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# Experimental Investigation of the Relationship Between the Yarn Tension and Bobbin Diameter in the Warping Process

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**Abstract**
*Yarns of different types are unwound from bobbins in different processes like warping, weaving, doubling and re-winding. A change in yarn tension from a full to empty bobbin causes serious product quality and machine efficiency problems in processes like weaving and winding. This paper investigates experimentally the relationship between yarn tension and bobbin diameter in the warping process. For this purpose, an experimental set up was built with a laser sensor measuring the bobbin diameter, a tension sensor for measuring yarn tension, a bobbin winding unit, PC, and DAQ card. A software program was developed in the C programming language to read and record the tension and bobbin diameter simultaneously. The unwinding speed and yarn number both had a significant effect on the relationship between the yarn tension and bobbin diameter. The effect of the unwinding speed became more pronounced with yarns getting thicker.*

**Key words:** *unwinding tension, unwinding, bobbin diameter, tension measurement, yarn tension, warping.*

## Introduction

Yarns produced in a spinning department are either used directly or go through some further processing like doubling, twisting, soft winding and dyeing before being used in processes like warping, weaving, knitting etc. In all these processes, controlling the yarn tension is important as it affects product quality and process efficiency. It is well known from practice that yarn tension tends to increase especially towards the empty bobbin diameter, and this requires some precautions to prevent quality and efficiency losses. A change in yarn tension from a full to empty bobbin causes warp sections of the same length to be wound at different diameters in the warping process. This creates tension differences between sections in the warp and causes irregular appearance on the fabric surface. Also in dye bobbins, tension change with respect to the bobbin diameter affects hardness variations in the radial direction. Today, many warping and winding machines employ feedback tension control systems to feed yarns at the adjusted tension. However, there are a lot of warping and winding machines running in industry without tension control. Determining the tension change from a full to empty bobbin will be helpful to improve process quality and efficiency. Also it will be useful data for the designing of tension control systems for bobbin and warping machines. When literature was reviewed, some research was found regarding the tension variation from a full to empty bobbin. These are reviewed below.

Pathfield investigated the motion and tension of an unwinding thread [1]. She put forward an empirical quadratic relation between yarn tension during unwinding and the balloon length/bobbin radius ratio. The equation included two constants related to air resistance and the winding angle, and she recommended practical values for them. She compared results of the empirical relation and measurements, and an agreement was found, for the most part, between theoretical and experimental results. It should be noted that the bobbin radius changed between 3.65 cm to 1.8 cm in the study, which was not sufficient to draw generalised results. Kurilenko, Matyushev and Goncharenko et al. investigated yarn tension during unwinding from a cylindirical bobbin of 3.3 tex continuous filament Kapron yarn [2]. They measured yarn tension at 6, 8 and 10 cm bobbin diameters, 5 cm, 10 cm and 15 cm yarn guide-bobbin front distances, and at 14.2 m/s, 12.5 m/s and 10.8 m/s unwinding speeds. Although tension changes were analysed for each parameter, three measurement points were not sufficient to obtain a proper curve for tension change with respect to bobbin diameter. Also up to only a 10 cm diameter bobbin did not include the effect of bobbin diameters used in industrial practice. Niederer measured yarn tension with respect to bobbin diameter to show the effect of the brake type on tension variation [3]. As the aim was to show the advantages and disadvantages of different brake types, he did not give the yarn type and number, nor the bobbin diameter, or any other parameters

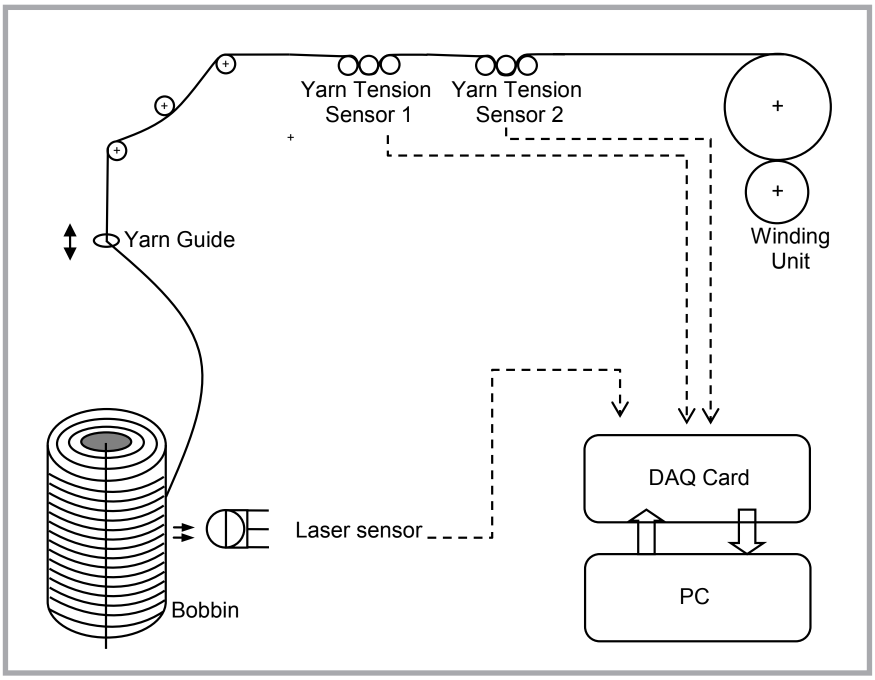

***Figure 1.** Experimental set-up.*

for the measurements. His measurement showed an increase in t the yarn tension during unwinding towards the empty bobbin diameter. His result showed that the additive brake type shifted up the input yarn tension curve by the amount of friction applied in the brake. Multiplying the type of brake shifted up the input yarn tension curve by increasing the fluctuation amplitude in the tension curve. He also showed that a Capstan overfeed yarn feeder reduced the tension level and that the tension increased towards the empty bobbin. Cooray and Fernando studied the conditions, both mathematically and experimentally, for uniform unwinding tension from bobbins and developed a device for this aim [4]. They concluded that the ratio of the distance between the yarn guide and bobbin front to the bobbin diameter should be between 9 and 15 for a uniform unwinding tension. They recommended a device to adjust the yarn guide position to keep this ratio at the desired interval for uniform tension during unwinding. In the experimental part, they measured yarn tension at three different diameters of a cotton bobbin between 13 cm and 7 cm. The unwinding speed was not mentioned in the publication. Godawat undertook experimental verification of the non-linear behaviour of over-end yarn unwinding from cylindrical packages [5]. He designed and built an experimental set- up measuring the yarn tension, bobbin diameter and balloon shape with a high speed camera. He made all the measurements using 70, 270 and 500 denier continuous filament polyester yarns with three different bobbin diameters, three different unwinding speeds (200, 600 and 1000 m/min) and three different yarn guide-bobbin front distances. Apart from analysing the effects of the bobbin diameter, bobbin front-yarn guide distance and unwinding speeds on yarn tension during unwinding, he also intended to test the validity of Pan's [6] mathematical model, which investigates and deduces relationships between the balloon shape and tension distribution in the end region of unwinding. After conducting experimental work and a numerical solution of Pan's mathematical equations, he concluded that the tensions measured and calculated did not match. He commented that exclusion of tangential air drag and gravitational force in the mathematical model could be the reason for this deviation. Also in Godawat's solutions the yarn tension during unwinding was not found to increase with a decreasing bobbin diameter in the unwinding of 70 denier polyester yarn and at a 200 m/min speed with 270 and 500 denier yarns, as predicted by theory.

Kong, Rahn and Goswami investigated steady-state yarn motion during unwinding from non-zero winding angle packages [7]. They numerically solved a mathematical model to predict yarn tension and geometric properties of an unwinding balloon (balloon height/bobbin radius) and sliding yarn. They also experimentally investigated the unwinding process and compared experimental results with theoretical ones. They presented some results as yarn tension versus the balloon height/bobbin radius ratio. They concluded that although the mathematical model agreed with experimental results, their theoretical model did not predict that single balloons tended to occur at a small balloon height and multiple balloons at a large balloon height. They also did not observe the theoretically observed half balloons in the experiments.

Pracek, Pusnik and Simoncic, et al. studied a model for simulating yarn unwinding [8]. After the combination of theoretical and experimental studies, they concluded that unwinding from cross wound packages at high velocities like 2000 m/min below a 150 mm bobbin radius was impossible due to the very high tension at lower radii. They recommended bobbin winding with alternating cross wound and parallel wound layers to be able to unwind up to a minimum of 100 mm radius.

Stojilijkovic DT, Petrovic VS, Zivkovic Z. et al. investigated unwinding from bobbins both thoretically and experimentally [9]. They developed a mathematical model taking into account the work of previous researchers and tested the result of this model against experimental research results. They concluded that good agreement was found between the results calculated and measured. However, a significant deviation occured between the tensions calculated and measured towards the empty bobbin. It should be noted here that only 14 tex cotton yarn of 3770 meters wound on a cone was used in the experiments.

Popova and Efremov [10] investigated the yarn tension bobbin diameter relation during unwinding from a cone bobbin using 50, 35.7, 25 and 18.5 tex cotton yarns. Tension measurements were carried out at 7 different diameters from a full to empty bobbin and with 400, 600, 800 and 1000 m/min unwinding speeds at the exit of the yarn guide. The distance between the bobbin front and yarn guide was not given in the research. Results showed that yarn tension increased with the unwinding speed. The increase in tension with the unwinding speed was more pronounced when the yarn became thicker. In general, tension increased along with the bobbin diameter for all yarn numbers from 18.5 to 50 tex. Tension increased at a higher rate than the unwinding speed.

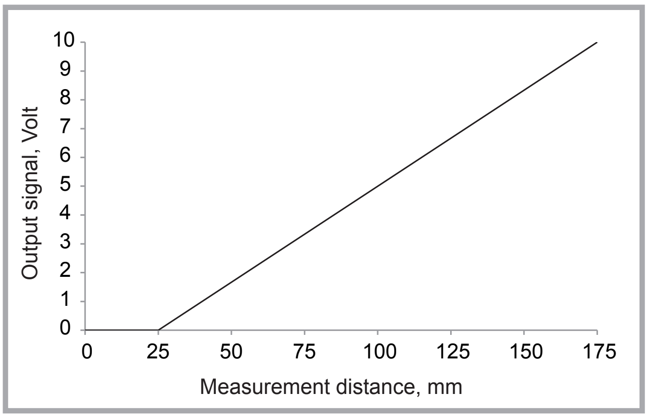

***Figure 2.** Output voltage measurement distance relation.*

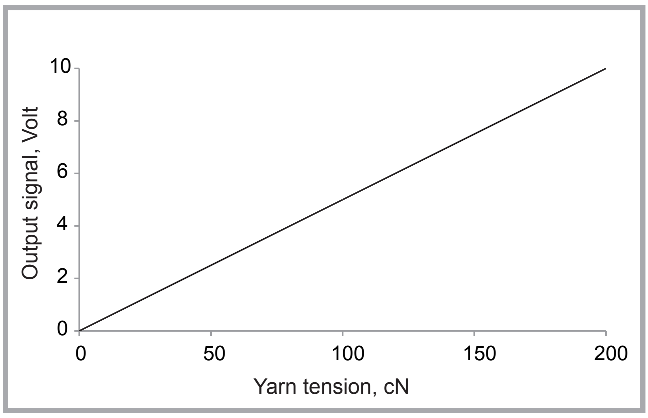

***Figure 3.** Calibration curve of the Schmidt tension sensor.*

Two variations in tension with respect to the bobbin diameter were found significant. At 18.5 tex for all speeds and 25 tex for a 1000 m/min speed, yarn tension decreased with a decrease in the bobbin diameter for a short period, and then it increased. After a continuous increase, tension decreased towards the empty bobbin. This was attributed to double balloon formation.

Fernando and Kuruppu [11] analysed theoretically the tension change during unwinding from conical bobbins in creels. They expressed mathematically the tension of warp yarn unwound from a cone placed for different regions of the warping creel. They solved the equations for 200 and 400 m/min speeds with 20 tex and 40 tex warp yarns. They found a significant tension change between the yarn guide at the tip of the balloon and the exit of the creel and stressed the importance of using tension controlled creels for good quality warp preparation. Although they solved equations for only one bobbin diameter, the equations include the bobbin diameter as a parameter, and warp tension can be solved for all bobbin diameters. No tension measurement or experimental verification is given in the publication.

There are more publications in the literature related to mostly theoretical analysis of yarn unwinding from bobbins and the motion of yarn [12-20]. Despite the practical importance, the relationship between yarn tension and the bobbin diameter has not been investigated experimentally by taking measurements for a higher number of bobbin diameters (a minimum of 7, 8 or more different diameters) using different yarn types and numbers as well as various winding and unwinding parameters. This paper presents an experimental research aiming at determining the relationship between yarn tension and the bobbin diameter during unwinding by taking into account the unwinding speed, yarn types and number, and bobbins of cylindrical and conical shape. Measurements were conducted at a minimum of 8 different bobbin diameters to obtain a precise yarn tension bobbin diameter curve. Research results targeted the warping process, but they can also be used for the winding process.

## Experimental work

An experimental set-up was developed as shown in ***Figure 1*** to investigate the relationship between yarn tension and the bobbin diameter. A single unit creel, a two-unit winder with adjustable winding speed, a laser sensor for bobbin diameter measurement, two tension sensors and a PC with a DAQ card constituted the hardware of the experimental set-up.

The laser sensor was mounted on the creel to measure bobbin diameters of maximum 300 mm. ***Figure 2*** shows the output voltage measuring distance relation of the laser sensor [21]. The laser sensor does not measure between a distance of 0 and 25 mm (dead distance). Then it produces an analog signal in proportion to distance. At 150 mm after the dead distance, the output voltage becomes 10 V. Also in the creel the bobbin tube center and yarn guide werer aligned, and the distance between the yarn guide and bobbin front was adjusted to 240 mm during all experiments.

After the yarn guide and other guide rollers, the yarn went through two tension sensors. The first tension sensor is of the Schmidt make and has a measuring interval of 0-200 cN. It has a linear calibration curve between the yarn tension and output voltage, as shown in ***Figure 3***, and the 10 volt output signal corresponds to 200 cN yarn tension [22].

Measurement of the first tension sensor was used in the experimental work to obtain the relationship between yarn tension and the bobbin diameter. The output of the second tension sensor was recorded for comparison purposes in the case of any signal loss or wrong measurement with the first tension sensor.

Output signals of the laser sensor and the first and second tension sensors are connected to a PC via a DAQ card. The DAQ card has a 12 bit bipolar ADC converter, therefore 11 bits are used for reading the signals, and the 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 3 sensor signals simultaneously. Tension and diameter measurements were carried out for each bobbin at 5 different unwinding speeds at a minimum of 8 different bobbin diameters from a full to empty bobbin. 15000 tension and diameter readings were recorded at 1 millisecond intervals for each bobbin diameter and unwinding speed. The average of 15000 measurements was calculated to obtain the bobbin diameter and average yarn tension at this diameter. Experimental work was carried out using both continuous filament polyester and cotton yarns of different numbers. 6 different continuous filament polyester and 5 different cotton yarn numbers were used with both cylindrical and conical bobbins. ***Tables 1, 2** &* ***3*** show the bobbin dimensions, crossing angle and yarn properties used in the experimental work.

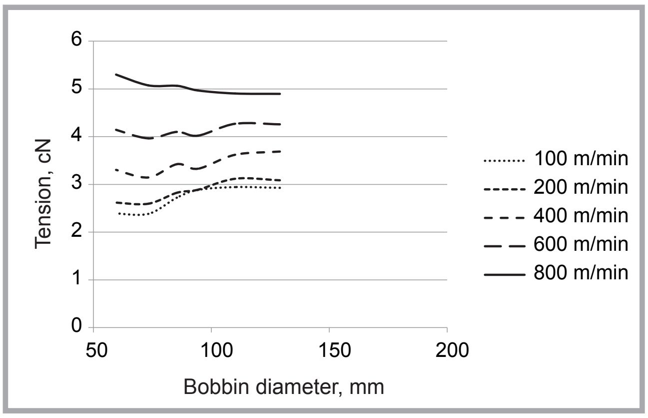

*Figure 4. Yarn tension bobbin diameter relation for 5.56 tex twisted continuous filament polyester yarn.*

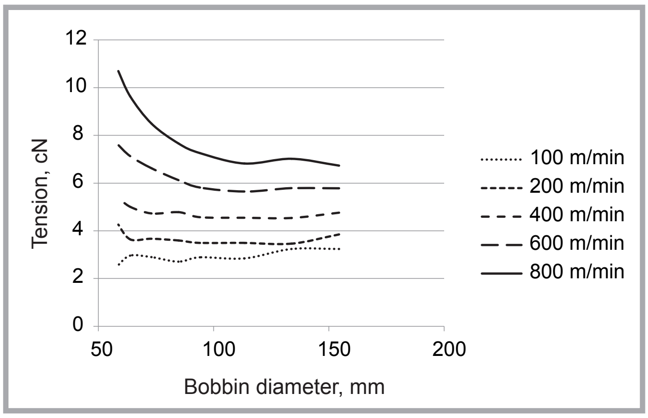

*Figure 5. Yarn tension bobbin diameter relation for 11.1 tex twisted continuous filament polyester yarn.*

## Results and discussion

### Experimental work with continuous filament polyester yarns

Experimental work with continuous filament polyester yarns was carried out at five different unwinding speeds of 100, 200, 400, 600 and 800 m/min using 6 different yarn numbers. The distance between the yarn guide and bobbin front was kept constant at 240 mm during all the experiments. Results are presented below.

***Figure 4*** shows the unwinding tension change with respect to the bobbin diameter for 5.56 tex polyester yarn at 100, 200, 400, 600 and 800 m/min unwinding speeds. Changing the unwinding speed from 100 m/min to 800 m/min increased the yarn tension by around 2 cN at the full bobbin diameter. At a 800 m/min unwinding speed, yarn tension slightly increased towards the empty bobbin diameter. Up to unwinding speeds of 600 m/min, yarn tension showed a slight decrease of around 0.5 cN. This decrease was thought to be due to the decreasing friction between the bobbin surface and yarn leaving the bobbin. As the yarn is too thin and has a small mass forming the balloon, the effect of the centrifugal force on yarn tension showed a limited effect, even at an 800 m/min unwinding speed.

***Figure 5*** shows unwinding tension change with respect to the bobbin diameter for 11.1 tex polyester yarn at 100, 200, 400, 600 and 800 m/min unwinding speeds. At the full bobbin diameter, yarn tension increased by around 4 cN with the speed changing from 100 to 800 m/min. Up to a 400 m/min unwinding speed, no significant change in yarn tension from the full to empty bobbin was observed. A less than 1 cN increase occurred up to the empty bobbin diameter with a 400 m/min unwinding speed. At 600 and 800 m/min speeds, yarn tension increased by around 2 and 4 cN from the full to empty bobbin. No significant change in tension was observed before a 80 mm bobbin diameter at a 600 m/min speed nor 100 mm diameter at a 800 m/min speed. The tension increase became steeper when unwinding approached the empty bobbin.

The yarn tension bobbin diameter relationship is shown in ***Figure 6*** for 16.7 tex polyester yarn. Similar to 11.1 tex polyester yarn, no significant tension change with a decreasing bobbin diamter was observed up to an unwinding speed of 400 m/min. A tension change occurred

*Table 1. Bobbin dimensions and polyester yarn properties used in the experimental work.*

| Yarn/bobbin properties | Full bobbin diameter, mm | Empty bobbin diameter, mm | Full bobbin length, mm | Empty bobbin length, mm | Crossing angle, degree |
|---|---|---|---|---|---|
| 5.56 tex twisted polyester yarn | 131 | 55 | 167 | 210 | 30 |
| 11.1 tex twisted polyester yarn | 156 | 55 | 157 | 210 | 30 |
| 16.7 tex twisted polyester yarn | 176 | 55 | 146 | 205 | 30 |
| 33.3 tex twisted polyester yarn | 136 | 55 | 168 | 210 | 30 |
| 66.6 tex intermingled polyester yarn | 158 | 75 | 204 | 250 | 35 |
| 100 tex intermingled polyester yarn | 200 | 75 | 218 | 250 | 35 |

*Table 2. Cylindrical bobbin properties used in the experimental work.*

| Yarn/bobbin properties | Full bobbin diameter, mm | Empty bobbin diameter, mm | Full bobbin length, mm | Empty bobbin length, mm | Crossing angle, degree |
|---|---|---|---|---|---|
| 11.8 tex cotton carded yarn | 189 | 59 | 140 | 140 | 30 |
| 14.8 tex cotton carded yarn | 216 | 59 | 140 | 140 | 30 |
| 19.7 tex cotton carded yarn | 225 | 59 | 140 | 140 | 30 |
| 29.5 texcotton carded yarn | 225 | 59 | 140 | 140 | 30 |
| 59.1 tex cotton carded yarn | 196 | 59 | 140 | 140 | 30 |

*Table 3. Conical bobbin properties used in the experimental work (Angle of conicity: 5°57', higher empty bobbin diameter: 73 mm, and lower empty bobbin diameter: 56 mm).*

| Yarn/bobbin properties | Higher full bobbin diameter, mm | Lower full bobbin diameter, mm | Bobbin length, mm | Crossing angle, degree |
|---|---|---|---|---|
| 11.8 tex cotton carded yarn | 205.3 | 181.4 | 143 | 30 |
| 14.8 tex cotton carded yarn | 232.4 | 206.9 | 143 | 30 |
| 19.7 tex cotton carded yarn | 242.8 | 208.8 | 143 | 30 |
| 29.5 tex cotton carded yarn | 245.8 | 206.3 | 143 | 30 |
| 59.1 tex cotton carded yarn | 243.5 | 216.5 | 143 | 30 |

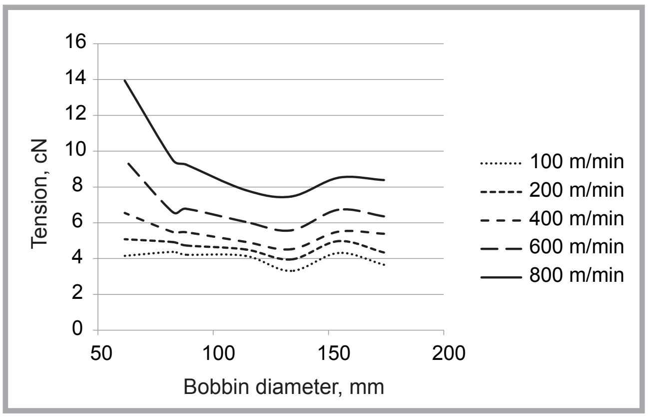

*Figure 6. Yarn tension bobbin diameter relation for 16.7 tex twisted continuous filament polyester yarn.*

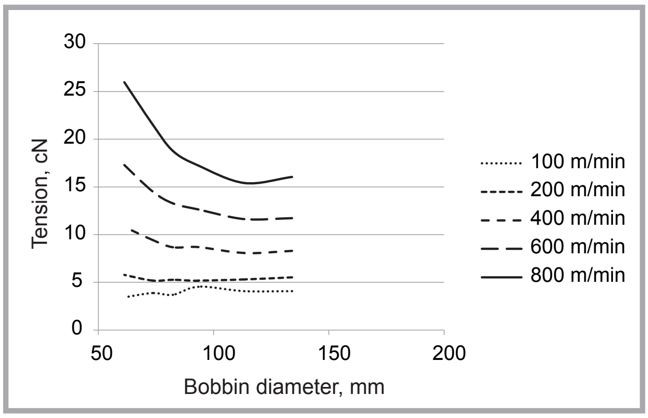

*Figure 7. Yarn tension bobbin diameter relation for 33.3 tex twisted continuous filament polyester yarn.*

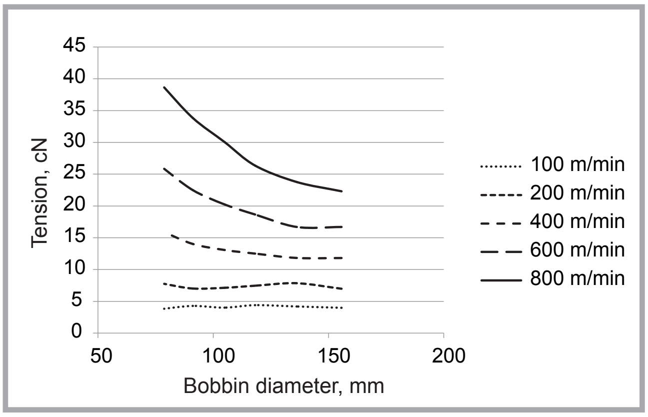

*Figure 8. Yarn tension bobbin diameter relation for 66.6 tex intermingled textured polyester yarn.*

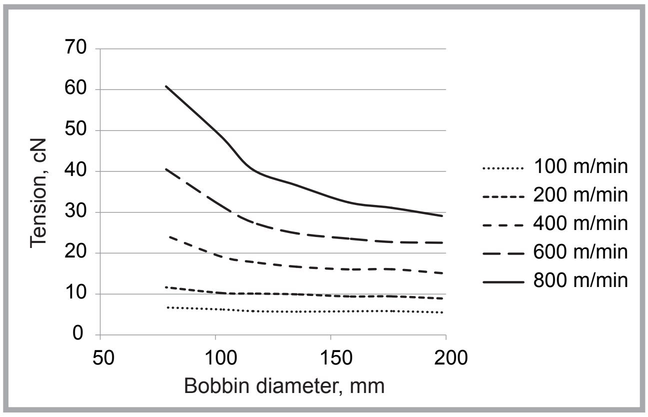

*Figure 9. Yarn tension-bobbin diameter relation for 100 tex intermingled textured polyester yarn.*

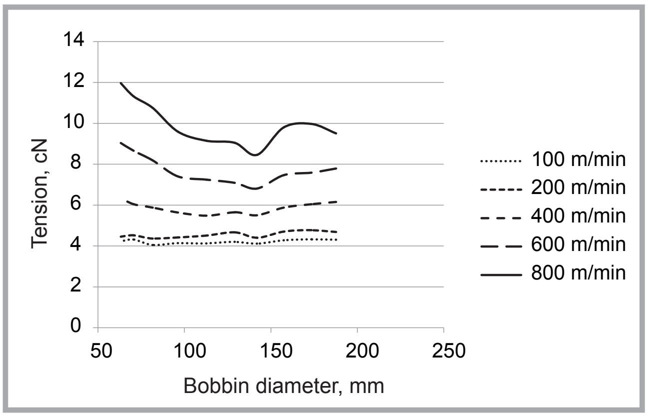

*Figure 10. Yarn tension bobbin diameter relation for 11.8 tex cotton yarn and cylindrical bobbin.*

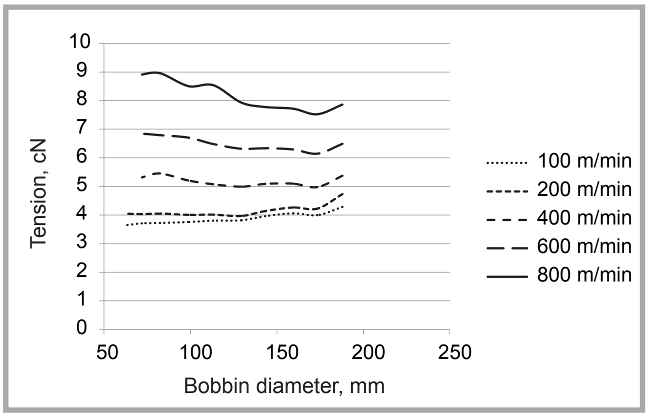

*Figure 11. Yarn tension bobbin diameter relation for 11.8 tex cotton yarn and conical bobbin.*

from the full to empty bobbin of around 4 cN and 6 cN with unwinding speeds of 600 and 800 m/min, respectively. Initially tension decreased at all speeds by around 1-2 cN. This is thought to be due to the friction between the unwound yarn and bobbin surface as a higher diameter bobbin was used.

***Figure 7*** shows tension change with respect to the bobbin diameter for 33.3 tex polyester yarn. No significant tension change occurred with respect to the bobbin diameter at unwinding speeds of 100 and 200 m/min. At 400 m/min, tension increased by around 2.5 cN towards the empty bobbin after 80 mm bobbin diameter. At unwinding speeds of 600 and 800 m/min, tension increased by about 6 and 10 cN, respectively. Tension changed slightly at higher bobbin diameters, and it increased at a higher rate towards the empty bobbin diameter. In fact, the relationship between the unwinding tension and bobbin diameter approaches a quadratic change at unwinding speeds of 600 and 800 m/min.

***Figure 8*** shows tension change with respect to the bobbin diameter for 66.6 tex polyester intermingled textured yarn. At unwinding speeds of 100 and 200 m/min, no significant change

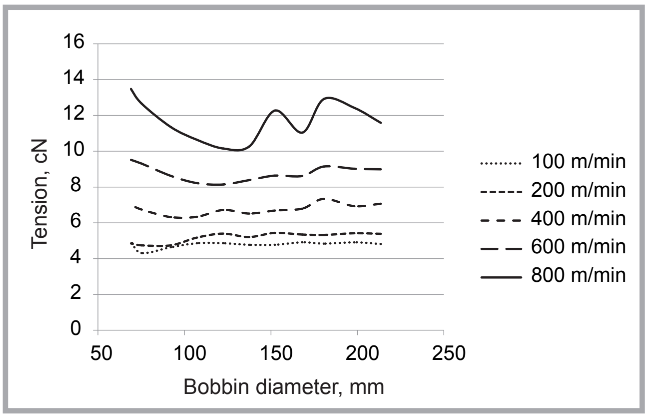

***Figure 12.*** *Yarn tension bobbin diameter relation for 14.8 tex cotton yarn and cylindrical bobbin.*

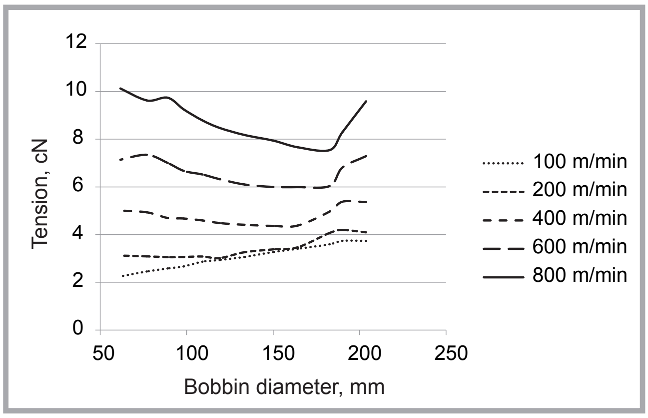

***Figure 13.*** *Yarn tension bobbin diameter relation for 14.8 tex cotton yarn and conical bobbin.*

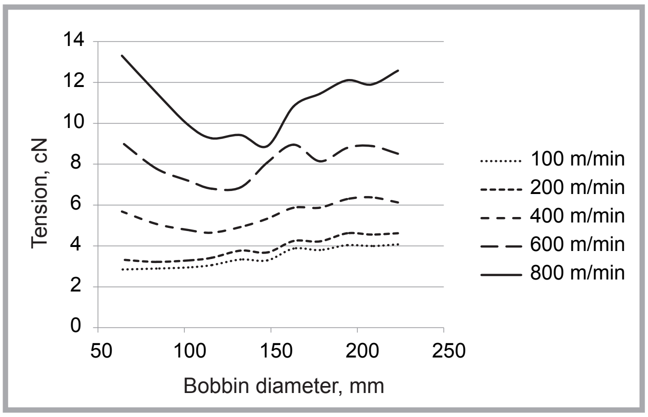

***Figure 14.*** *Yarn tension bobbin diameter relation for 19.7 tex cotton yarn and cylindrical bobbin.*

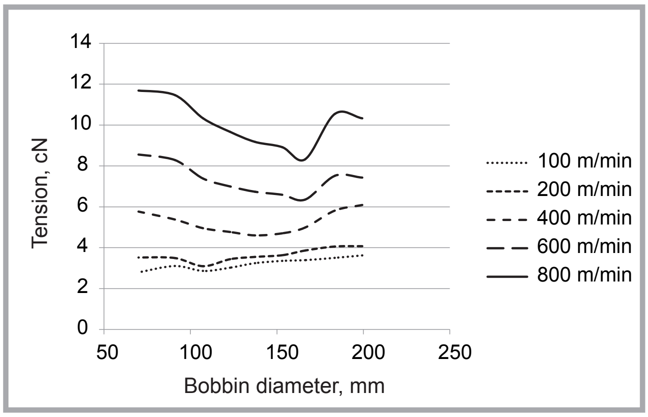

***Figure 15.*** *Yarn tension bobbin diameter relation for 19.7 tex cotton yarn and conical bobbin.*

in yarn tension was obtained. The yarn tension bobbin diameter relationship showed a quadratic change at unwinding speeds of 400, 600 and 800 m/min. Tension increased by around 4 cN, 10 cN and 15 cN at unwinding speeds of 400, 600 and 800 m/min, respectively, from the full to empty bobbin. These results show that the centrifugal force arising due to the rotation of yarn around the bobbin axis during unwinding has a dominating effect on yarn tension with this yarn number.

A similar tension change is observed with 100 tex polyester textured intermingled yarn, as shown in ***Figure 9***. Again no significant tension change was observed from the full to empty bobbin at unwinding speeds of 100 and 200 m/min. At unwinding speeds of 400, 600 and 800 m/min, tension changed at an increasing rate up to the empty bobbin diameter. Tension increased by around 10 cN, 15 cN and 30 cN at speeds of 400, 600 and 800 m/min, respectively, which had very significant practical importance. Here too, the centrifugal force had a determining effect on yarn tension change with respect to the bobbin diameter.

### Experimental work with cotton yarns wound on cylindirical and conical bobbins

Experimental work wih cotton yarns was conducted using cylindirical as well as conical bobbins.

***Figures 10*** and ***11*** show unwinding tension change with the bobbin diameter for 11.8 tex cotton yarn of cylindrical and conical bobbins, respectively. In the case of unwinding from a cylindrical bobbin, yarn tension decreased with an around 50 mm decrease in the bobbin diameter, and then it increased until the empty bobbin diameter at speeds of 400 m/min and above. Yarn tension fluctuated around 3.5 cN at 800 m/min, 2 cN at 600 m/min and 1 cN at 400 m/min unwinding speed from the full to empty bobbin. At speeds of 100 and 200 m/min, almost no significant tension change occurred. The reason for the higher initial tension is thought to be due to friction between the unwound yarn and bobbin surface. The friction between the bobbin surface and unwound yarn decreases with a decreasing bobbin diameter, and therefore yarn tension decreases. On the other hand, the angular rotation of yarn around the bobbin axis increases with a decreasing bobbin diameter, which causes the centrifugal force to increase. Especially after a 135 mm bobbin diameter, yarn tension continuously increased because of the effect of the centrifugal force with a decreasing bobbin diameter.

Yarn tension fluctuation was limited in the case of unwinding from a conical bobbin, as seen in ***Figure 11***. At all speeds, yarn tension decreased with a small decrease in the bobbin diameter, and then it increased at speeds of 600 and 800 m/min. Yarn tension fluctuated around 1.5 cN at 800 m/min speed and 1 cN at 600 m/min. At speeds of 100, 200 and 400 m/min, no significant tension change occurred with respect to the bobbin diameter. Compared to the cylindrical bobbin, friction between unwound yarn and the bobbin surface decreases because of the conical shape of the bobbin. Because of this, yarn

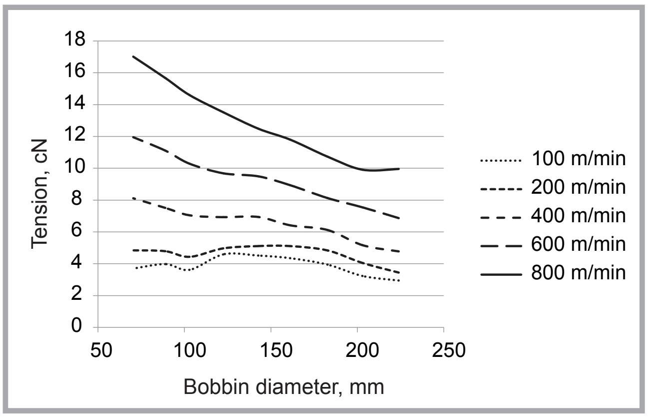

***Figure 16.*** *Yarn tension bobbin diameter relation for 29,5 tex cotton yarn and cylindrical bobbin.*

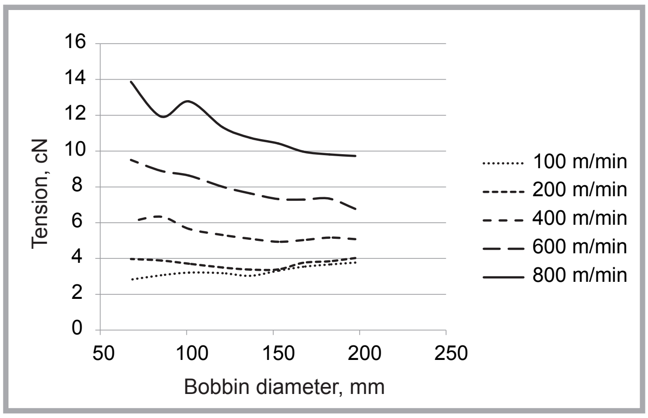

***Figure 17.*** *Yarn tension bobbin diameter relation for 29.5 tex cotton yarn and conical bobbin.*

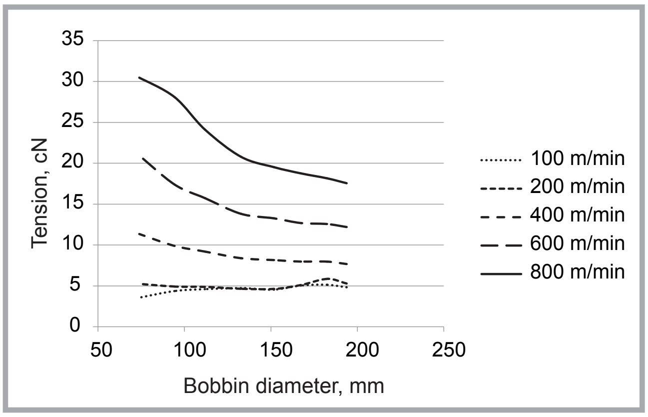

***Figure 18.*** *Yarn tension bobbin diameter relation for 59.1 tex cotton yarn and cylindrical bobbin.*

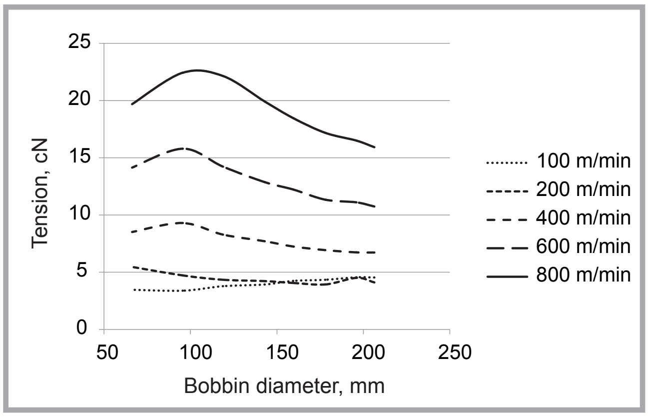

***Figure 19.*** *Yarn tension bobbin diameter relation for 59.1 tex cotton yarn and conical bobbin.*

tension started to increase at speeds of 600 and 800 m/min after a small decrease in the bobbin diameter. The increase in tension is thought to be due to the increasing angular rotation of yarn around the bobbin with a decreasing bobbin diameter. It should be pointed out that the yarn tension increase in conical bobbins with a decreasing bobbin diameter corresponds to almost half of the tension increase in a cylindrical bobbin.

Yarn tension change during unwinding with respect to the bobbin diameter is shown in ***Figure 12*** for 14.8 tex cotton yarn and a cylindrical bobbin. As in 11.8 tex cotton yarn, yarn tension decreased with a decreasing bobbin diameter up to a 150 mm bobbin diameter and then tended to increase up to the empty bobbin at speeds of 600 and 800 m/min. No significant fluctuation in tension was observed at speeds of 100, 200 and 400 m/min. It fluctuated around 2 cN and 4 cN for speeds of 600 m/min and 800 m/min, respectively. As in the conical 14.8 tex cotton yarn bobbin (***Figure 13***), a similar change to the 11.8 tex cotton yarn conical bobbin was also observed in yarn unwinding tension with respect to the bobbin diameter. Unwinding started with a higher tension due to friction between the bobbin surface and unwound yarn. It decreased during an around 30 mm decrease in the bobbin diameter and then started to increase due to the centrifugal force. Tension changed by around 2.5 cN and 1.5 cN at speeds of 800 and 600 m/min respectively. While the tension fluctuated around 1 cN at 400 m/min, it decreased from the full to empty bobbin by around 1.5 cN at speeds of 100 and 200 m/min. Moreover, in 14.8 tex cotton yarn, yarn tension changed less in respect of the bobbin diameter with a conical bobbin.

***Figures 14*** and ***15*** show the unwinding tension bobbin diameter relationship for cylindrical and conical bobbins of 19.7 tex cotton yarn, respectively. Yarn tension decreased up to the middle of the bobbin diameter, and then it increased in the cylindrical bobbin (***Figure 14***). No significant change was observed in yarn tension between the full and empty bobbin. However, it fluctuated from the full to empty bobbin around 2.0 cN, 2.5 cN and 4.5 cN at speeds of 400, 600 and 800 m/min, respectively. At 100 and 200 m/min speeds, yarn tension decreased by around 1.5 cN from the full to empty bobbin. As in 14.8 tex and 11.8 tex yarns, friction between the bobbin surface and unwound yarn was higher, and this increased yarn tension at higher bobbin diameters. Yarn tension decreased with a diminishing bobbin diameter due to the decreasing friction between the bobbin surface and unwound yarn up to the middle of the bobbin diameter. Then the effect of centrifugal forces on yarn tension became increasingly higher, and hence tension increased. In the conical bobbin, yarn tension decreased during an about 30 mm decrease in the bobbin diameter, and it then increased up to the empty bobbin at unwinding speeds of 400, 600 and 800 m/min (***Figure 15***). Tension fluctuated around 1.5 cN, 2 cN and 4 cN at unwinding speeds of 400, 600 and 800 m/min, as in 14.8 tex and 11.8 tex cotton yarns.

***Figures 16*** and ***17*** show yarn tension versus the bobbin diameter for cylindrical and conical bobbins of 29.5 tex cotton yarn. In a 29.5 tex cotton yarn cylindrical bobbin, no tension decrease was observed up to a certain diameter after the full bobbin diameter at speeds of 400, 600 and 800 m/min (***Figure 16***). Tension increased up to the empty bobbin by about 7.5 cN, 5 cN and 3 cN at speeds of 800, 600 and 400 m/min respectively. Only a slight variation was observed at speeds of 100 and 200 m/min from the full to empty bobbin diameter. ***Figure 17*** shows unwinding tension change in the conical bobbin. Different from 11.8 tex, 14.8 tex and 19.7 tex cotton yarns, firstly yarn tension did not show any decrease, and then ir increased along with the bobbin diameter. Yarn tension fluctuated around 4 cN, 2.5 cN and 1 cN at speeds of 800, 600 and 400 m/min, respectively. Tension change between the full and empty bobbin diameters was found to be significantly lower (almost half) with conical bobbins.

***Figures 18*** and ***19*** show the yarn tension bobbin diameter relationship for cylindrical and conical bobbins of 59.1 tex cotton yarn. With the cylindrical bobbin (***Figure 18***), no tension change was observed at speeds of 100 and 200 m/min. At speeds of 400 m/min and above, tension increased with decreasing bobbin diameters, which was at a higher rate towards the empty bobbin diameter. From the full to empty bobbin, tension increased by around 12.5 cN, 7.5 cN and 3 cN at unwinding speeds of 800, 600 and 400 m/min respectively. In the conical bobbin (***Figure 19***), yarn tension increased with a decreasing bobbin diameter up to 90-100 mm diameter and then decreased after this diameter until the bobbin became empty for all speeds above 400 m/min. A decrease in tension below a 90-100 mm bobbin diameter was observed to be due to double balloon formation at speeds of 400, 600 and 800 m/min. A double balloon was formed only at an 800 m/min speed with 29.5 tex cotton yarn. It was formed in 59.1 tex cotton yarn at speeds above 400 m/min, and caused the tension to decrease. Yarn tension fluctuated around 7 cN, 5 cN and 2.5 cN at speeds of 800, 600 and 400 m/min, respectively. This tension fluctuation is significantly lower compared to unwinding from a cylindrical bobbin.

The diameter of bobbins of cotton yarns of all counts was almost the same. Yarn tension during unwinding decreased up to a certain diameter and then increased until the bobbins became empty for 11.8 tex, 14.8 tex and 19.7 tex cotton yarns. But this tension decrease at higher bobbin diameters was not observed with 29.5 tex and 59.1 tex cotton yarns. The reason for this is thought to be due to the early separation of yarn from the bobbin surface owing to the centrifugal force and, hence, decreasing friction between the bobbin surface and unwound yarn for the thicker 29.5 tex and 59.1 tex cotton yarns. Comparing ***Figures 10***, ***12*** and ***14*** with ***Figures 11***, ***13*** and ***15*** clearly shows that tension decreases over a shorter period of diameter decrease and then starts to increase with the conical bobbin. This is because friction between the conical bobbin surface and unwound yarn decreases earlier in conical bobbins than in cylindrical ones due to the bobbin geometry.

## Conclusions

An experimental research was carried out to investigate the relationship between the yarn tension and bobbin diameter during unwinding from bobbins in the warping process for spun and continuous filament yarns. The following conclusions can be drawn regarding the experimental research.

- The unwinding speed and yarn number were found to be the most important parameters affecting the relationship between the unwinding tension and bobbin diameter for both spun and continuous filament yarns.
- In the unwinding of cotton yarns from cylindrical bobbins, the initial higher tension decreased up to a certain decreasing bobbin diameter, and then it increased up to the empty bobbin with 11.8 tex, 14.8 tex and 19.7 tex cotton yarns. There was no significant tension difference between the full and empty bobbin diameters. It is thought that friction between the bobbin surface and unwound yarn is the reason for the initial higher tension at the full bobbin diameter. Tension decreased with a decreasing bobbin diameter because of decreasing friction between the yarn and bobbin surface, and then it increased up to the empty bobbin. This is attributed to the increasing centrifugal force and decreasing friction with the diminishing bobbin diameter. However, tension change showed a different characteristic with 29.5 tex and 59.1 tex cotton yarns, as there was none at high bobbin diameters; however, it increased with a higher rate towards the empty bobbin. As this happens with coarser yarns, the reason could be that unwound yarn is separated from the bobbin surface earlier due to the higher centrifugal force, and as a result friction between the bobbin surface and unwound yarn decreases.
- Unwinding from conical bobbins limited the tension increase with respect to the bobbin diameter. An about 40% less yarn tension increase from the full to empty bobbin was observed compared to unwinding from cylindrical bobbins at 800 m/min speed. A decrease in tension was observed at around empty bobbin diameters in 59.1 tex cotton yarn at all speeds above 400 m/min and in 29.5 tex only at 800 m/min speed. This is thought to be due to double balloon formation.
- In the case of unwinding of continuous filament polyster yarns, the unwinding tension bobbin diameter relation approached a quadratic change at unwinding speeds of 400 m/min and above and with yarns of 33.3 tex and thicker. No significant tension change with respect to the bobbin diameter was observed at speeds under 200 m/min for all yarn counts. This could be attributed to the significant effect of the centrifugal force on yarn tension.
- The unwinding of finer yarns (16.7 tex and finer) at speeds lower than 400 m/min did show a slight tension increase only at small bobbin diameters. Yarn tension remained stable during most of the diameter change.
- No tension variation of first a decrease and then an increase was observed with respect to the bobbin diameter as in finer cotton yarns. This is attributed lower friction between the bobbin surface and continuous filament polyester yarn.
- This paper investigated yarn unwinding tension change with respect to the bobbin diameter considering the yarn count, unwinding speed and yarn type. There are also other parameters like the distance between the yarn guide and bobbin front surface (balloon height), winding types, and winding parameters, such as the winding angle, pressure angle and winding tension. These parameters are also expected to affect the relationship between the

yarn unwinding tension and bobbin diameter. Research regarding the effect of these parameters on the relationship between the yarn unwinding tension and bobbin diameter is currently in progress.

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