Yarn Tension Change with Respect to Bobbin Diameter in Yarns Including Lycra Component

Özge Çelik¹ and Recep Eren²

¹² Uludag University, Faculty of Engineering, Textile Engineering Department, Gorukle Campus 16059 Nilüfer-Bursa, Turkey

Corresponding author: celikozge@uludag.edu.tr

Abstract The yarn is transferred from one bobbin to another in many textile processes. In these kinds of processes like warping, weaving, doubling and twisting, yarn tension change with respect to bobbin diameter has a significant role because it affects product quality and machine efficiency. Yarns including lycra component are widely used in fabric production which are sensible to tension changes. This paper presents an experimental research aiming at determining the relationship between yarn tension and bobbin diameter during unwinding for continuous filament polyester-lycra yarns. For this aim, an experimental research set-up was established representing unwinding from bobbins in many textile processes. Experimental research set-up consists of a winding machine, a creel with single bobbin holder, a laser sensor measuring bobbin diameter, a tension sensor for measuring yarn tension, a PC and a DAQ card. A software program was developed in C programming language to read and record the tension and bobbin diameter simultaneously as a data file. Based on the recorded data, average values of warp tension and bobbin diameter were calculated and relationship between yarn tension and bobbin diameter was obtained in this way. Experimental work was carried out for 3 different yarn numbers (75, 150 and 300 denier) at 5 different unwinding speeds (100, 200, 400, 600 and 800 m/min). The results were compared with the yarns without lycra component and found to be in agreement with theoretical findings in the literature expressing that high elasticity of yarns limited the tension change from full to empty bobbin.

Keywords—At least four keywords or phrases in alphabetical order, separated by commas. Bobbin diameter, tension measurement, unwinding tension, yarn elasticity, yarn tension

I. INTRODUCTION

Before using in weaving, warping, knitting etc. departments, yarns sometimes undergo different processes like dyeing, doubling, twisting. While going through all these processes, yarn tension changes with respect to the bobbin diameter. Due to the aim to achieve higher processing speeds, tension changes become more pronounced. Tension change from full to empty bobbin diameter has a significant effect on the product quality as well as process efficiency. Hence, optimization the parameters affecting this tension change plays an important role. Yarn tension tends to increase towards to empty bobbin diameter inherently. In warping process, yarn tension change causes warp sections of the same length to be wound at different diameters and this leads tension differences between sections on the warp and causes irregular appearance on the fabric surface. Besides, in bobbins to be dyed tension change with respect to bobbin diameter affects hardness variations in radial direction. Although today many warping and winding machines have their own tension controlling systems to keep the tension at an adjusted value, machines without tension control are still in use in industry. Yarns including lycra component are widely employed in weaving sector which are sensible to tension changes. This paper investigates experimentally yarn tension change with respect to bobbin diameter during unwinding in yarns including lycra component.

There are numerous theoretical and experimental research investigating the unwinding behavior of yarns from bobbins. Without considering centrifugal and Coriolis forces Mack [1] formulated the differential equations for spinning balloons. Padfield [2] investigated the motion and tension of an unwinding thread and modified Mack’s equations by adding effect of Coriolis forces. She suggested an empirical quadratic relation between yarn tension during unwinding and balloon length/bobbin radius ratio. She didn’t consider the effects of gravitational force and the internal elastic forces within the yarn. Booth [3] studied the sliding region of over-end unwinding and investigated the dynamics of the yarn motion over the bobbin surface. Kothari and Leaf [4-8] improved Padfield’s [2] theory by adding the effects of gravity and tangential air drag. Fraser, Ghosh, and Batra [9] presented an integrated model for both balloon and sliding regions for the first time. Ghosh, Murthy, and Batra [10] analyzed
Fraser, Ghosh, and Batra’s [9] study and recommended the third region for unwinding process (stationary region). Popova and Efremov [11] investigated the yarn tension bobbin diameter relation during unwinding from cone bobbins. Kurilenko, Matyushev and Goncharenko et al. [12] investigated yarn tension during unwinding from a cylindrical bobbin. They measured yarn tension at 3 different bobbin diameters, 3 different yarn guide-bobbin front distances and 3 different unwinding speeds. Cooray and Fernando [13] studied the conditions both mathematically and experimentally for a uniform unwinding tension from bobbins and developing a device for this aim. Godawat [14] studied the experimental verification of non-linear behavior of over-end yarn unwinding from cylindrical packages. He designed and built an experimental set up measuring yarn tension, bobbin diameter and balloon shape by a high-speed camera. Apart from analyzing the effects of bobbin diameter, bobbin front-yarn guide distance and unwinding speeds on yarn tension during unwinding, he also intended to test the theory of Pan’s [15] mathematical model which investigates and deduces relationships between balloon shape and tension distribution in the end region of unwinding. Kong, Rahn and Goswami [16] investigated steady-state yarn motion during unwinding from nonzero winding angle packages. Pracek, Pusnik and Simoncic, et al. [17] studied a model for simulating yarn unwinding. Çelik [18] investigated yarn tension change with respect to bobbin diameter during unwinding experimentally for both continuous filament polyester (twisted and intermingled) yarn of 7 different numbers and cotton yarns of 5 different numbers. For each yarn or bobbin, experiments were carried out with 3 different bobbin front surface-yarn guide distances (120 mm, 240 mm, 480 mm) and 5 different unwinding speeds (100 m/min, 200 m/min, 400 m/min, 600 m/min and 800 m/min). In addition, the effect of winding types (random winding, step precision winding and precision winding for 2 different winding ratios) on the relationship between the yarn tension and bobbin diameter was investigated.

When literature was reviewed it is realized that most of the studies which reveal models for unwinding and balloon formation made the same simplifying assumption that the yarn is inextensible [2, 3, 5, 6, 9, 16]. In 1992, Fraser [19] published a framework for unwinding of non-linear elastic or viscoelastic yarns and investigated the relation between the elastic or viscoelastic properties of the yarn and the yarn tension during unwinding. He presented balloon equations which included linear elasticity term and made numerical solutions of these equations for small values of elasticity. He assumed that yarn inextensibility is acceptable for typical yarns. He concluded that the inclusion of elasticity in the theoretical model caused a decrease in balloon tension and also in balloon radius. Nevertheless, he indicated that this effect is very slight for real yarns (yarns not including lycra or similar elastic component). So, the inextensibility assumption is reasonable for these types of yarns and the extensibility of these yarns could be neglected. But for highly extensible yarns, yarn extensibility must be considered.

Godawat [14] referred a study which was done by Ma, Ghosh and Batra and investigating unwinding an elastic yarn from a cylindrical bobbin. They presented an integrated model for elastic yarn unwinding process obtained for balloon, sliding and stationary regions. According to Godawat [14] they concluded that when the balloon was formed as a single loop for the yarns which had an initial modulus higher than 0.1 N/Tex (almost all man-made fibers and natural fibers), the effect of elasticity was negligible, and these types of yarns could be assumed as inextensible. However, for the yarns which had an initial modulus less than 0.1 N/Tex (elastomeric yarns) both the balloon radius and yarn tension decreased with decreasing initial modulus.

Available research in the literature provides no experimental result for tension change with respect to bobbin diameter for yarns having high elasticity. This paper presents an experimental work investigating yarn tension change during unwinding for textured polyester with lycra component.

II. METHODS AND PROCEDURES

An experimental set-up was built to investigate the relationship between yarn tension and bobbin diameter during unwinding for continuous filament polyester-lycra yarns. Experimental set up had a laser sensor measuring bobbin diameter, a tension sensor for measuring yarn tension, a bobbin winding unit and a PC and a DAQ card. A software program was developed in C programming language to read and record the tension and bobbin diameter simultaneously.

Experimental set up had a single unit creel as shown in Fig. 1. The single unit creel had a bobbin holder, yarn guides as well as laser bobbin diameter measurement sensor. Laser sensor was mounted on the creel to measure bobbin diameters of maximum 300 mm.
After the yarn guide and other guide roller, yarn went through the tension sensor as shown in Fig. 2. The tension sensor is of Schmidt made and has measuring interval of 0-200 cN [20].

Output signals of laser sensor and tension sensor are connected to a PC by a DAQ card. DAQ card has 12 bits bipolar ADC converters, therefore 11 bits are used for reading the signals and last bit is reserved as a sign bit. Hence, 10 volts are converted to 2047 numbers for diameter and tension measurements. A software program was developed in C programming language to read and record 2 sensor signals simultaneously.

In the experimental work, 75 denier, 150 denier and 300 denier yarns with lycra were unwound from bobbins at 100, 200, 400, 600 and 800 m/min speeds. Yarn tension was recorded at 13 different diameters and the relationship between yarn tension and bobbin diameter was obtained by averaging yarn tension for each bobbin diameter. Distance between yarn guide and bobbin front was kept constant at 240 mm during all the experiments.

Table I shows the bobbin dimensions and yarn properties used in the experimental work.

| Yarn number | Yarn and bobbin properties | 75 denier | 150 denier | 300 denier |
|-------------|----------------------------|-----------|------------|------------|
| Lycra yarn number | 36 dtex                  | 44 dtex   | 78 dtex    |
| Lycra drawing ratio | 3.4                    | 3.4       | 3.6        |
| Full bobbin diameter (mm) | 230                     | 250       | 240        |
| Empty bobbin diameter (mm) | 76                      | 75        | 75         |
| Full bobbin length (mm) | 215                     | 215       | 220        |
| Empty bobbin length (mm) | 255                     | 245       | 255        |
| Winding angle (degree) | 31                      | 31        | 31         |

III. RESULTS AND DISCUSSION

Figure 3 shows unwinding tension change with respect to bobbin diameter for 75 denier polyester-lycra yarn at 100, 200, 400, 600 and 800 m/min unwinding speeds. Changing unwinding speed from 100 m/min to 800 m/min increased yarn tension around 4 cN at full bobbin diameter. At all speeds during unwinding tension tended to decrease up to half of the full bobbin diameter and then it increased up to empty bobbin diameter. Tension change from full to empty bobbin diameter increased with increasing unwinding speeds. A less than 1 cN tension fluctuation occurred up to the empty bobbin diameter with 100 m/min, 200 m/min, 400 m/dak and 600 m/dak...
unwinding speeds. At 800 m/min unwinding speed, tension fluctuation occurred around 1.5 cN from full to empty bobbin diameter. The reason for the higher initial tension is thought to be due to the friction between unwound yarn and bobbin surface. Friction between bobbin surface and unwound yarn decreases with a decrease in bobbin diameter and therefore yarn tension decreases. On the other hand, angular rotation of yarn around bobbin axis increases with decreasing bobbin diameter and this causes centrifugal force to increase. After half bobbin diameter, yarn tension continuously increased because of the effect of centrifugal force with decreasing bobbin diameter. As the yarn is too thin and has a small mass forming the balloon, the effect of centrifugal force on yarn tension showed a limited effect even at 800 m/min unwinding speed.

Figure 3. Yarn tension bobbin diameter relation for 75 denier continuous filament polyester-lycra yarn.

Figure 4 shows unwinding tension change with respect to bobbin diameter for 150 denier polyester-lycra yarn at 100, 200, 400, 600 and 800 m/min unwinding speeds. At 100 m/min and 200 m/min unwinding speeds, tension change showed a slight decrease at around 0.5 cN from full to empty bobbin. At 400 m/min, 600 m/min and 800 m/min unwinding speeds, tension decreased very slightly up to half bobbin diameter, then it increased up to empty bobbin diameter. Tension change increased as unwinding speed increased. Tension increased less than 1 cN at 400 m/min unwinding speed whereas it occurred around 1.5 cN at 600 m/min unwinding speed and 3 cN at 800 m/min unwinding speed.

Figure 5 shows tension change with respect to bobbin diameter for 300 denier polyester-lycra yarn. No significant tension change occurred with respect to bobbin diameter at 100 m/min and 200 m/min unwinding speeds. At 400 m/min, tension increased very slightly towards empty bobbin diameter. At 600 m/min and 800 m/min unwinding speeds, tension increased about 3 cN and 7 cN respectively. Tension changed slightly at higher bobbin diameters and it increased at a higher rate towards empty bobbin diameter. In fact, the relationship between unwinding tension and bobbin diameter shows a change like quadratic curve at 600 m/min and 800 m/min unwinding speeds.
Table II shows the maximum tension (max tension), minimum tension (min tension), average tension and difference between maximum and minimum tension values from full to empty bobbin diameter for each yarn number and unwinding speed used in the experimental work.

| Yarn number (denier) | Tension (cN) | Unwinding speed (m/min) | 100 | 200 | 400 | 600 | 800 |
|---------------------|--------------|-------------------------|-----|-----|-----|-----|-----|
| 75                  | Max tension  | 3.97                    | 4.38 | 5.50 | 7.07 | 8.82 |
|                     | Min tension  | 3.16                    | 3.64 | 4.94 | 6.17 | 7.34 |
|                     | Average tension | 3.40          | 3.88 | 5.19 | 6.52 | 7.79 |
|                     | Difference between max and min tension | 0.80 | 0.74 | 0.56 | 0.90 | 1.48 |
| 150                 | Max tension  | 3.68                    | 4.09 | 5.64 | 8.27 | 11.40 |
|                     | Min tension  | 3.08                    | 3.53 | 5.00 | 6.71 | 8.48 |
|                     | Average tension | 3.26          | 3.73 | 5.30 | 7.11 | 9.26 |
|                     | Difference between max and min tension | 0.60 | 0.56 | 0.64 | 1.56 | 2.92 |
| 300                 | Max tension  | 4.44                    | 5.50 | 8.18 | 12.60 | 19.07 |
|                     | Min tension  | 3.93                    | 4.76 | 7.15 | 9.47 | 12.00 |
|                     | Average tension | 4.16          | 5.02 | 7.45 | 10.34 | 14.07 |
|                     | Difference between max and min tension | 0.51 | 0.73 | 1.03 | 3.13 | 7.07 |

To analyze the effect of yarn elasticity on tension change during unwinding, results of this paper (polyester yarn with lycra component) were compared with Çelik’s [18] results of 75 denier, 150 denier and 300 denier intermingled polyester textured yarn without lycra component (distance between yarn guide and bobbin front and the unwinding speeds are equal). When the graphs showing yarn tension change from full to empty bobbin diameter were examined, it was realized that same yarn numbers with and without lycra component showed the same characteristics.

Table III shows the difference between maximum and minimum tension values from full to empty bobbin diameter for 75 denier, 150 denier and 300 denier polyester yarns without lycra component [18]. Although they showed the same yarn tension change characteristics, as seen from the Table II and Table III, yarn elasticity showed a decreasing effect on yarn tension change from full to empty bobbin especially for higher unwinding speeds. Tension fluctuation occurred as about 2,5 cN at 400 m/min, 6 cN at 600 m/min and 11 cN at 800 m/min unwinding speeds for 300 denier polyester yarn without lycra component, whereas it occurred about 1 cN, 3 cN and 7 cN respectively with lycra component. For 150 denier yarn, without lycra component this tension difference was about 1,5 cN, 2,5 cN and 4 cN respectively, with lycra component it was about 0,5 cN, 1,5 cN and 3 cN. Lycra component showed a very limited effect on 75 denier polyester yarn. At even 600 m/min unwinding speed the difference of this value between with and without lycra component was 0,05 cN, at 800 m/min unwinding speed this difference tension value was just 0,32 cN.
TABLE III

| Yarn number (denier) | Unwinding speed (m/min) |
|----------------------|-------------------------|
|                      | 100  | 200  | 400  | 600  | 800  |
| 75 denier            | 0.67 | 0.54 | 0.36 | 0.95 | 1.80 |
| 150 denier           | 1.08 | 1.18 | 1.73 | 2.55 | 3.77 |
| 300 denier           | 0.84 | 0.98 | 2.37 | 5.87 | 11.01 |

IV. CONCLUSION

An experimental research was carried out to investigate the relationship between yarn tension and bobbin diameter during unwinding from bobbins for polyester yarns including lycra component. Following conclusions can be drawn regarding the experimental research.

- In polyester yarns with lycra component, unwinding tension-bobbin diameter relation showed almost the same characteristic with polyester yarns without lycra component.
- In accordance with the literature, the amount of tension increase from full to empty bobbin decreased significantly with polyester yarns with lycra component. Tension change with respect to bobbin diameter became more pronounced as the yarn got thicker and unwinding speed increased like 600 m/min and 800 m/min.
- Although tension increase decreased with polyester yarns having lycra component, it is still important from practical and processing point of view because this tension change causes more yarn elongation therefore mass change in unit area of a fabric.

ACKNOWLEDGMENT

This research has been done as a part of research project supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK). We would like to express our sincere thanks to Technological Research Council of Turkey (TÜBİTAK) for supporting this project (Project Number: 215M372). Also, we would like to thanks to administration of Polyteks Tekstil San. Araştırma ve Eğitim A.Ş. for providing yarns used in the experiments.

REFERENCES

[1] C. Mack, “Theoretical Study of Ring and Cap spinning Balloon Curves (With and Without Air Drag)”, J. Text. Inst., 44, pp. 483-498, 1953.
[2] D.G. Padfield, “The Motion and Tension of an Unwinding Thread I” Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences; 245(1242), pp. 382-407, 1958.
[3] K. H. V. Booth, “Vibration in Tension of An Unwinding Thread” British J. of Appl. Physics, 8, pp. 142-144, 1957.
[4] V.K. Kothari and G.A.V. Leaf, “The Unwinding of Yarns From Packages, Part I: The Theory of Yarn Unwinding”, J. Text. Inst., 70, pp. 89-95, 1979a.
[5] V.K. Kothari and G.A.V. Leaf, “The Unwinding of Yarns From Packages, Part II: Unwinding From Cylindrical Packages”, J. Text. Inst., 70, pp. 95-105, 1979b.
[6] V.K. Kothari and G.A.V. Leaf, “The Unwinding of Yarns From Packages, Part III: Unwinding From Conical Packages”, J. Text. Inst., 70, pp. 172-183, 1979c.
[7] V.K. Kothari and G.A.V. Leaf, “The Unwinding of Yarns From Packages, Part IV: Two-for-One Twisting: The Storage Disc and Balloon”, J. Text. Inst., 70, pp. 184-192, 1979d.
[8] V.K. Kothari and G.A.V. Leaf, “The Unwinding of Yarns From Packages, Part V: Two-for-One Twisting: Before the Storage Disc”, J. Text. Inst., 70, pp. 193-198, 1979e.
[9] W. B. Fraser, T. K. Ghosh and S. K. Batra, “On Unwinding Yarn From A Cylindrical Package”, Proc. R. Soc. London, A436, pp. 479-498, 1992.
[10] T.K. Ghosh, A.S. Murthy and S.K. Batra, “Dynamic Analysis of Yarn Unwinding From Cylindrical Packages, Part I: Parametric Studies of the Two-Region Problem”, Text. Res. J., 71(9), pp. 771-778, 2001.
[11] G.K. Popova and E.D. Efmerov, “The Yarn Tension in Unwinding From a Cone Bobbin Under Warping Conditions”, Tech. Of Textile Industry U.S.S.R., 1, pp. 46-50, 1970.
[12] Z.N. Kurtinienko, I.I. Matyushev, A.E. Goncharenko and A.F. Mel’nikov, “Yarn Tension During Unwinding From a Package”, Khimicheskie Volokna, 3, pp. 43-44, 1980.
[13] T. Cooray and E. Fernando, “Mathematical Modeling of Over-end Yarn Withdrawl, and the Development/ Design of a Device For Uniform Unwinding Tension” in 85th Textile Conference, Colombo, Srilanka, 1-3 March 2007, pp. 798-812.
[14] P. Godawat, “Experimental Verification of Non-Linear Behavior of Over-end Yarn Unwinding from Cylindrical Packages”, MSc Thesis, North Carolina State University, USA, 2003.
[15] Z. Pan, “Dynamic Analysis of Over-end Unwinding of Yarn”, PhD Thesis, North Carolina State University, USA, 2001.
[16] X.M. Kong, C.D. Rahn and B.C. Goswami, “Steady-State Unwinding of Yarn from Cylindrical Packages”, Textile Research Journal, 69(4), pp. 292-306, 1999.
[17] S. Pracek, N. Pusnik, B. Simoncic and P.E.F. Tavcer, “Model for Simulating Yarn Unwinding from Packages”, Fibres & Textiles in Eastern Europe, 23 2(110), pp. 25-32, 2015.
[18] Ö. Çelik, “Experimental Investigation Of The Factors Affecting Yarn Tension During Unwinding From Bobbin”, PhD Thesis, Uludag University, Turkey, 2018.
[19] W.B. Fraser, “The Effect of Yarn Elasticity on An Unwinding Balloon”, J. Text. Inst., 83(4), pp. 603-613, 1992.
[20] Schmidt Control Instruments Tension Sensor: Stationary Electronic Tension Meter, Single Place Systems3Rollers (accessed 2017, December 24), Available: http://www.hansschmidt.com/EN/products/tension_meter/stationary_electronic/single_place_systems_3_rollers/ts_series/model_ts1.