Spindle Speed Optimization of a Ring Spinning Machine for Better Surface Irregularity and Hairiness of Yarn and Fabric

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Abstract: Producing yarn from natural fibers without creating irregularities in structure or having fibers protruding from the surface, remains the goal of spinners. This is a problem, as structural irregularities such as hairiness affect subsequent fabric manufacturing processes and the aesthetics of the final fabric. This work therefore focused on investigating the effects of varying the spindle speed of a ring spinning frame on the structure of yarn (i.e., its surface regularity and hairiness), its strength and the surface pilling of fabric made from such yarn with a view to optimizing the spindle speed. For this, yarns with counts of 20, 25, and 30 tex were produced at six different spindle speeds ranging from 11,000 to 21,000 rpm with an interval of 2,000 rpm. All other parameters were kept constant, including the draft for a particular count, the type and weight of the traveler, and the diameter of the ring. The results obtained revealed that as the spindle speed was increased to 17,000 rpm, the yarn structure became more regular and less hairy, thereby becoming stronger. Beyond 17,000 rpm, however, both the regularity and strength decreased, with the hairiness continuing to increase with increasing spindle speed. Consequently, the surface pilling of the fabric was found to be optimized when made from yarns produced at a spindle speed of 17,000 rpm.

Keywords: spindle speed, yarn structure, irregularity, hairiness, yarn strength, surface pilling

1. Introduction

It is well-known that the properties of a yarn are related to its structure. Variances in the properties of yarns spun by different process conditions may be attributed to the differences in their structures [1−3]. The interaction between the fiber structure and the properties is determined by the dynamics and mechanism of the spinning process. The tensile response of staple yarns is usually determined by their structure and the mechanical properties of the constituent fibers [4−8]. One of the features of yarn structure is its visual form, which is created merely by the outlying layer of it. The other feature is the interior and exterior build up. There are many variants of the yarn structure, including the variations which are caused intentionally by the spinner for any specific end use. However, many of these variations are machine dependent. For example, it is difficult to produce a yarn equivalent to a ring-spun yarn by the open-end spinning processes [8,9]. The structure of a yarn can be opened or closed; voluminous or compact; smooth or rough or hairy; soft or hard; round or flat; thin or thick [10]. In addition, yarn structure not only affects appearance, it also has a greater or lesser influence on; handle, strength, elongation, insulating capacity, covering power, ability to resist wear, damage, strains, resistance to abrasion, ability to dye absorption, and the tendency towards longitudinal bunching of fibers and wearing comfort [11].

In its application, the structure of yarn plays the most important role. However, hairiness has always been a problem and many attempts have been undertaken in the
past to reduce yarn hairiness in order to make the outer edges of yarn smoother. New technologies, like compact spinning, have shown to reduce yarn hairiness and have gained a lot of commercial prominence in the recent years, [12–14] but their production cost is so high that their commercial application has been minimized [15,16]. The yarn structure depends primarily upon the raw material, spinning process, spinning unit, machine, machine settings and twist [17]. Many of these have been investigated in the past and optimized already for particular end used. However, the machine manufacturers are extensively focusing on increasing spindle speed, which limits wider application of the machine. Hence, it is important to optimize the spindle speed of ring spinning machine for different types of the cotton, based on visual assessment of the changes in the surface structure of yarn.

2. Experimental

Variations in the structure and characteristics of yarn were investigated through varying spindle speed of ring spinning machine. All the other machine parameters including twist multiplier, twist, size and weight of ring, size and shape of traveler were kept constant during yarn formation of a particular count. In consort with that, the ambient conditions were also kept to vary as least as possible within the limits of spinning cotton yarn throughout the process. It was so to get structural changes merely from disparity of spindle speed. Yarn structural changes were examined at six different spindle speeds from around 11,000 rpm to 21,000 rpm with a 2,000 rpm interval. Three yarn counts were prepared in the same manner, 20, 25, and 30 tex. A total of eighteen yarn types were made to investigate evenness, hairiness index, strength, and surface structure of yarn and fabric made of these yarns. Raw material used for the work was staple cotton fibers in the form of bale, trade name MNH-93, which is Pakistani cotton. The cotton fiber properties are given in Table 1.

Throughout the process starting from bale opener to drawn sliver formation, RIETER® systems were used including Mixing bale opener (MBO) 3/4®, UNI-Clean B11®, UNI-Flex B60®, Chute feed A70®, High-Per Card C-51®, RSB-D35C®. Roving frame used was FA 415A®, Jiangsu, China, and Ring spinning machine used was EJM168®, Shanghai Erfangji Co, China. Winding machine used was Schlafhorst Autoconer 238® winding machine. Testing machine for

Table 1. Properties of cotton fiber

<table>
<thead>
<tr>
<th>Fiber properties</th>
<th>Value</th>
</tr>
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<tr>
<td>50% Span length</td>
<td>14.30</td>
</tr>
<tr>
<td>2.5% Span length</td>
<td>30.37</td>
</tr>
<tr>
<td>Uniformity ratio</td>
<td>47.11</td>
</tr>
<tr>
<td>MIC value</td>
<td>4.6</td>
</tr>
<tr>
<td>Bundle fiber strength</td>
<td>7 gf/tex</td>
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<tr>
<td>Short fiber index (SFI)</td>
<td>4.68</td>
</tr>
</tbody>
</table>

Table 2. Experimental design

<table>
<thead>
<tr>
<th>Spindle speed (rpm)</th>
<th>Count (Ne)</th>
<th>Twist per inch (TPM)</th>
<th>Draft</th>
<th>Twist multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>11000, 13,000, 15,000, 17,000, 19,000, 21,000</td>
<td>20</td>
<td>700</td>
<td>16</td>
<td>4.0</td>
</tr>
<tr>
<td>11000, 13,000, 15,000, 17,000, 19,000, 21,000</td>
<td>25</td>
<td>790</td>
<td>21</td>
<td>4.0</td>
</tr>
<tr>
<td>11000, 13,000, 15,000, 17,000, 19,000, 21,000</td>
<td>30</td>
<td>860</td>
<td>25</td>
<td>4.0</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1. Effect of Spindle Speed on Unevenness of Yarn

Unevenness was measured according to ASTM D1425 with 400 m/min withdrawal speed. The effect of spindle speed on yarn unevenness U % for 20, 25, and 30 tex yarn counts is shown in the following Figure 1.

The above figure reveals a trend of the irregularity found in the yarn with respect to the variation in spindle speed. Yarn unevenness kept on decreasing as the spindle speed was increased from 11,000 rpm up to 17,000 rpm. This can be ascribed based on the fact that as the spindle speed increase, the ratio of dynamic to static frictional force of the drafted ribbon increases. As a consequence, the floating fibers prefer to take the intermediate speed and ensure shuffling of the fibers in the drafting zone [18]. These factors may be responsible for the decrease in irregularity. At around 17,000 rpm, the yarn irregularity was found to be minimal. With the increase in this ratio, fibers move in a more controlled
manner so that the erratic movement of floating fibers is restricted, reducing the yarn U% [19]. Beyond 17,000 rpm, the yarn irregularity started to increase again. At higher spindle speed, the rubbing forces between the yarn surface and different machine parts, together with larger balloon diameter, abrade the surface of yarn [18], disturbing the alignment of the fiber array in yarn body. This results in increased irregularity of the yarn. It can be said that irregularity can be minimized by drafting the yarn at 17,000 rpm spindle speed. Figure 1 also reveals that U% increases with decreasing count.

3.2. Effect of Spindle Speed on Hairiness Index

USTER® Tester 4 measures both unevenness and hairiness at the same time. Therefore standard method used was same as given in previous section. Yarn hairiness was found to have variation with respect to the variation in the spindle speed. These results are compared in Figure 2, for 20, 25, and 30 tex yarns respectively.

It is noticeable in the Figure 2 that hairiness kept on decreasing as the spindle speed increased from 11,000 rpm to 17,000 rpm. This may have been resulted because as the increase in spindle speed which makes the twist to flow closer to front roller nip and spinning triangle became smaller and fibers in selvedge better integrated into the yarn [20]. It then started to increase after 17,000 rpm. It can be ascribed based on the fact that at higher spindle speeds, above 17,000 rpm, air drag and heat generation due to frictional contact of the fibers increases, together with the centrifugal force acting outwards on the yarn, this results in increased spinning tension and that gives more outward force of the tail end of the fibers causing formation of more protruding ends. Thus, it can be said that at 17,000 rpm we can produce a yarn that is optimum in terms of hairiness.

3.3. Effect of Spindle Speed on Yarn Strength

The results for the effect of spindle speed on yarn tensile strength are shown in Figure 3. As shown in this figure, as the spindle speed increases from 11,000 rpm up to 17,000 rpm the breaking strength correspondingly increases however it decreases gradually as the speed is increased beyond 17,000 rpm. Strength of the yarn is dependent on the fiber strength initially and then the alignment of the fibers in the fiber strand [21,22]. A regular yarn without many hairs on its surface can better withstand the force acting on it. Therefore, it was found that the yarns spun at 17,000 rpm have better strength as compared to other yarn spun at lesser or high spindle speed. Drafting force increases the normal force over the fibers and this may reduce the fiber slippage and hence more fibers can be caught within the yarn twist easily, resulting in greater yarn strength. The resulted breaking force is reported to be maximum at 17,000 rpm. However, the breaking force decreases as the spindle speed increases beyond 17000 rpm. This can be based on the fact that at elevated spindle speeds, the yarn hairiness increases and it is also shown in the previous section. These protruding fiber
3.4. Effect of Spindle Speed on Surface Structure of Yarn

An observable effect of variation in spindle speed was observed on the surface structure of yarn. Video Microscope was used to view and analyze the structure of yarn and investigate the type of variation. The followings are video microscope images of the three counts of yarn spun at around 11,000, 13,000, 15,000, 17,000, 19,000 and 21,000 rpm spindle speed.

Starting from the first part of all Figures 4, 5, and 6, showing spindle speed of 11,000 rpm, a similar trend was observed, that the fibers in the yarn are not very much aligned and in turn they are not readily twisted. The fibers are seen to be in an arbitrary position within the yarn structure. The fibers are seen to be in arranged randomly, having found no proper alignment, at the yarn surface. As the spindle speed is increased, the fibers are seen to become parallel and due to that they are caught in the twist. A further increase in the spindle speed gets the fibers more parallel and yarn structure seems to be regular as shown in the figure at 13,000 rpm and 15,000. It is seen that at 17,000 rpm spindle speed, the yarn surface structure is most smooth and are most alligned. These images are in good agreement with the results obtained for unevenness and strength showing lowest unevenness and highest strength at 17,000 rpm. After 17,000 rpm spindle speed, the surface structure is seen to get hairy as observable in the images and more hairy at 21,000 rpm spindle speed and can go beyond if spindle speed is increased further.

3.5. Effect of Spindle Speed on Surface Pilling

To confirm the effect of spindle speed on surface irregularity and hairiness, fabric made of produced yarns, was tested for surface pilling. ASTM D3511 “Standard Test Method for Pilling Resistance” was used to check the surface pilling of the as produced fabric samples. A clear change was observed which follows the same trend as in the hairiness of yarn. As shown in Figure 7, the least pilling on the fabric surface was obtained at 17,000 which is in good agreement with yarn hairiness results.

4. Conclusions

Most of the manufacturers run their machines at higher speeds to get higher productivity but at the cost of yarn
quality. From the experiments it can be concluded that the unevenness and hairiness of yarns produced of MNH-93® can be kept lowest at spindle speed of around 17,000 rpm. The structure of yarn was found to be more regular at nearby 17,000 rpm spindle speed which, gives yarn more strength and carries these advantages when being woven in terms smoother fabric surface and lesser surface pilling.

Acknowledgement

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References