Spirality in Plain-Jersey Fabrics Knitted of Three-Ply Cotton Yarns

By Ryuzo Oinuma* and Hiraku Takeda**, Members, TMSJ

*Miyagi University of Education, Sendai 980, Japan

**Faculty of Engineering, Yamagata University, Yonezawa 992, Japan

Based on the Journal of the Textile Machinery Society of Japan, Proceeding, Vol. 39, No. 2, P65-P71 (1986-2)

Abstract

The effects of some factors on the spirality in plain-jersey fabrics knitted of three-ply cotton yarns are investigated experimentally, and the following equation is derived statistically:

$$PS(\%) = (a\sqrt{l} + b)Sn + c/l + d$$

where $PS(\%)$ is the percentage spirality in cotton plain-jersey fabrics, Sn the number of snarls per yarn length of 25 cm, l the loop length in mm, and a , b , c and d are constants. Let $PS(\%)$ and Sn be positive for the Z direction and negative for the S direction.

The values of a and b are approximately constant and independent of the knitting machine speed and the method of the relaxation treatment used. On the other hand, the values of c and d are dependent on them. The values calculated from this equation agree well with the experimental values.

1. Introduction

Fabric distortions such as “bow” and “spirality” degrade the quality of weft-knitted fabrics^[1,2]. “Bow” is the fabric distortion in the course direction caused by the multi-feeder knitting or by the uneven take-down tension on a knitting machine^[1-3]. “Spirality” is the loop distortion caused by the yarn torque^[1,2,4,5]. “Bow” can be almost corrected by the fabric finishing processes such as heat setting and tentering, whereas “spirality” in plain-jersey fabrics knitted of cotton or wool yarns is only temporarily corrected by the finishing processes, since the spirality is regenerated by repeated launderings and wearings. Therefore, cotton or wool plain-jersey fabrics are knitted of balanced plied yarns, or by feeding a S-twist single yarn and a Z-twist single yarn alternately. Thus the spirality in plain-jersey fabrics knitted of cotton or wool yarns is a serious problem in view of the knitting efficiency and the quality of knitted fabrics. However, a little has been reported on the spirality in plain-jersey fabrics knitted of plied cotton or wool yarns.

This paper attempts to investigate the effects of some factors such as the number of snarls, the loop length, the knitting machine speed, and the relaxation treatment on the spirality in plain-jersey fabrics knitted of three-ply cotton yarns.

2. Experimental Methods

2.1 Yarn details

Knitting yarns used were three-ply yarns (single yarn; a combed cotton yarn c30s/1 cotton count (19.7 tex), 10.9 turns/cm in the Z direction single twist). Three single yarns were plied to make up plied yarns of four twist values, 0,

2.0, 4.0 and 6.0 turns/cm in the S direction. To determine the relative torque of plied yarns, their number of snarls (Sn) was measured. A deadweight of 1.0 g was attached at the center of the yarn length of 25 cm, and the two ends of this yarn were brought together. The direction and the number of snarls were measured 30 times for each of them, and the average of 30 readings was taken. Let Sn be positive for the Z direction and negative for the S direction. Snarl of the S direction occurs with the Z-twist yarn, and that of the Z direction is caused by the S-twist yarn.

Details of the knitting yarns are shown in Table 1. Each of the four plied yarns was used to knit a group of plain-jersey fabrics designated by the number shown in the last column of Table 1.

Table 1 Details of knitting yarns

Yarn Twist (turns/cm)		Snarling (number/ 25 cm)	Group
Single	Three-ply		
Z 10.9	0	-7.30	1
Z 10.9	S 2.0	-0.40	2
Z 10.9	S 4.0	3.57	3
Z 10.9	S 6.0	7.93	4

2.2 Fabric details

A 1-feeder, 92 needles, 4-in-diameter circular rib knitting machine was used with a variable speed mechanism. A cam box on the machine turns anticlockwise. The flat-bottom stitch cam was used with 45° cam angle. To manufacture plain-jersey fabrics only, the machine was stripped of all unnecessary parts (i.e. the dial, its support,

and the take-down mechanism). To ensure a constant take-down tension, a deadweight was tied on a fabric. The input tension was controlled by a tension disc before entering a feeder. The machine speed was set at 56 or 84 rev/min, the input tension at 10.0 gf and the take-down weight at 3.0 kg. Each of the four knitting yarns was knitted, in triplicate, into plain-jersey fabrics with three different loop lengths, respectively.

The following relaxation treatments were applied to each fabric after knitting.

(1) Dry relaxation(DR); The fabrics were conditioned for at least 24 hrs in a standard atmosphere (20°C, 65% RH).

(2) Wet relaxation (WR); The fabrics were soaked in boiling water for 1 hr, briefly hydroextruded, and dried in a drying oven at 70°C for 2 hrs. Then the fabrics were conditioned in the same way as the dry relaxation method.

(3) Laundering treatment (LT); The fabrics in a washing net were washed in a household washing machine at 40°C with water (liquor: fabric 50:1) containing 0.2% household detergent for 5 hrs. After washing, the fabrics were rinsed three times in water at 40°C for 7 min. Then the fabrics were dried and conditioned in the same way as the wet relaxation method.

Fig. 1 Measuring board of “spirality”

After the relaxation treatment, the spirality and the loop length of each fabric were measured. The spirality was measured five times for each fabric using a 15 cm² transparent plastic board as shown in Fig 1, and the average of five readings was taken. In Fig. 1, the distance between the horizontal lines AB and CD was 10 cm, and EF was the perpendicular from the point E to the line CD, and EG was the line along a wale in the fabric. If the distance FG is represented in *h* cm, then the percentage spirality (*PS*(%)) in fabrics is expressed by the following equation:

$$PS(\%) = (h/10) \times 100$$
Each fabric was raveled, and the course length was measured 10 times using a course length tester under 10.0 g weight. The loop length (*l*) was calculated from the number of needles and the average course length.

3. Results and Discussion

3.1 *PS* (%) changes with loop length

Dhingra and Postle^[6] have shown that the yarn torque is redeveloped in an initially balanced yarn by the application of tension in textile processes such as winding, weaving, knitting, etc. Many studies^[7–10] have shown that the knitting tension is dependent on the input tension, the

take-down weight, the cam setting, the cam angle, etc.

Firstly, to investigate the effects of the input tension and the take-down weight on *PS*(%), plain-jersey fabrics were knitted with the different input tension (5.0, 10.0 and 20.0 gf) and the take-down weight (1.0, 2.0 and 3.0 kg) for three cam settings. It was clarified that these two factors affected the loop length and did not affect *PS*(%) in the dry relaxed state. In other words, *PS*(%) in fabrics of the same loop length was approximately equal for different knitting conditions. Therefore, the loop length was controlled by cam setting in this study.

PS(%) changes caused by increasing the loop length after each relaxation treatment are shown in Tables 2, 3 and 4, respectively.

PS(%) changes caused by increasing the loop length in a same group show similar behaviour for all machine speeds and relaxation treatments. The values of *PS*(%) with increased loop length increase towards the Z direction in Group 1, and decrease towards the Z direction or increase towards the S direction in Groups 2, 3 and 4.

Table 2 *PS*(%) changes with loop length (after dry relaxation)

Group	Machine speed			
	56 rev/min		84 rev/min	
	Loop length (mm)	<i>PS</i> (%)	Loop length (mm)	<i>PS</i> (%)
1	5.40	36.6	5.31	35.1
	6.29	42.8	6.54	39.4
	8.32	56.1	8.24	56.2
2	5.42	18.2	5.27	20.1
	6.55	15.3	6.30	15.7
	8.30	13.1	8.10	9.7
3	5.40	5.0	5.25	5.1
	6.56	−5.6	6.35	−8.3
	8.31	−15.1	8.10	−18.0
4	5.45	−15.6	5.32	−14.2
	6.66	−38.2	6.49	−39.8
	8.42	−49.0	8.04	−48.6

Table 3 *PS*(%) changes with loop length (after wet relaxation)

Group	Machine speed			
	56 rev/min		84 rev/min	
	Loop length (mm)	<i>PS</i> (%)	Loop length (mm)	<i>PS</i> (%)
1	5.36	33.6	5.27	32.6
	6.19	39.5	6.44	38.7
	8.18	54.9	8.11	56.2
2	5.35	16.3	5.23	17.7
	6.46	14.2	6.22	15.0
	8.19	12.5	7.99	13.4
3	5.35	3.6	5.20	3.6
	6.50	−6.0	6.31	−8.4
	8.19	−17.8	7.95	−21.5
4	5.33	−15.1	5.23	−14.6
	6.49	−36.5	6.39	−38.7
	8.16	−51.4	7.88	−50.9

Table 4 *PS*(%) changes with loop length (after washing treatment)

Group	Machine speed			
	56 rev/min		84 rev/min	
	Loop length (mm)	<i>PS</i> (%)	Loop length (mm)	<i>PS</i> (%)
1	5.23	33.0	5.24	32.0
	6.19	39.2	6.39	38.3
	8.18	54.0	8.10	55.1
2	5.33	15.4	5.20	17.3
	6.46	13.3	6.18	14.8
	8.19	11.2	7.98	12.4
3	5.33	3.3	5.18	3.3
	6.48	-6.2	6.28	-8.3
	8.17	-19.3	7.94	-24.4
4	5.31	-15.1	5.20	-13.5
	6.46	-35.6	6.37	-36.7
	8.16	-52.2	7.86	-51.5

Now, it is assumed that the relation between *PS*(%) and the loop length is approximately linear at shorter loop lengths in one group, the value of *PS*(%) approaches a constant value at the loop length of about 3.40 mm (fabric tightness $K = \sqrt{T}/l = 22.6$, where T is the linear density in tex and l the loop length in cm) when this relation is extrapolated. Since the maximum value of K is under 20 for cotton plain-jersey fabrics^[11], the fabric of $K = 22.6$ can not be knitted in practice. The values of *PS*(%) at the loop length of 3.40 mm for each of machine speeds and relaxation treatments are shown in Table 5. The values of *PS*(%) increase with increased machine speed, and decrease with relaxation treatments ($DR > WR > LT$).

3.2 Effects of loop length and *Sn* on *PS*(%)

Leaf^[12] has shown that the direction of torsion on the right-hand side of the loop is opposite to that on the left-hand side of the loop, and the maximum torsion in the loop is about 6 turns/in.

To observe the state of loop distortion, a simulation was carried out using a rubber tube instead of a yarn. When a rubber tube was bent in a form of a loop, the rubber loop was distorted towards the Z direction upon fixing the left-hand end of the loop and turning the right-hand end of the loop inwards (this loop distortion was obtained when the Z-twist yarn was bent in a form of a loop), and vice versa. This rubber loop distortion increased together with the increase of the loop length and the number of turns on the loop end.

If it is assumed that *PS*(%) is only caused by the yarn torque, *PL*(%) (*PS*(%) at the same loop length) may be in proportion to *Sn* through the origin. The values of

Table 5. The values of *PS*(%) at loop length of 3.40 mm

Machine speed (rev/min)	Relaxation treatment		
	<i>DR</i>	<i>WR</i>	<i>LT</i>
56	23.0	20.0	19.0
84	28.0	23.0	22.0

PL(%) for each level of loop lengths calculated from the values in Tables 2, 3 and 4 using the interpolation or the extrapolation method are shown in Tables 6, 7 and 8 for each of relaxation treatments, respectively.

Table 6 The values of *PS*(%) at the same loop length (after dry relaxation)

Group	<i>PS</i> (%)			
	$l = 5.00$ mm	$l = 6.00$ mm	$l = 7.00$ mm	$l = 8.00$ mm
Machine speed: 56 rev/min				
1	33.8	40.8	47.5	54.0
2	19.3	16.7	14.7	13.5
3	8.7	-0.5	-8.0	-13.4
4	-7.2	-25.9	-40.3	-46.4
Machine speed: 84 rev/min				
1	34.0	37.5	43.9	53.8
2	21.3	17.0	13.4	10.0
3	8.1	-4.0	-11.9	-17.4
4	-7.2	-29.1	-42.7	-48.4

Table 7 The values of *PS*(%) at the same loop length (after wet relaxation)

Group	<i>PS</i> (%)			
	$l = 5.00$ mm	$l = 6.00$ mm	$l = 7.00$ mm	$l = 8.00$ mm
Machine speed: 56 rev/min				
1	31.0	38.1	45.8	53.5
2	17.0	15.1	13.7	12.7
3	6.5	-1.8	-9.5	-16.5
4	-9.0	-27.5	-41.1	-50.0
Machine speed: 84 rev/min				
1	31.3	36.2	44.6	55.0
2	18.2	16.1	14.3	13.4
3	5.7	-4.6	-13.9	-21.9
4	-9.8	-31.0	-43.7	-51.9

Table 8 The values of *PS*(%) at the same loop length (after washing treatment)

Group	<i>PS</i> (%)			
	$l = 5.00$ mm	$l = 6.00$ mm	$l = 7.00$ mm	$l = 8.00$ mm
Machine speed: 56 rev/min				
1	30.8	37.8	45.2	52.9
2	15.6	14.2	12.6	11.0
3	6.0	-2.2	-10.2	-18.1
4	-9.3	-27.4	-40.9	-50.5
Machine speed: 84 rev/min				
1	30.7	36.2	44.3	54.1
2	17.9	15.3	13.7	12.5
3	5.2	-5.3	-15.3	-25.0
4	-9.5	-29.4	-43.7	-52.9

An approximately linear relation between $PL(\%)$ for each level of loop lengths and Sn was obtained as follows for each of machine speeds and relaxation treatments:

$PL(\%) = kSn + m$ (1)
where k and m are constants. Let $PL(\%)$ and Sn be positive for the Z direction and negative for the S direction.

The values of k and m for each level of loop lengths calculated from the values in Tables 6, 7 amd 8 using the square method are shown in Table 9 for each of machine speeds and relaxation treatments.

Table 9 The values of k and m

Loop length (mm)	DR		WR		LT	
	k	m	k	m	k	m
Machine speed: 56 rev/min						
3.40	0	23.0	0	20.0	0	19.0
5.00	-2.65	16.2	-2.59	13.8	-2.59	13.2
6.00	-4.31	11.9	-4.24	10.0	-4.21	9.6
7.00	-5.69	8.9	-5.64	7.6	-5.60	7.0
8.00	-6.56	8.2	-6.78	6.4	-6.78	5.3
Machine speed: 84 rev/min						
3.40	0	28.0	0	23.0	0	22.0
5.00	-2.70	16.6	-2.67	13.9	-2.63	13.6
6.00	-4.35	9.5	-4.37	8.3	-4.29	8.3
7.00	-5.65	6.1	-5.81	5.8	-5.77	5.4
8.00	-6.70	5.9	-7.11	5.4	-7.16	4.0

With increasing loop length, the absolute values of k increase, and the values of m decrease. The values of k for each level of loop lengths are approximately constant for all machine speeds and relaxation treatments. On the other hand, the values of m for each level of loop lengths decrease with relaxation treatments ($DR>WR>LT$). As the values of m in all cases are not zero, the regression line for each level of loop lengths is moved parallel towards the S direction by the distance m , so as to make the value of m zero and eq. (1) be rewritten as $PL(\%) = kSn$. This equation satisfied the above assumptions. Therefore, it is considered that $PS(\%)$ is the sum of the net spirality (kSn) caused by the yarn torque and the additional spirality (m) caused by all other factors. As the values of $PS(\%)$ become equal to the additional spirality only at the loop length of 3.40 mm (Table 5), the net spirality becomes zero. From the results of investigating the relation between k , m and the loop length statistically, it became clear that the absolute values of k were in proportion to the square root of the loop length and the values of m in inverse portion to the loop length. Then eq. (1) is rewritten as the following equation that can be applied to all loop lengths:

$PS(\%) = (a\sqrt{l}+b)Sn+c/l+d$ (2)
where l is the loop length in mm, and a , b , c and d are constants. Let $PS(\%)$ and Sn be positive for the Z direction

and negative for the S direction.

The values of a , b , c and d calculated from the values in Table 9 using the square method are shown in Table 10 for each of machine speeds and relaxation treatments.

Table 10 The values of a , b , c and d

Machine speed (rev/min)	Relaxa- tion	a	b	c	d
56	DR	-6.80	12.54	90.9	-3.3
	WR	-6.97	12.89	82.0	-3.7
	LT	-6.95	12.86	80.9	-4.2
84	DR	-6.90	12.68	138.8	-12.6
	WR	-7.03	12.96	109.6	-9.1
	LT	-7.30	13.56	109.2	-9.6

To check the validity of eq. (2), the values ($CS(\%)$) calculated by substituting each value of loop lengths in Tables 2-4 into eq. (2) were compared with the experimental results ($ES(\%)$). The best-fit regression line is expressed by the following equation:

$CS(\%) = 0.98ES(\%)+0.18$ (3)
with the correlation coefficient of 0.993. The slope of this line is closer to 1.0 and the intercept nearly zero. For these reasons, the calculated values agree well with the experimental results.

The values of a and b are approximately constant and independent of the machine speed and the method of the relaxation treatment used. On the other hand, the values c and d are dependent on them. In other words, the net spirality is in proportion to the number of snarls and the square root of the loop length, and independent of the machine speed and the method of the relaxation treatment used. On the other hand, the additional spirality is in inverse proportion to the loop length, and dependent on them.

3.3 Effects of machine speed and relaxation treatment on additional spirality

Knapton, Truter, and Aziz^[11] have shown that the initial wet relaxation causes considerable area shrinkage in cotton plain-jersey fabrics, and further cycles of laundering and tumble-drying cause further small area shrinkages.

It seems that the decrease of the additional spirality during relaxation treatments must be caused by the area shrinkage in cotton plain-jersey fabrics.

The movement of yarn within knitting zone and the direction of loop distortion are shown in Figs. 2(a) and (b), respectively.

With reference to Fig. 2(a), consideration is made on the movement of yarn within knitting zone as follows when the balanced yarn is knitted into plain-jersey fabrics. As soon as needle $N1$ leaves the point C of cam, the yarn tensions at $T1$ and $L1$ rapidly decrease and the yarn moves from $L1$ to $T2$, that is, the robbing-back occurs^[7,8,9,13,14]. When needle $N2$ leaves the point C , a similar movement of yarn within knitting zone takes place.

Fig. 2 Movement of yarn within knitting zone (a) and direction of loop distortion (b)

As the yarn tension at $T2$ is smaller than that at $L2$, the yarn length of $T2$ becomes longer than that of $L2$. For this reason, the loop must be distorted into the form as shown by the dotted line (Fig. 2(b)). Therefore, the loop distortion in fabrics takes the form shown by the full line, this is, the additional spirality in the Z direction occurs. If it is assumed that the additional spirality is caused by the movement of yarn within knitting zone, the direction of the additional spirality may be determined by that of the machine rotation. Namely, the additional spirality in the Z direction will be caused by the anticlockwise rotation of the cam box or the clockwise rotation of the cylinder, and vice versa. This assumption agrees with the experimental results. The additional spirality changes caused by increasing machine speed are attributed probably to "needle fling" (changes in needle direction due to the inertia force on the needle after the knitting point)^[7].

4. Conclusions

The effects of some factors on the percentage spirality ($PS(\%)$) in plain-jersey fabrics knitted of three-ply cotton yarns are investigated experimentally, and the following results are obtained:

(1) $PS(\%)$ is the sum of the net spirality due to the yarn torque and the additional spirality due to all other factors, and the following equation is derived statistically:

$$PS(\%) = (a\sqrt{l} + b)Sn + c/l + d$$

where Sn is the number of snarls per yarn length of 25 cm, l the loop length in mm, and a , b , c and d are constants. Let $PS(\%)$ and Sn be positive for the Z direction and negative for the S direction. The values calculated from this equation agree well with the experimental results.

(2) The net spirality is in proportion to the number of snarls and the square root of the loop length, and independent of the machine speed and the method of the relaxation treatment used.

(3) The additional spirality is in inverse proportion to the loop length, and dependent on the machine speed and the method of the relaxation treatment used. The decrease of the additional spirality during relaxation treatments is caused probably by the area shrinkage in cotton plain-jersey fabrics. The additional spirality occurred during knitting is caused probably by the movement of yarn within knitting zone (the robbing back).

Acknowledgement

The authors wish to thank Professor M. Maruyama of Miyagi University of Education for his helpful advice.

References

- [1] "Meriyasu Gijutsu Hikkei (Yokoami Hen)" p. 276 p. 278, p. 318, *Text. Mach. Soc. of Japan*, (1977).
- [2] D. S. Lyle; "Modern Textiles", p. 170, John Wiley & Sons Inc., (1976).
- [3] Y. Miyagawa; *J. Text. Mach. Soc. of Japan*, **25**, P271 (1972).
- [4] G. A. Carnaby; *J. Text. Inst.*, **64**, 738 (1973).
- [5] J. M. Bennet and R. Postel; *J. Text. Inst.*, **70**, 142 (1976).
- [6] R. C. Dhingra and R. Postel; *J. Text. Inst.*, **67**, 409 (1976).
- [7] J. J. F. Knapton and D. L. Munden; *Text. Res. J.*, **36**, 1072, 1081 (1966).
- [8] N. Aisaka; *J. Text. Mach. Soc. of Japan*, **24**, P314 (1971).
- [10] G. R. Wray and N.D. Burns; *J. Text. Inst.*, **67**, 123, 167 (1976).
- [11] J. J. F. Knapton, E. V. Truter and A. K. M. A. Aziz; *J. Text. Inst.*, **66**, 413 (1975).
- [12] G. A. V. Lead; *J. Text. Inst.*, **51**, T49 (1960).
- [13] D. Peat and E. R. Spicer; *J. Text. Inst.*, **65**, 388 (1974).
- [14] T. W.-Y. Lau and J. J. F. Knapton; *J. Text. Inst.*, **69**, 169, 176, 187 (1978).