasticity limits were defined as well as the yield point of the wound yarns analysed. Making use of the recommendations of some investigators, it was possible to project the breaking forces, elasticity limit force and forces at the yield point. The quality control of raw materials, process control and yarn quality control are a necessary help for the technologist to establish a well-set winding process. It is only on the basis of the exact parameters provided by such controls that it becomes possible to intervene correctly and in time in order to achieve optimal results and obtain good quality wound yarn.

Key words: *winding process, deformation characteristics, elasticity limits, yield point.*

Introduction

By increasing the winding speed, new problems appear connected with the yarn tension and its variation, which presents an outstanding problem concerning the quality of the wound yarn. At high speeds there is no time for the relaxation processes to develop, so the yarn winds up the spool with residual deformations and internal tensions, which cause the instability of the yarn dimensions and has a great influence on its behaviour in the subsequent processing procedures [1 – 3] .

Many papers have dealt with the change in balloon shape and yarn tension force in the balloon [2, 3]. An important contribution to this matter was given by research workers at University of Sidney and Clemson University, who analysed nonlinear phenomenon in high-speed yarn transport [4 – 10]. Fraser gave a mathematical model describing the influence of air-drag and balloon-limiter frictional drag on yarn tension in a balloon during winding (***Figure 1***) [11].

The purpose of this paper is to present the derivation of equations for the ballooning of elastic yarn together with some numerical examples to illustrate the effect of yarn elasticity on balloon shape and tension [11].

Accurate positioning of the yarn tension force in processing procedures and its influence on yarn deformation characteristics is a problem that is being intensively worked on: this paper is a part of the effort to solve it. A voluminous paper dealing with this problem was published at Chemnitz Technical University. Deformation characteristics of 65 yarns of various compositions and various uses were examined [12].

The elasticity limit and yield point are important items among fibre and yarn characteristics. They are determined on the basis of graphically interpreted force-elongation dependence. It must be kept in mind that textile fibres and yarns, as typical polymer bodies, possess all three rheological properties (elasticity, viscoelasticity and plasticity), and that under strain the deformations of all three types develop simultaneously at different speeds. Owing to this, even slight strains cause residual (irreversible) deformations of textile materials. Therefore, the

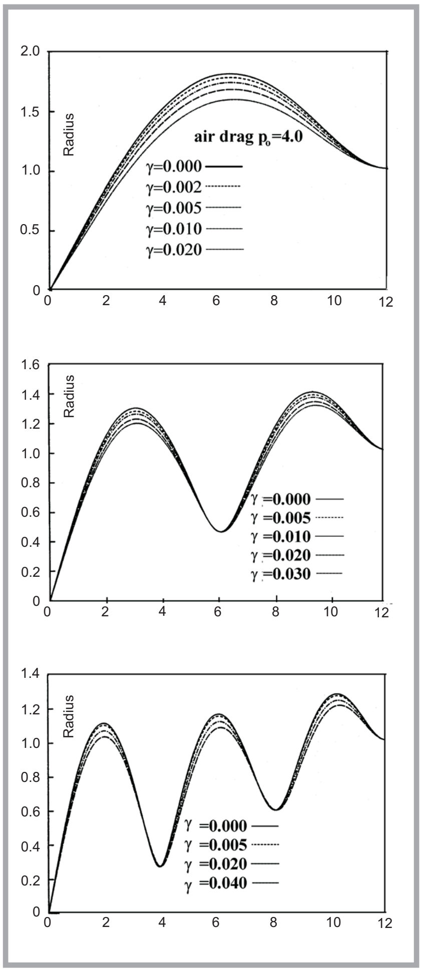

Figure 1. *Unwinding balloon profiles for n=1 (a), n=2 (b) and n=3 (c) [11].*

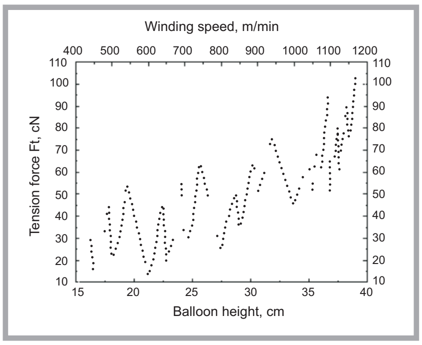

Figure 2. *Dependence of yarn tension forces in cN of 25 tex yarn on the position of yarn on a spinning cop (balloon height) and winding speed [1, 17].*

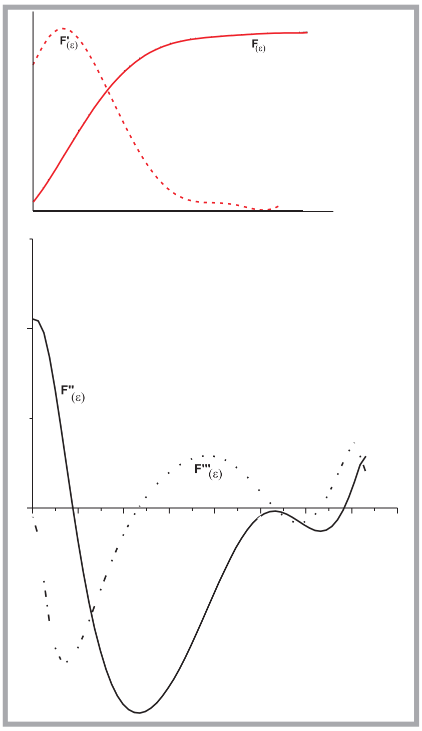

Figure 3. *First, second and third derivatives of the F-ε curve.*

elasticity limits of textile materials are very low. Wegener [13 – 16] defines the elasticity limit as tension that does not cause deformation higher than 0.1% after one minute of relaxation.

Material and examination methods

Woolen yarns from wool fibres T-62 and T-63 spun by the worsted spinning process were used in this investigation. Three yarn types of linear densities of 25, 23 and 21 tex, were spun. Woolen yarns are interesting since woolen fibres have an outstanding viscoelastic deformation component and long relaxation times, which makes them sensitive to tension in the winding process. Material was wiound on an AUTOCONER 238 winding machine with a balloon restrictor, produced by the firm “SCHLAFHORST”. After a relaxation period of two weeks, the mechanical properties of the deformation of the wound yarns were examined.

Yarns tension was measured in the free zone between the tensioner and the sector where it was cross wound onto the bobbin. When examining yarn tensions in the process of winding the yarn onto the bobbins, it must be borne in mind that the resulting tension, with which the yarn is wound onto the bobbins, consists of the tension produced by the yarn unwinding from the bobbin (balloon height), the winding speed and additional tension produced by the tensioners [1, 17].

Combining the factors, quite a number of yarn tension variations were obtained to investigate their influence on the mechanical properties of the yarns.

The procedures for sample production and tension force measurement were the same for all the types of yarn, results of which are given in ***Figure 2*** [1, 17].

For the determination of the breaking mechanical properties of wound yarns, an INSTRON automatic dynamometer was used. On the basis of the F-ε curve, the elasticity limits and yield point of the yarns analysed were defined for all the linear densities.

Borders between the areas of the F-ε curve mentioned were bending points at which the curves changed their slope. In fact the curve slope represented the curve modulus at certain points. On the basis of the model curve the force and relative elongation values at the elasticity limit of the wound yarns Fe (local maximum F′(ε), i.e. F″(ε) = 0) Were determined. Force and relative elongation values at the yield point Fcg of the wound yarns were determined at the point where F′″(ε) = 0 (***Figure 3***) [17 – 22].

Examination results

Figure 4 shows collective F-ε curves of wound yarns made of T-62 wool fibres obtained by winding yarns of 23 tex linear density.

Examination results of the breaking characteristics of the wound yarns are given in ***Tables 1, 2*** and ***3***.

The collective curves F-ε (***Figure 4***) and results given in ***Tables 1, 2*** and ***3*** indicate the following:

- the breaking force values of wound yarns decrease with a decrease in the linear density and yarn twist of wound yarns
- the same decrease tendency was also noted in elongation at break.

Results obtained by the analysis of F-ε curves for 21, 23 and 25 tex wound yarns are shown in ***Tables 4, 5*** and ***6***.

The results given in ***Tables 4, 5*** and ***6*** (see pages 32 and 33) indicate that with the linear density decrease, the elasticity and yield point value and the elongation decrease. The F-ε curve with a gentler slope in the first, linear part of the curve, indicates a smaller deforma-

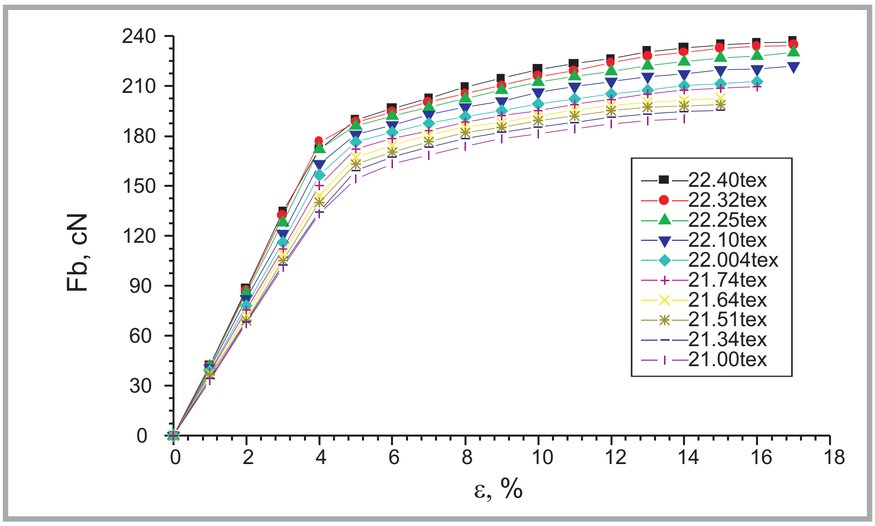

Figure 4. *Collective curve F-ε of wound yarns of 23 tex linear density; (Fb-breaking forces, ε_b- elongations at break).*

Table 1. *Breaking characteristics of 21 tex wound yarns: Fsm - starting modulus for (ε = 1%), Tm - yarn twisting, Fb - breaking force, ε_b - breaking elongation.*

T-62						T-63					
No	Tt, tex	Fb, cN	ε_b, %	Fsm, cN	Tm, m^{-1}	No	Tt, tex	Fb, cN	ε_b, %	Fsm, cN	Tm, m^{-1}
1	20.75	194.4	14.01	40.2	730.12	11	20.62	184.42	13.80	39.21	720.15
2	20.68	192.3	13.90	40.0	728.11	12	20.58	182.33	13.20	38.12	718.71
3	20.54	189.6	13.75	38.6	720.14	13	20.32	178.56	13.02	37.41	710.54
4	20.32	184.4	13.02	36.2	718.15	14	20.12	173.44	12.98	35.22	708.32
5	20.26	180.6	12.91	34.8	715.10	15	20.02	170.61	12.56	33.98	705.16
6	20.10	174.2	12.26	32.0	710.12	16	19.98	166.92	11.85	31.02	702.75
7	20.00	170.3	12.16	31.0	705.14	17	19.64	162.31	11.72	30.82	692.13
8	19.74	162.4	11.89	30.6	700.10	18	19.32	160.41	11.32	29.56	690.80
9	19.62	156.0	10.22	30.0	695.13	19	19.22	153.60	9.75	29.12	685.72
10	19.58	152.3	10.15	29.6	690.14	20	19.18	150.23	9.42	28.56	680.12

Table 2. *Breaking characteristics of 23 tex wound yarns; Fsm - starting modulus for (ε=1%), Tm-yarn twisting, Fb-breaking force, ε_b-breaking elongation,*

T-62						T-63					
No	Tt, tex	Fb, cN	ε_b, %	Fsm, cN	Tm, m^{-1}	No	Tt, tex	Fb, cN	ε_b, %	Fsm, cN	Tm, m^{-1}
21	22.40	236.4	17.4	42.3	655.40	31	22.12	226.41	16.41	41.31	640.14
22	22.32	234.2	17.3	42.2	650.68	32	22.02	224.22	16.31	41.21	635.15
23	22.25	230.2	17.1	41.5	648.54	33	21.98	220.18	16.18	40.58	630.12
24	22.10	222.0	16.8	40.5	646.52	34	21.56	218.35	15.96	39.56	625.18
25	22.00	212.6	16.4	38.8	642.40	35	21.13	210.26	15.41	37.65	618.14
26	21.74	209.6	16.2	38.0	628.10	36	20.98	208.98	15.18	37.82	610.13
27	21.64	202.7	15.1	37.2	618.15	37	20.64	201.56	14.92	36.72	607.18
28	21.51	198.8	15.0	36.5	600.30	38	20.51	197.81	14.74	35.65	590.20
29	21.34	195.4	14.9	34.4	580.20	39	20.34	194.47	13.74	33.28	565.13
30	21.00	190.4	14.6	33.2	570.50	40	20.12	189.41	13.41	32.18	558.14

tion modulus. The forces (Fe and Fcg) in worsted yarns spun from woolen fibres are quite high, which is illustrated by their relations to the breaking force (Fe/Fb and Fcg/Fb). Therefore, the F-ε graph has an extremely convex shape with the curve having a greater slope in the elastic area (greater deformation modulus) and greater slope in the viscoelastic part.

Projection of the mechanical properties of wound yarn affected by deformation is very important; ***Figure 5*** shows a graphic illustration of the relations between the breaking force, the force at the elasticity and yield point of the wound yarns. The dependence given can be graphically presented in figures, or as an equation.

The projected breaking force of the wound yarns is determined from the following relation:

$$Fb_{projct} = Fb_{fib}\, N_{fib}\, \eta \cos\beta = \\ = Fb_{fib}\, N_{fib}\, Fb_{yarn} /(Fb_{fib}\, N_{fib}) \cos\beta = \\ = Fb_{yarn} \cos\beta$$

where is:
- Fb_{fib} - breaking force of the fibre,
- N_{fib} - number of fibres at the yarn cross section,
- η - coefficient of fibre strength utilisation.

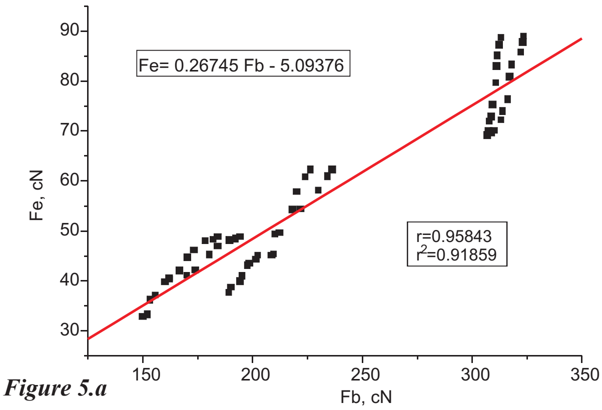

Figure 5.a

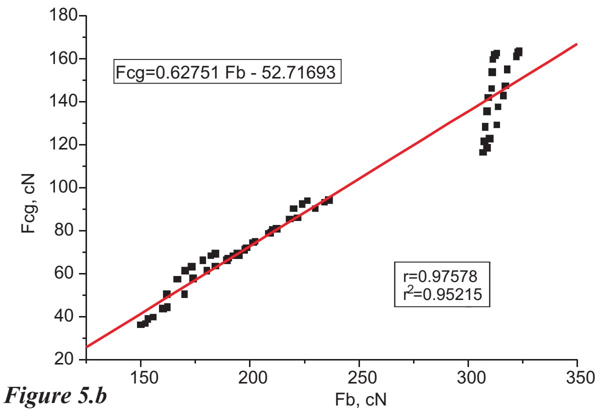

Figure 5.b

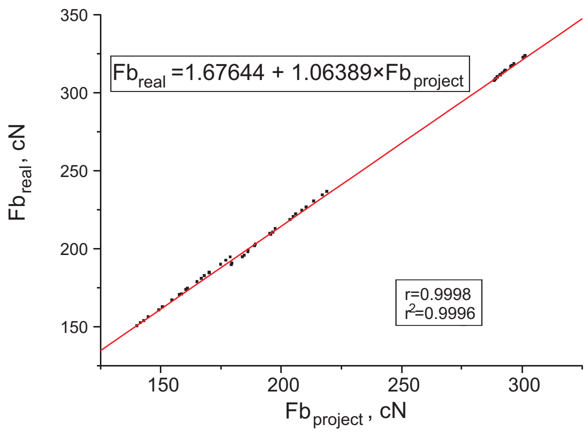

Figure 6. *Dependence graph: $Fb_{real} = f(Fb_{project})$ for all the wound yarns.*

Figure 5. *Dependence graph: Fe = f(Fb) (a), and Fcg = f(Fb) (b) for all the wound yarns.*

Table 3. Breaking characteristics of 25 tex wound yarns; Fsm - starting modulus for (ε=1%), Tm-yarn twisting, Fb-breaking force, $ε_b$-breaking elongation.

T-62						T-63					
No	Tt, tex	Fb, cN	$ε_b$, %	Fsm, cN	Tm, m^{-1}	No	Tt, tex	Fb, cN	$ε_b$, %	Fsm, cN	Tm, m^{-1}
41	24.80	323.5	19.2	62.1	730.12	51	24.35	313.48	18.92	61.20	720.15
42	24.78	323.3	19.15	61.8	728.11	52	24.28	312.32	18.84	60.81	718.71
43	24.75	322.4	19.1	60.8	720.14	53	24.15	311.46	18.65	59.72	710.54
44	24.65	318.2	19.0	55.7	718.15	54	24.09	311.25	18.26	54.36	708.32
45	24.50	317.18	18.0	50.7	715.10	55	23.98	310.98	17.95	49.81	705.16
46	24.43	316.50	17.1	47.7	710.12	56	23.76	309.54	16.87	46.23	702.75
47	24.28	314.01	16.1	44.0	705.14	57	23.56	308.76	15.96	43.18	692.13
48	24.12	313.41	16.0	43.3	700.10	58	23.32	308.12	15.74	42.15	690.80
49	24.02	310.05	15.1	41.2	695.13	59	23.12	307.54	14.75	40.91	685.72
50	23.85	308.78	14.9	38.6	690.14	60	23.08	307.02	13.79	37.56	680.12

Table 4. *Results of analyses of F-ε curves for 21 tex wound yarns; Fe- forces at the elasticity limit, Fcg- forces at the yield limit, εe-elongation at the elasticity limit, εcg- elongation at the yield limit.*

Characteristics	T-62									
	1	2	3	4	5	6	7	8	9	10
εe, %	1.18	1.178	1.16	1.07	1.05	0.98	0.94	0.80	0.75	0.69
Fe, cN	48.80	48.31	48.09	46.93	45.09	42.01	41.02	40.26	37.08	33.15
εcg, %	1.87	1.84	1.82	1.60	1.58	1.44	1.42	1.28	1.15	1.13
Fcg, cN	69.21	68.26	66.17	63.24	61.22	57.48	50.40	44.33	39.62	36.70
Characteristics	T-63									
	11	12	13	14	15	16	17	18	19	20
εe, %	1.175	1.174	1.158	1.04	1.01	0.96	0.92	0.76	0.72	0.67
Fe, cN	48.70	48.21	47.95	46.06	44.56	41.97	40.58	39.65	36.12	32.85
εcg, %	1.82	1.80	1.78	1.58	1.56	1.42	1.40	1.24	1.11	1.08
Fcg, cN	69.01	68.12	66.10	63.06	61.08	57.24	50.12	43.56	38.74	35.87

The twisting angle β, i.e. the angle between the winding spiral tangent and yarn axis is calculated from the relation:

$$\beta = \text{arc tg}\ (\pi\ d_{yarn}\ Tm\ 10^{-3})$$

where
- d_{yarn}-yarn diameter,
- Tm- yarn twistg of the wound yarns.

In ***Table 7*** (see page 32) values of the projected and real breaking forces of the wound yarns are given. The results obtained show that the projected values differ from the real ones.

Figure 6 shows the dependence between the real and projected breaking forces of the wound yarns.

Based on the projected breaking forces, it is possible to find a dependence between the projected breaking forces and forces at the elasticity limit and yield limit of the wound yarns (***Figures*** *7* and ***8***).

In this way the mechanical characteristics of wound yarn deformation can be projected properly depending on their future purpose.

Conclusions

Yarns wound with a tension force of greater intensity have an F-ε curve with a gentler slope in the first, linear part of the curve, i.e. smaller deformation modulus. The forces (Fe and Fcg) in worsted yarns spun from woolen fibres are quite high, which is illustrated by their existence in the breaking force (Fe/Fb and Fcg/Fb). Therefore, the F-ε graph has an extremely convex shape with the curve having a greater slope in the elastic area (greater deformation modulus) and greater slope in the viscoelastic part.

Deformation properties of wound yarns depend on their structural and design solutions, as well as on the technological conditions of winding. The most important factors are the raw material composition, and the structural, physical and mechanical properties of the fibres incorporated into the yarn.

The results obtained indicate that an increase in the tension force brings about a variation in wound yarn properties, where the linear density, yarn twisting, the breaking force and elongation at

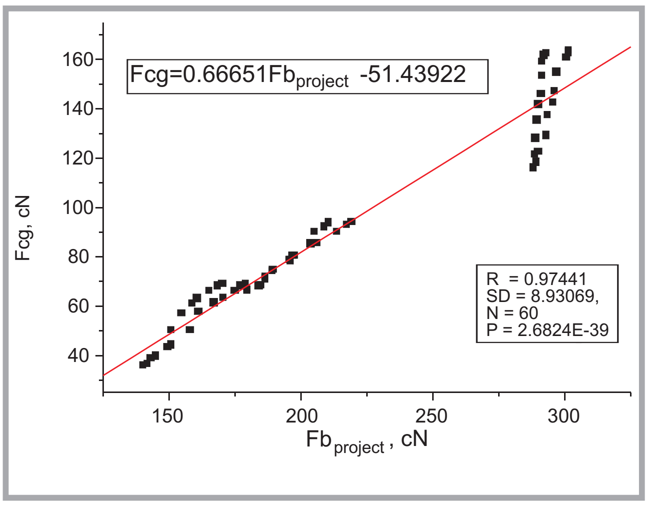

Figure 8. *Graph representing the dependence between the projected breaking forces and forces at the yield limit: $Fcg_{real} = f(Fb_{project})$ for the all the wound yarns.*

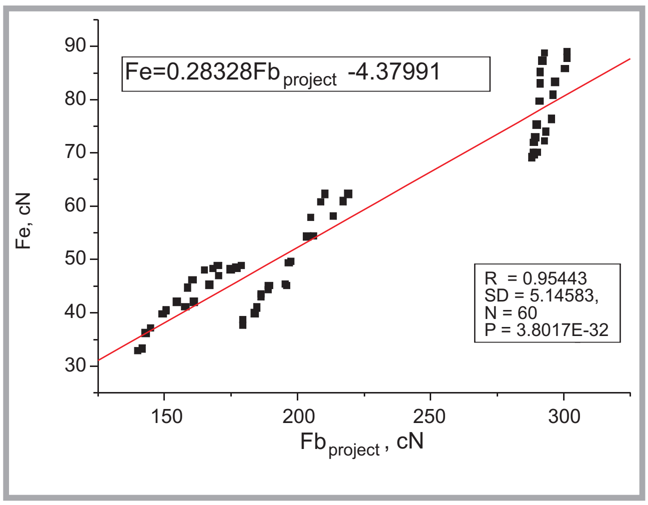

Figure 7. *Graph representing the gependence between the projected breaking forces and forces at the elasticity limit: $Fe_{real} = f(Fb_{project})$ for all the wound yarns.*

Table 5. *Results of analyses of F-ε curves for 23 tex wound yarns; Fe- forces at the elasticity limit, Fcg- forces at the yield limit, εe-elongation at the elasticity limit, εcg- elongation at the yield limit.*

Characteristics	T-62									
	21	22	23	24	25	26	27	28	29	30
εe, %	1.45	1.43	1.42	1.40	1.29	1.28	1.20	1.18	1.13	1.07
Fe, cN	62.17	60.89	58.01	54.39	49.54	45.27	44.95	43.36	40.85	38.57
εcg, %	2.56	2.53	2.49	2.46	2.28	2.27	2.12	2.10	2.08	1.98
Fcg, cN	94.08	92.97	90.23	85.69	80.57	78.80	74.79	71.76	68.58	66.88
Characteristics	T-63									
	31	32	33	34	35	36	37	38	39	40
εe, %	1.43	1.42	1.41	1.39	1.278	1.26	1.19	1.17	1.12	1.04
Fe, cN	62.14	60.78	57.86	54.18	49.24	45.02	44.16	43.02	39.80	37.56
εcg, %	2.55	2.52	2.48	2.45	2.27	2.26	2.10	2.08	2.06	1.96
Fcg, cN	93.86	92.17	90.02	85.24	80.36	78.42	74.21	71.02	68.12	66.49

Table 6. *Results of Analyses of F-ε curves for 25 tex wound yarns; Fe - forces at the elasticity limit, Fcg - forces at the yield limit, εe - elongation at the elasticity limit, εcg - elongation at the yield limit.*

Characteristics	T-62									
	41	42	43	44	45	46	47	48	49	50
εe, %	1.71	1.70	1.68	1.65	1.53	1.48	1.33	1.30	1.22	1.15
Fe, cN	88.98	87.76	85.70	83.24	80.85	76.33	73.95	72.18	70.05	69.62
εcg, %	2.96	2.93	2.89	2.87	2.68	2.52	2.32	2.30	2.09	2.06
Fcg, cN	163.6	162.8	160.8	154.9	147.3	142.7	137.6	129.1	122.6	118.3
Characteristics	T-63									
	51	52	53	54	55	56	57	58	59	60
εe, %	1.70	1.69	1.67	1.64	1.51	1.45	1.32	1.29	1.21	1.13
Fe, cN	88.60	87.23	85.02	82.98	79.58	75.22	72.88	71.87	69.89	69.12
εcg, %	2.94	2.91	2.85	2.83	2.64	2.50	2.30	2.28	2.06	2.02
Fcg, cN	162.4	161.6	159.2	153.5	146.1	141.6	135.4	128.0	121.4	116.1

Table 7. *Real and projected values of the breaking forces of the wound yarns.*

T-62						T-63					
21 tex		23tex		25tex		21 tex		23tex		25tex	
Fb_{real}	Fb_{proj}	Fb_{real}	Fb_{proj}	Fb_{real}	Fb_{proj}	Fb_{real}	Fb_{proj}	Fb_{real}	Fb_{proj}	Fb_{real}	Fb_{proj}
194.4	179.11	236.4	219.17	323.5	301.53	184.42	170.26	236.4	210.6	313.48	293.03
192.3	177.27	234.2	217.35	323.3	301.40	182.33	168.39	234.2	208.79	312.32	292.04
189.6	175.09	230.2	213.75	322.4	300.63	178.56	165.27	230.2	205.24	311.46	291.36
184.4	170.47	222.0	206.31	318.2	296.85	173.44	160.69	222.0	203.92	311.25	291.23
180.6	167.07	212.6	197.76	317.18	296.05	170.61	158.85	212.6	196.82	310.98	291.11
174.2	161.36	209.6	195.55	316.5	295.48	166.92	154.85	209.6	195.94	309.54	289.95
170.3	157.93	202.7	189.51	314.01	293.33	162.31	150.99	202.7	189.25	308.76	289.42
162.4	150.85	198.8	186.55	313.41	292.92	160.41	149.42	198.8	186.41	308.12	289.05
156.0	145.05	195.4	184.92	310.05	289.99	153.6	143.23	195.4	184.14	307.54	288.68
152.3	141.75	190.4	179.72	308.78	289.27	150.23	140.31	190.4	179.58	307.02	288.25

break, as well as, the forces at the elasticity limit and yield point also tend to decrease.

Awareness of the relationship between the breaking forces of wound yarn yarn and forces at the yield point and elasticity limit enables the simulation of yarn behaviour during winding. Besides this, conditions for the correct projection of yarns depending on their final use are thereby established.

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