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An Experimental Investigation of Yarn Tension in Simulated Ring Spinning

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Abstract: Yarn tension is a key factor that affects the efficiency of a ring spinning system. In this paper, a specially constructed rig, which can rotate a yarn at a high speed without inserting any real twist into the yarn, was used to simulate a ring spinning process. Yarn tension was measured at the guide-eye during the simulated spinning of different yarns at various balloon heights and with varying yarn length in the balloon. The effect of balloon shape, yarn hairiness and thickness, and yarn rotating speed, on the measured yarn tension, was examined. The results indicate that the collapse of balloon shape from single loop to double loop, or from double loop to triple etc, lead to sudden reduction in yarn tension. Under otherwise identical conditions, a longer length of yarn in the balloon gives a lower yarn tension at the guide-eye. In addition, thicker yarns and/or more hairy yarns generate a higher tension in the yarn, due to the increased air drag acting on the thicker or more hairy yarns.

Keywords: Ring spinning, Yarn ballooning, Yarn tension, Yarn hairiness, Air drag

Introduction

Ring spinning produces high quality yarns [1], but the spinning efficiency is low and power consumption per unit yarn production is high for ring spinning. The low spinning efficiency is due to the relatively high yarn tension during ring spinning, which increases the chance of ends-down. The high power consumption is caused by high air drag from the ballooning yarn [2] and yarn hairiness [3], which also generate high yarn tension during ring spinning. Many researchers have studied air drag and yarn tension in ring spinning [2,4-8]. Zhu *et al.* [9,10] measured spinning tension using a rubber string and polyester yarns on a Balloon Test System (BTS). Sharma and Rahn [11] measured yarn tension using polyester filaments on the BTS with a balloon control ring. These researchers used a fixed balloon height for their experiments. Since cotton and wool yarns are mostly spun on a ring spinning system and the balloon height changes during spinning, it is necessary to examine the tension of yarns spun from natural fibres at different balloon heights.

Experimental

Balloon Testing Device

We constructed an experimental yarn ballooning rig based on the concept of an air-drag tester as shown in Figure 1 [5], but with a different mechanical design. The yarn ballooning rig can rotate a yarn at high speeds without inserting any real twist into the yarn. We used it to simulate ring spinning, so that yarn tension at the guide-eye can be measured for different yarns, 'twisting' speeds and balloon heights. We examined various factors that affect the air drag and yarn tension using the experimental rig.

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Figure 2 shows the specially constructed instrument used to measure the yarn tension at guide-eye. It consists of a motor controller attached to the yarn ballooning device, a computer data acquisition system, and Instron with a separate tension sensor mounted on its crosshead through an arm. The "ring radius" or distance between the rotating eyelet and the centre of the ballooning device is fixed at 30 mm. The vertical distance between the guide-eye and the eyelet is the balloon height and can be pre-set by adjusting the guide-eye position. The guide-eye is vertically aligned with the centre of the yarn ballooning device.

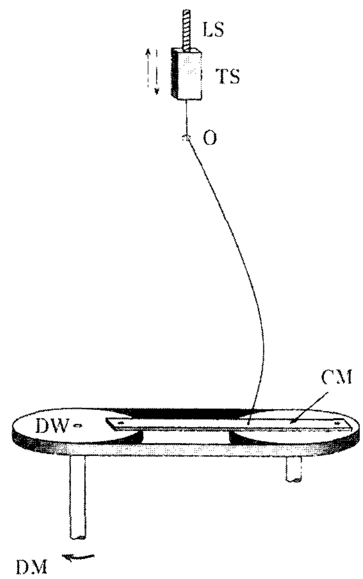
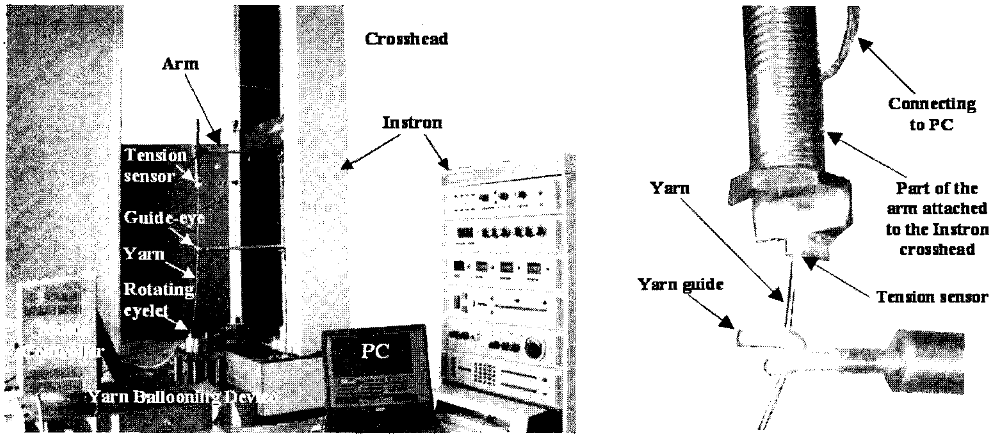


Figure 1. Sketched air-drag tester by Clark *et al.* [5], where LS is a lead-screw, TS is a tension-measuring device, O is guide-eye, CM is a crank mechanism, DW is the drive wheel of the crank mechanism and DM is a drive motor.



(a) (b)

Figure 2. Experimental set-up for measuring yarn tension at the guide-eye: (a) whole balloon testing devices and (b) a close view of the measuring unit and the yarn guide.

One end of a yarn, which passes through the guide-eye, is attached to the tension sensor and another end is fixed on the eyelet. The yarn segment between the guide-eye and eyelet forms a ballooning curve while the eyelet is rotating and this segment is defined as the yarn-length in the balloon. The yarn-length in the balloon increases while the arm, on which the tension sensor is fixed, moves downward (Figure 2). When the arm goes to the lower limit, the yarn-length between guide-eye and eyelet reaches the "maximum" value. The yarn-length in balloon decreases while the arm moves upward until it reaches the upper limit. The arm speed is set at 200 mm/min. When the eyelet starts rotating, the yarn segment between the guide-eye and rotating eyelet will form a ballooning curve and generate tension in the ballooning yarn. The tension signal at the guide-eye is digitised by the computer data acquisition system.

Materials

We have used three different types of yarns with various counts and hairiness for the experiments. Therefore, we can examine the effects of yarn thickness and hairiness on the yarn tension. Table 1 gives the details of the yarn characteristics.

For the hairiness results listed in Table 1, we tested the yarns at a speed of 400 m/min for a minimum of 3.5 minutes (or 1,400 m of yarn length) using the Uster Tester 4.

For yarn tension measurement, we 'spun' the yarns at different 'twisting' speeds on the ballooning rig, with the balloon height varying from 120 mm to 360 mm. We measured the yarn rotating speed with a digital tachometer during the tests, and used a digital camera with video capability to capture the balloon shape.

Table 1. Yarn specifications

	Two-fold wool	Two-fold cotton	Single cotton
Count (tex)	70.1	50.4	38
Uster hairiness (H)	12.0	8.1	8.1

Results and Discussion

Effects of Yarn-length in Balloon on Balloon Shape

Figure 3 shows the effect of yarn-length in balloon, for the 70.1 tex two-fold wool yarn, on the balloon shapes at a balloon height of 300 mm and a rotating speed of 4200 rpm. When the ratio of yarn-length in balloon to balloon-height ($R_{l/h}$) is 1.03, 1.10, 1.20, 1.35 and 1.65, the balloon has 1, 2, 3, 4 and 5 loops respectively.

When the yarn-length in balloon is close to the "minimum" value of $\sqrt{h^2+a^2}$ (where h is the balloon height and a is the ring radius), the balloon is almost in the axial plane (a plane that contains ballooning yarn and passes the centre line of the balloon rig), as shown in Figure 3(a). When the yarn-length in balloon is increased, the axial plane will twist some radians due to the air drag on the ballooning yarn and yarn hairs. For ease of statement, we call the twist angle of the ballooning yarn at the rotating eyelet relative to the guide-eye as the offset-angle [radian]. Figures 3(a)-(e) correspond to an offset-angle of around 0.4π, 1.5π, 2.5π, 3.3π and 4.4π, respectively. As the yarn-length in balloon is continuously increased, the offset-angle increases further, and then the yarn in the balloon will usually form knots and break at the rotating speed under consideration.

Effects of Yarn Type and Count on Yarn Balloon

Figure 4 displays a comparison of pure wool 70.1 tex two-fold yarn, cotton 50.4 tex two-fold yarn and cotton 38 tex single yarn at the same rotating speed of 5300 rpm. When

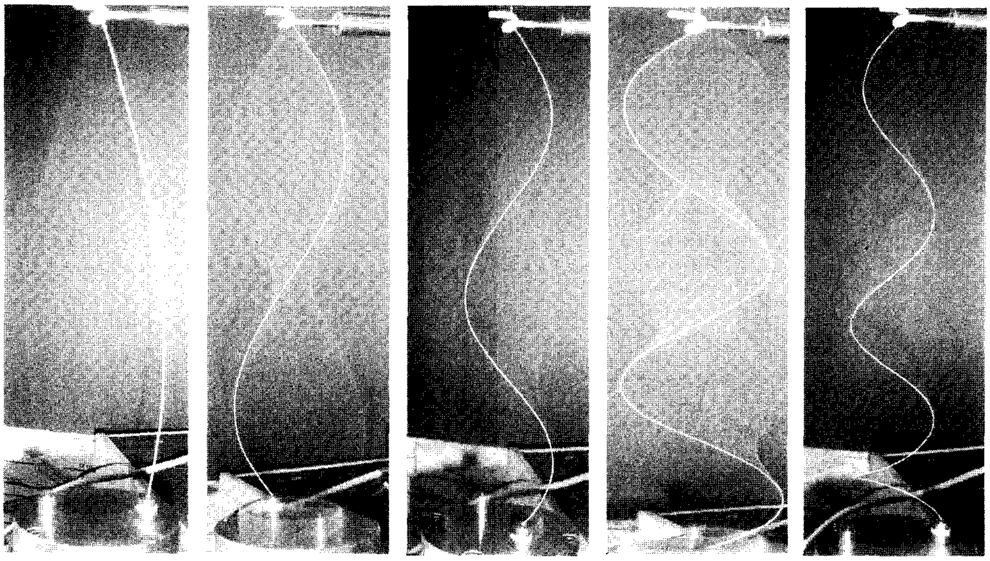


Figure 3. Balloon shapes for varying yarn-length in the balloon with a balloon height of 300 mm (Yarn-length in balloon: (a) 309 mm, (b) 330 mm, (c) 360 mm, (d) 405 mm, and (e) 495 mm).

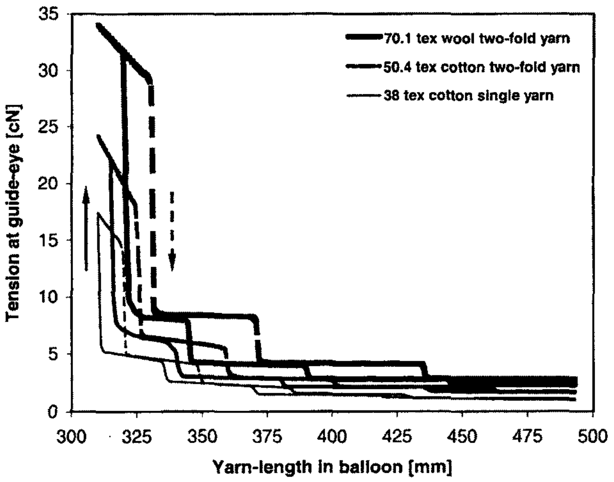


Figure 4. Yarn tension at the guide-eye against yarn-length in balloon at a rotating speed of 5300 rpm (solid lines: tension was measured as the yarn-length in balloon was decreased; broken lines: tension was measured as the yarn-length in balloon was increased).

the yarn-length in balloon is 310 mm, the tensions at guide-eye are 33.95 cN, 24.13 cN and 17.45 cN for the two-fold wool yarn, two-fold cotton yarn and single cotton yarn, respectively. These results are expected because of the different yarn counts. Heavy yarns have a higher centrifugal force during rotation, which leads to higher yarn tension. In addition, the air drag is different for these yarns also. To isolate the yarn count effect, we expressed the yarn tension in terms of specific tension, i.e., the ratio of yarn tension over yarn-count. The specific tension for the three different yarns are 0.484 cN/tex for pure wool two-fold yarn, 0.479 cN/tex for cotton two-fold yarn and 0.459 cN/tex for cotton single yarn. These differences in specific tension are due to the different air drag acting on the yarns. The two fold wool yarn has the highest hairiness index value (Table 1) and the largest yarn thickness, the air drag acting on this yarn is the largest, hence also the specific tension. The two cotton yarns have the same hairiness index values (Table 1), but the two-fold cotton yarn is heavier and has a larger 'diameter', hence its air drag and specific tension is slightly higher.

The downward pointing arrow in Figure 4 indicates a sudden reduction in yarn tension, which corresponds to the collapse of the single loop balloon into a double loop one. The yarn tension then remains relatively stable until the double balloon collapses into a triple one. These results are consistent with previous findings [9].

Effects of Ring Rail Movement Direction on Spinning Tension

For each yarn, Figure 4 shows the complete cycle of yarn tension as the yarn-length in balloon increases from the shortest to longest (dashed line) and then from the longest to shortest (solid line). At the same yarn-length in balloon, the point on the dashed line is higher than that on the solid line, and the points on the dashed line and solid line are very close together when the yarn-length in balloon is approaching the minimum length or the number of balloon loops is more than 3. However, there is a noticeable difference between the points on the dashed line and solid line for the same yarn-length in balloon while the balloon loops change between

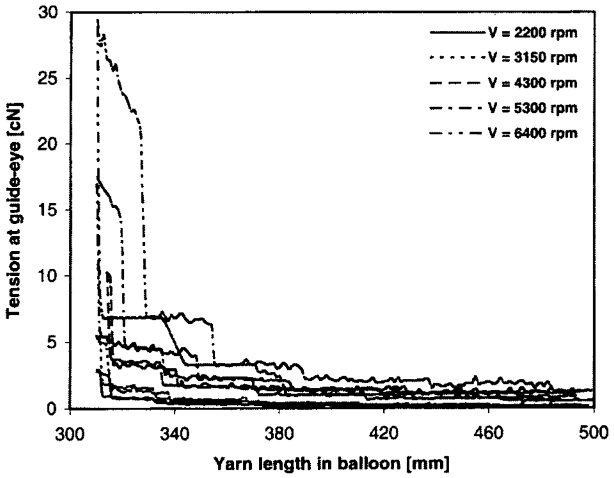


Figure 5. Yarn tension at the guide-eye against yarn length in balloon for varying rotating speeds (38 tex cotton single yarn, balloon height: 300 mm).

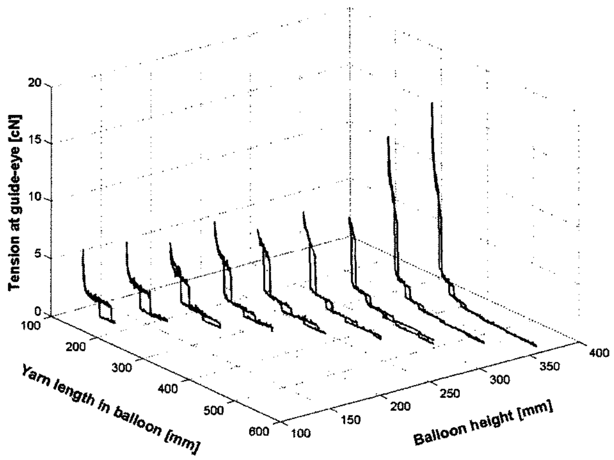


Figure 6. Yarn tension at the guide-eye against yarn-length in balloon with a rotating speed of 3050 rpm and varying balloon heights.

single and double or between double and triple. This result confirms that the yarn tension is different when the ring rail moves upward and downward in ring spinning.

Effects of Rotating Speed on Spinning Tension

Figure 5 shows the tension curves for the single cotton yarn of 38 tex at different rotating speeds and a balloon height of 300 mm. When yarn-length in balloon is 315 mm, the tension levels at the guide-eye are 5.19 cN, 7.95 cN and 14.65 cN for the rotating speed of 2300 rpm, 3100 rpm, 4200 rpm, respectively. When the yarn-length in the balloon is 310 mm, the tension levels at the guide-eye are 23.38 cN for the rotating speed of 5300 rpm and 36.04 cN for the rotating speed of 6300 rpm.

The ratios of the max tension at guide-eye to rotating speed [cN/rpm] from Figure 5 are 0.0023, 0.0025, 0.0034, 0.0044 and 0.0056 for rotating speed of 2300 rpm, 3150 rpm, 4300 rpm, 5300 rpm and 6400 rpm, respectively. This means that the larger the spindle speed, the quicker the increase of the tension at guide-eye, confirming that spindle speed is one of the main factors that affect spinning tension in ring spinning.

Effects of Balloon Height on Spinning Tension

Figure 6 shows the effect of balloon heights on the tension for the two-fold cotton yarn of 50.4 tex at the same spinning speed of 3050 rpm. We measured yarn tension at the guide-eye for a given ratio of yarn-length in balloon over balloon-height ($R_{l/h}$ = 1.05). The yarn tension results are 4.27 cN, 4.20 cN, 4.91 cN, 6.34 cN, 6.11 cN, 7.43 cN, 7.78 cN, 9.88 cN, and 10.51 cN, when the ratio of balloon-height over ring-radius ($R_{h/r}$) is 4, 5, 6, 7, 8, 9, 10, 11, and 12, respectively. These results indicate that for a given rotating speed, the increase in yarn tension at guide-eye is proportional to the balloon-height. It suggests that decreasing the balloon-height is one of the methods that reduce spinning tension in ring spinning.

Conclusion

A ring spinning process was simulated using a purpose-built yarn ballooning rig. The rig allows the rapid rotation of a yarn without inserting any real twist into the yarn, and the balloon height and yarn length in the balloon are changeable. Yarn tension at the guide-eye was measured for different yarns under different conditions. The results indicate that:

(1) Yarn tension experiences a sudden drop when the rotating yarn balloon collapses from a single loop one to a double loop one. Similarly, the tension undergoes an obvious change when the balloon loops change between double and triple, but the tension change is small when the balloon loops change between triple and quadruple, or between quadruple and above.

(2) Yarn tension is higher for single loop balloon than for multi-loop balloon, and decreases as yarn-length in balloon increases. Within the same number of loops in the balloon and when the balloon has two or more loops, the tension keeps almost the same as the yarn-length in balloon varies.

(3) Yarn hairiness and thickness, through their effects on air drag acting on the yarn, affect the measured yarn tension. The effect of yarn rotating speed on yarn tension is very significant.

(4) Yarn tension increases when the ratio of balloon height to ring-radius increases, in particular, when the ratio is greater than 10.

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