Mechanism of End Breakage due to Knots in Weft Knitting Zone
Part 2 : End Breakage in 1×1 Rib Knitting Zone

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Abstract
The mechanism of the end breakage due to knots (a weaver's knot and a fisherman's knot) in the 1×1 rib knitting zone is investigated in detail, using a high speed video camera.

The results obtained are as follows:
1) It clarifies that the end breakage due to knots in the 1×1 rib knitting zone occurs in the following three steps: 1) jam of knots at a cylinder needle-hook, 2) increase in the yarn tension, 3) end breakage due to knots.
2) The end breakage due to air-splice in the 1×1 rib knitting zone does not occur under every knitting condition.
3) The rate of jammed knots, the end breakage rate for jammed knots and that for knots increase with the increase of the depth of stitch draw, the input tension and the take-down weight for any knot.
4) The rate of jammed knots, the end breakage rate for jammed knots and that for knots due to a fisherman's knot are always more than those due to a weaver's knot under every knitting condition.

1. Introduction
End breakage and yarn faults such as slubs and nepes cause 70% of all the defects of circular knitted fabrics made of spun yarns. Since slubs and nepes decrease the knitting efficiency and the quality of knitted fabrics, those are removed beforehand and replaced knots in winding. Although the size of knitting defect due to knots is smaller than that due to yarn faults, the knots causes the end breakage in the weft knitting zone. Therefore, in the weft knitting of spun yarns having many knots, end breakage due to knots is a serious problem in terms of knitting efficiency and quality of knitted fabrics. However, few works have been reported on the subject of weft knitting.
The author has shown the effect of some factors (the depth of stitch draw, the input tension, the take-down weight, the step length of cam and the cam angle) on the end breakage rate due to a weaver's knot in the 1×1 rib knitting zone. The authors described the mechanism of the end breakage due to knots (a weaver's knot and a fisherman's knot) in the plain weave knitting zone in Part 1.
This paper attempts to consider the mechanism of the end breakage due to knots (a weaver's knot and a fisherman's knot) in the 1×1 rib knitting zone using a high speed video camera.

2. Experimental

2.1 Details of yarn joints
A Mesdan air-splicer (Jointair 04C) or a mechanical knotter (Weaver's knotter A/775 or Fisherman's knotter 815-A) was mounted on a Kamimat automatic winder #550.
The knitting yarn used was a combed cotton yarn c30s/1 cotton count (19.7 tex) and was tied in about 100 joints (an air-splice, a weaver's knot and a fisherman's knot).
The profiles, the dimensions and the breaking strength and elongation of a cotton c30s/1, an air-splice, a weaver's knot and a fisherman's knot were shown in Figure 1 and in Tables 1 and 2 of Part 1, respectively.

2.2 Details of knitting
A 6-feeder, 1128-needle (dial and cylinder needles combined), 18 gauge, 10-in. diameter circular rib knitting machine was used with a positive-yarn-feeding device (IRO system).
Knitting timing used was the regular timing of about 11 dial needle delay. The depth of stitch draw is represented by the vertical distance between the upper surface of a dial needle and the knitting point as shown in Figure 4. The input tension was controlled by a positive-yarn-feeding device and measured with a yarn tension meter before the yarn enters the feeder. To ensure a constant take-down tension, a dead-weight was tied to the fabric. To take photographs of the knitting behavior using a high speed video camera, the knitting machine speed was reduced 2.7 rev./min using the Ringcone variable speed drive. The cam angle was set at 50.0°, and the step length of cam at 3.20 mm.
The dimensions of knitting elements are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Dimensions of knitting elements</th>
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</thead>
<tbody>
<tr>
<td>Knitting elements</td>
</tr>
<tr>
<td>Thickness of needle (mm)</td>
</tr>
<tr>
<td>Thickness of verge (mm)</td>
</tr>
<tr>
<td>Needle spacing (mm)</td>
</tr>
</tbody>
</table>
The yarn consisting of about 100 joints was fed to one feeder and normal yarns were fed to five feeders. Each set of 1x1 rib knitted fabrics was knitted under various knitting conditions. Each fabric was raveled and the course length was measured 30 times using a course length tester under 10 g weight. The stitch length is the value of the mean course length divided by the number of cylinder needles.

2.3 Observation of end breakage

Photographs of the knitting behavior were taken of the knitting of each 1x1 rib knitted fabric under various knitting conditions with a high speed video camera (the camera speed at 200 frames/sec). Eight frames can be taken of the knitting behavior as the needle moves one needle spacing.

The process of end breakage due to knots in the 1x1 rib knitting zone was observed and the number of knots (Nk), that of jammed knots (Nj) and that of end breakage due to knots (Ne) were counted by playing back of photographs of the knitting behavior. The judgment of end breakage due to knots was made by the observation of the loss of a loop on the dial needle.

The rate of jammed knots (Rj), the end breakage rate for jammed knots (Rk) and that for knots (EBR) are given as percentages by:

\[ R(\%) = \frac{N_j}{N_k} \times 100 \]  
\[ R_j(\%) = \frac{N_e}{N_j} \times 100 \]  
\[ EBR(\%) = \frac{N_e}{N_k} \times 100 \]

3. Results and Discussion

3.1 Process of end breakage due to knots

The knitting defects (knitting holes) due to knots on the 1x1 rib knitted fabrics are illustrated Figure 1.

The knitting hole due to an air-splice does not occur under every knitting condition. From Figure 1, the knitting hole due to both knots causes by the end breakage in the 1x1 rib knitting zone and this end breakage occurs near the knot on the take-down side, as in the case of the plain-weft knitting zone shown in Part 1.

From observations using a high speed video camera, the end breakage due to a weaver's knot and a fisherman's knot in the 1x1 rib knitting zone occurs similarly. The process of end breakage due to a fisherman's knot may be described as below.

This process of end breakage due to a fisherman's knot in the 1x1 rib knitting zone is shown in Figure 2.

The 1x1 rib knitting behavior is very complex in comparison with the plain-weft knitting behavior. Therefore, a schematic diagram of the process of end breakage due to a fisherman's knot in the 1x1 rib knitting zone neglecting the contact surface between the cylinder needle or the dial needle and an old loop is shown in Figure 3.

The numbers in Figures 2 and 3 express the order of knitting process, but 2 frames skip from 1 to 7, 4 frames from 7 to 10, 24 frames from 10 to 11 and 36 frames from 11 to 12. The needle below the mark V indicates the same needle. On frame 3 in Figure 3, a short rectangle is a dial verge, a long rectangle is a cylinder verge, mark • between dial verges is a dial needle-head and mark • between cylinder verges is a cylinder needle-head. The cylinder needle descends from the left-hand end to the knitting point and moves parallel on the step of the cam between about three needle spacings and then ascends.

An explanation of the process of end breakage due to a fisherman's knot in the 1x1 rib knitting zone is shown in Table 2. Table 2 should be read in connection with Figure 3.

![Air-splice](image1)

![Weaver's knot](image2)

![Fisherman's knot](image3)

Figure 1 Knitting holes due to knots

3.2 Jamming of knots and end breakage

A schematic diagram of the 1x1 rib knitting zone is shown in Figure 4.

From Figures 2 and 3, the knot jams at the cylinder needle-hook (C1) after it passes on the upper surface of the dial needle (D1) as shown in Figure 4. When the position of the lower surface of a cylinder needle-head is at the upper distance of the dimension of the knot from the upper surface of a dial needle (the initial state of the jam), the knot begins to
jam at a cylinder needle-hook. Then the knot is jamming in the space between a cylinder needle-hook and -latch and an old loop and this state continues until a cylinder needle casts off an old loop. The position of an old loop held by a cylinder needle is dependent on the stitch length. The shorter the stitch length is, the nearer to the position of an old loop is a dial needle. If the knot locates in the yarn fed from the input side between a cylinder needle $C_i$ moves from the initial state of the jam to the casting off an old loop, it jams at a cylinder needle-hook or in the space between a cylinder needle-hook and -latch and an old loop.

Let $l$ be the yarn length fed to the cylinder needles $C_1$ and $C_2$ between a cylinder needle $C_i$ moves from the initial state of the jam to the casting off an old loop and let $L$ be the stitch length. The rate of jammed knots is dependent on the value of $l/L$, that is, the greater the value of $l/L$ is, the greater is the rate of jammed knot.

We considered that the knot will jam in the space between a needle-hook and -latch and an old loop or in the space between a needle-head and a verge in the plain-weft knitting.
zone in Part 1, but the knot does not jam in the space between a cylinder needle-head and a cylinder verge in the 1×1 rib knitting zone.

The plain-weft knitted fabrics were knitted on a 22-gauge knitting machine and the 1×1 rib knitted fabrics were knitted on a 18-gauge knitting machine. The dimensions of knitting elements on a 22-gauge knitting machine were shown in Table 3 in Part 1 (needle spacing: 1.15 mm, thickness of needle: 0.34 mm and that of verge: 0.40 mm) and those on a 18-gauge knitting machine are shown in Table 1 (cylinder needle spacing: 1.42 mm, thickness of cylinder needle: 0.38 mm and that of cylinder verge: 0.40 mm).

Figure 3  Schematic diagram of process of end breakage due to a fisherman’s knot
Since the yarn and the knot are compressed in the knitting zone, the dimensions of those will be the values measured on a slub catcher. From Table 1 in Part 1, the dimension of an air-splice measured on a profile projector is 1.44 times that measured on a slub catcher. Therefore, the dimension of yarn in knitting zone will be 0.123 mm (= 0.177/1.44).

If a cylinder needle-head deflects easily, the space between a needle-head and a verge (S) is given by

22-gauge: S = 1.15 - 0.34 - 0.123 = 0.287 mm
18-gauge: S = 1.42 - 0.38 - 0.123 = 0.517 mm

It is assumed that the diameters of knots (a weaver’s knot or a fisherman’s knot) obey the normal distribution. The rate of the jam of knots in the space between a needle-head and a verge is 98% for a weaver’s knot and 100% for a fisherman’s knot on the 22-gauge knitting machine. On the other hand, both knots do not jam in the space between a needle-head and a verge (S).

Table 2 Process of end breakage due to a fisherman’s knot in the 1×1 rib knitting zone

<table>
<thead>
<tr>
<th>No.</th>
<th>Explanation of process of endbreakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The knot enters the knitting zone.</td>
</tr>
<tr>
<td>2</td>
<td>The knot jams at the marked cylinder needle-hook.</td>
</tr>
<tr>
<td>Between 2 and 3</td>
<td>The knot is in contact with the marked cylinder needle-head and descends with that.</td>
</tr>
<tr>
<td>4</td>
<td>End breakage occurs on the right side of the marked cylinder needle and the loop held by the dial needle on the right side of the marked cylinder needle disappears.</td>
</tr>
<tr>
<td>5</td>
<td>The loop held by the cylinder needle on the right side of the marked cylinder needle disappears and this cylinder needle descends below the cylinder needle on the step of the cam.</td>
</tr>
<tr>
<td>Between 6 and 8</td>
<td>Two loops held by two dial needles on the right side of the marked cylinder needle disappears.</td>
</tr>
<tr>
<td>9</td>
<td>The loops held by the marked cylinder needle and by the dial needle on the left side of this cylinder needle disappear.</td>
</tr>
<tr>
<td>Between 9 to 11</td>
<td>The state of frame 9 proceeds gradually.</td>
</tr>
<tr>
<td>12</td>
<td>The loops held by two cylinder needles and by three dial needles disappear.</td>
</tr>
</tbody>
</table>
head and a verge on the 18-gauge knitting machine, so the space (0.517 mm) is larger than the maximum value of the dimension of a knot (a weaver’s knot: 0.48 mm, a fisherman’s knot: 0.50 mm) measured on a slub catcher.

The variation of the rate of jammed knots ($R_j$), the end breakage rate of jammed knots ($R_e$) and the end breakage rate for knots ($EBR$) with the depth of stitch draw is shown in Table 3.

### Table 3: Effect of depth of stitch draw on $R_j$, $R_e$ and $EBR$

<table>
<thead>
<tr>
<th>Kind of knot</th>
<th>Stitch draw length (mm)</th>
<th>$N_k$</th>
<th>$N_j$</th>
<th>$R_j$ (%)</th>
<th>$N_e$</th>
<th>$R_e$ (%)</th>
<th>$EBR$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WK</td>
<td>2.4</td>
<td>6.02</td>
<td>122</td>
<td>28</td>
<td>23.0</td>
<td>5</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>6.30</td>
<td>96</td>
<td>29</td>
<td>30.2</td>
<td>10</td>
<td>34.5</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>6.52</td>
<td>100</td>
<td>40</td>
<td>40.0</td>
<td>23</td>
<td>57.5</td>
</tr>
<tr>
<td>FK</td>
<td>2.4</td>
<td>6.02</td>
<td>101</td>
<td>45</td>
<td>44.6</td>
<td>21</td>
<td>46.7</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>6.30</td>
<td>99</td>
<td>57</td>
<td>57.6</td>
<td>31</td>
<td>54.4</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>6.52</td>
<td>96</td>
<td>62</td>
<td>64.6</td>
<td>49</td>
<td>79.0</td>
</tr>
</tbody>
</table>

**WK:** Weaver’s knot, **FK:** Fisherman’s knot,

Input tension: 5.0 gf, Take-down weight: 8.0 kg.

$R_j$, $R_e$ and $EBR$ due to both knots increase with the increase of the depth of stitch draw. The stitch length increases with the increase of the depth of stitch draw. $R_j$ increases with the increase of the depth of stitch draw, probably due to the increase of the value of $l/L$. $R_e$ and $EBR$ increase with the increase of the depth of stitch draw, so the value of $l/L$ and the yarn tension in sections $ab$ and $cd$ increase with that of the depth of stitch draw.

The variation of the rate of jammed knots ($R_j$), the end breakage rate for jammed knots ($R_e$) and the end breakage rate for knots ($EBR$) with the input tension is shown in Table 4.

### Table 4: Effect of input tension on $R_j$, $R_e$ and $EBR$

<table>
<thead>
<tr>
<th>Kind of knot</th>
<th>Input Stitch tension length (mm)</th>
<th>$N_k$</th>
<th>$N_j$</th>
<th>$R_j$ (%)</th>
<th>$N_e$</th>
<th>$R_e$ (%)</th>
<th>$EBR$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WK</td>
<td>5.0</td>
<td>6.02</td>
<td>122</td>
<td>28</td>
<td>23.0</td>
<td>5</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>5.74</td>
<td>99</td>
<td>28</td>
<td>28.3</td>
<td>8</td>
<td>28.6</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>5.54</td>
<td>83</td>
<td>26</td>
<td>31.3</td>
<td>10</td>
<td>38.5</td>
</tr>
<tr>
<td>FK</td>
<td>5.0</td>
<td>4.02</td>
<td>101</td>
<td>45</td>
<td>44.6</td>
<td>21</td>
<td>46.7</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>3.98</td>
<td>105</td>
<td>50</td>
<td>47.6</td>
<td>27</td>
<td>54.0</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>3.90</td>
<td>90</td>
<td>62</td>
<td>68.9</td>
<td>37</td>
<td>59.7</td>
</tr>
</tbody>
</table>

**WK:** Weaver’s knot, **FK:** Fisherman’s knot,

Depth of stitch draw: 2.4 mm, Take-down weight: 8.0 kg.

$R_j$, $R_e$ and $EBR$ due to both knots increase with the increase of the take-down weight. The take-down weight has hardly any effect on the stitch length. $R_j$ increases with the increase of the take-down weight, probably due to the increase of the value of $l/L$. $R_e$ and $EBR$ increase with the increase of the take-down weight, so the value of $l/L$ increases and $\%RB$ (the percent robbing back) decreases with that of the take-down weight.

$R_j$, $R_e$ and $EBR$ due to a fisherman’s knot are always more than those due to a weaver’s knot under every knitting condition. The state of each type of knot both normal and squeezed with fingers was shown in Figure 7 of Part 1. From Figure 7 in Part 1, the thickness of a weaver’s knot squeezed with fingers is equal to that of the normal state of a weaver’s knot. Since the direction of the tails of a fisherman’s knot is opposite to each other, the thickness of a fisherman’s knot squeezed with fingers is the sum of the diameter of the yarn and the knot as shown in Figure 7 of Part 1. It is considered that $R_j$, $R_e$ and $EBR$ due to a fisherman’s knot is always more than those due to a weaver’s knot, so the thickness of a fisherman’s knot is larger than that of a weaver’s knot.
3.3 Mechanism of end breakage due to knots in 1x1 rib knitting zone

From Figures 1-4 and result of 3.2, it is clear that the end breakage due to knots in the 1x1 rib knitting zone occurs in the following three steps. Using Figure 4, therefore, the mechanism of the end breakage due to knots in the 1x1 rib knitting zone may be described as below.

1) Jam of knots in the space: The knot jams at the cylinder needle-hook(C1) after it passes on the upper surface of the dial needle (D1). When the position of the lower surface of a cylinder needle-head(Ci) is at the upper distance of the dimension of the knot from the upper surface of a dial needle (the initial state of the jam), the knot begins to jam at a cylinder needle-hook. Then the knot is jamming in the space between a cylinder needle-hook and -latch and an old loop and this state continues until a cylinder needle casts off an old loop, that is, if the knot locates in the yarn fed from the input side between a cylinder needle Ci moves from the initial state of the jam to the casting off an old loop, it jams at a cylinder needle-hook or in the space between a cylinder needle-hook and -latch and an old loop.

2) Increase of yarn tension: When the knot jams at a cylinder needle-hook, or in the space between a cylinder needle-hook and -latch and an old loop, the yarn from the input side is not fed into sections ab, bc and cd. Since the increase of yarn length in sections ab, bc and cd with the descent of the cylinder needles C1 and C2 has to be compensated by yarn elongation and robbing-back, the yarn tension in sections ab, bc and cd increases rapidly.

3) End breakage: When the yarn tension in section ab or cd becomes larger than the breaking strength of a knotted yarn, the end breakage due to a knot occurs at any point in section ab or cd, that is, near the knot on the take-down side.

4. Conclusion

The mechanism of the end breakage due to joints (an air-splice, a weaver's knot and a fisherman's knot using a combed cotton yarn c30s/1 cotton count) in the 1x1 rib knitting zone is investigated in detail, using a high speed video camera. By playing back of photographs of the knitting behavior, the process of end breakage due to knots was observed and the number of knots, that of jammed knots and that of end breakage due to knots were counted.

The results obtained are as follows:

1) By observation using a high speed video camera, the end breakage due to an air-splice in the 1x1 rib knitting zone does not occur under every knitting condition.

2) The rate of jammed knots, the end breakage rate for jammed knots and that for knots increase with the increase of the depth of stitch draw, the input tension and the take-down weight for any knot.

3) The rate of jammed knots, the end breakage rate for jammed knots and that for knots due to a fisherman's knot are always more than those due to a weaver's knot under every knitting condition.

4) It clarifies that the end breakage due to knots in the 1x1 rib knitting zone occurs in the following steps.

1) Jam of knots: The knot jams at the cylinder needle-hook(C1) after it passes on the upper surface of the dial needle (D1). When the position of the lower surface of a cylinder needle-head(Ci) is at the upper distance of the dimension of the knot from the upper surface of a dial needle (the initial state of the jam), the knot begins to jam at a cylinder needle-hook. Then the knot is jamming in the space between a cylinder needle-hook and -latch and an old loop.

2) Increase of yarn tension: When the knot jams at a cylinder needle-hook, or in the space between a cylinder needle-hook and -latch and an old loop, the yarn from the input side is not fed into sections ab, be and cd. Since the increase of yarn length in sections ab, be and cd with the descent of the cylinder needles C1 and C2 has to be compensated by yarn elongation and robbing-back, the yarn tension in sections ab, be and cd increases rapidly.

3) End breakage: When the yarn tension in section ab or cd becomes larger than the breaking strength of a knotted yarn, the end breakage due to a knot occurs at any point in section ab or cd, that is, near the knot on the take-down side.

References


(4) P.Mehta; Knit.Tim., 40, No.19, 39(1971)