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Analysis of the Twist Structure in Self-twist Yarn

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Abstract
This paper mainly discussed the twist structure and property difference between in-phase self-twist yarn and phased self-twist yarn. There are three kinds of zones along the yarn: the twist-twist zone, twist-notwist zone and notwist-notwist zone in one cycle length of self-twist yarn. The existence of the phase difference makes the length of the notwist-notwist zone decrease. When the size of the phase difference (value c)is closer to or equal to the length of the zero zone(value b), the minimum length of the notwist-notwist zone will be obtained so that the best properties of self-0twist yarn can be achieved. The result for in-phase and phased self-twist yarn shows that the above conclusion is correct.

Key words: *self-twist, twist distribution, in-phase; phased, twist roller.*

Introduction

In ST (self-twist) spinning (***Figure 1***), two feeding strands are twisted by the oscillating motion of ST rollers [1-3]. Therefore in the two strands, the twisting torque is stored , the sections reversed and fibers deformed. When the twist restraint is removed, the twisting torque tends to untwist the strand. However, frictional contact between the two strands cause it, in untwisting, to twist about the other strand and thus ply itself with it. This plying continues until the twisting torque is balanced by the plying torque of the ST yarn.

Between two neighbouring twist zones, on each single strand there is a zero twist zone. If both strands are converged, their zero twist zones will coincide just in time. This resultant ST yarn is defined as "in-phase" yarn [4-6] and these places of zero twist on ST yarn are the weak points. If the zero twist zones of two single strands stagger each other, at that time, the zero twist zone of ply yarn will emerge in the opposite twist of two single strands. Then the strength of ST yarn can be significantly improved. This is termed the phased yarn.

In the study of ST yarn, Henshaw [7-9] established a ST yarn model which is applied to derive an explanation for the stability of ST yarn. Henshaw revealed ST yarn is a two-ply structure in which both strands and plying have alternating twists along the yarn, and he set up a mechanical model for it. Ellis and Walls [10] focused on the derivation of a formula for strand twist, ST and pairing twist. Cui [11] introduced the twist distribution in different convergence modes. But there are few studies on the twist structure of in-phase yarn and phased yarn along the ST yarn length. Hence, it is the purpose of this paper to discuss the twist structure of seven different phased ST yarn and their structure properties.

It is defined that one cycle length of ST yarn is X, the length of the S twist zone and Z twist zone in one cycle length *a* (equal in theory), the length of the zero twist zone *b*, and that the phase difference is *c*. The phase difference is defined as the stagger distance between the two strands. In general, the length *a* is greater than the length *b*, and X is equal to $2(a + b)$. Therefore the half cycle length is $\frac{X}{2} = (a + b)$. Then seven phases are discussed: (1) $c = 0$; (2) $0 < c < b$; (3) $c = b$; (4) $b < c < a$; (5) $c = a$; (6) $a < c < a+b$; (7) $c = a + b$. The experiment scope of values *a* and *b* is, respectively, 50-90 mm and 15-55 mm.

Forming process of in-phase ST yarn and its characteristics ($c = 0$)

Figure 2 shows one cycle length of in-phase ST yarn. Now suppose AA' is the position of the convergence point of two strands. If two sections a with S twist meet at point A, due to the untwisting torque of each strand, they will cling to each other around the axis to form two-ply yarn with Z twist. However, if two zero twist zones of two strands coincide just in time, because of no untwisting

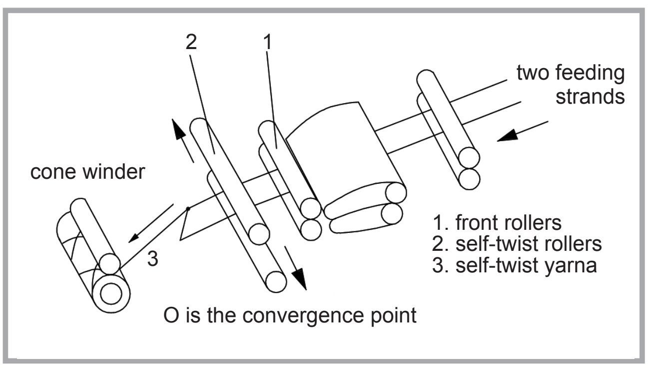

Figure 1. *A schematic diagram fo self-twist spinning process.*

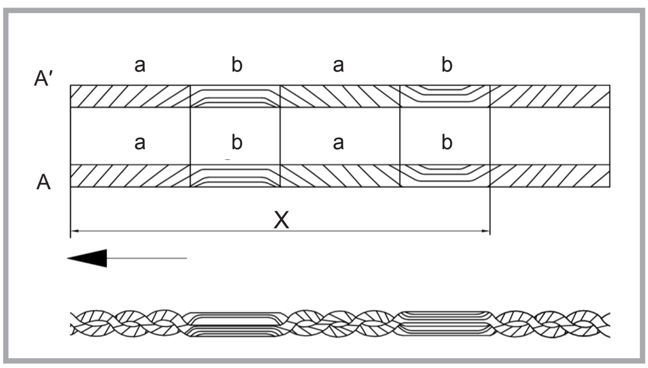

Figure 2. *Schematic diagram (c = 0) of in-phase ST yarn.*

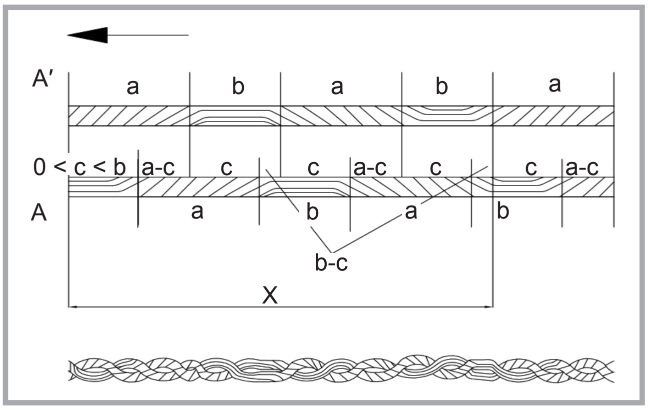

Figure 3. Schematic diagram (0 < c < b) of phased ST yarn.

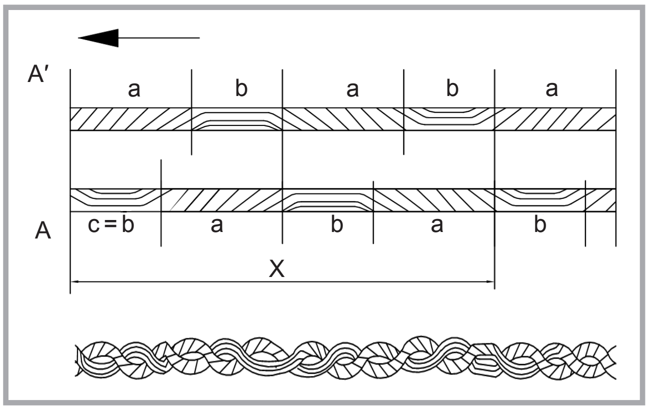

Figure 4. Schematic diagram (c = b) and effect drawing of phased ST yarn.

torque existing, then the zero twist zone of the ST yarn emerges. It is the weakest place along the yarn length. Successively the next zone will be the convergence of two Z twist zones of two strands, and the ST yarn formed is two-ply yarn with S twist. Similarly the weakest place also exists. The actual ST yarn is shown in ***Figure 5***.

Forming process of phased ST yarn and its characteristics *(c ≠ 0)*

0 < c < b

Figure 3 is a schematic diagram and effect drawing for phased ST yarn (*0 < c < b*) in one cycle length. Suppose AA' is the position of the convergence point of two strands. The ST yarn goes forward as the arrow direction. We can see from ***Figure 3***, when a phase difference *c* exists in two strands, two yarn sections *a* with an S twist zone S stagger a certain distance *c*. Section *a* with S twist on the top strand meets section *c* with zero twist and sections *a-c* with the same twist direction as the strand above. The untwisting torque of section *a* of the above strand becomes the main torque and causes ST formation. The next section *b* with zero twist on the top strand meets section *c* with S twist, where the untwisting torque of section *c* will cause the top strand with zero twist to rotate around the axis of the yarn and form ST yarn.

Next section *a* with Z twist on the top strand will utilise the untwisting torque itself to prompt section *c* with zero twist and sections *a-c* with the same twist direction of the top strand to be twisted into ST yarn. In the next neighbouring section, section *b* with zero twist on the top strand meets section *c* with Z twist on the bottom strand and sections *b-c* with zero twist. The untwisting torque of section *c* will force the strand to rotate around the axis of the yarn to form ST yarn. Over the whole cycle length, only two sections *b-c* with zero twist meet the zero twist of the top strand to form a weak zone along the yarn. It is shown from the above analysis that the length of the zero twist zone has been considerably decreased, but the zero twist zone on a single strand and the twist zone on the other strand still exist.

c = b

Figure 4 is a schematic diagram and effect drawing for phased ST yarn (*c = b*) in one cycle length. Suppose AA' is the position of the convergence point of two strands. The ST yarn goes forward in the arrow direction. We can see from ***Figure 4*** that the length *b* with zero twist on each strand meets the twist zone of another strand. Two twist zones of two strands meet in the same twist direction, which causes a better ST effect. The ST yarn formed absolutely does not possess a weak twist zone. In theory, if the phase difference *c* is equal to the length *b,* the best performance of ST yarn can be achieved.

Figures 5, 6 and *7* are, respectively, samples of phased yarn (*c = 0*), phased yarn 1 (*0 < c < b*), and phased yarn 2 (*c = b*) in one cycle length.

It is shown in ***Figure 5*** that in one cycle length X, fibers in the zero twist zone on two strands present a discrete state, are spiralled slightly and are basically parallelled by the axis of the ST yarn. The twist zones on the ST yarn are similar to those of two-ply yarn in ring spinning and the twist distribution remains uniform on the whole.

It is shown in ***Figure 6*** that in one cycle length X, the zero twist zone still exists, but the length with zero twist has been decreased. We can also see from the coloured strand that twist obviously exists in the strand, which will conduce to improving the strength and elongation of breakage of the ST yarn.

From ***Figure 7*** it can be observed that in one cycle length X, the zero twist zone on each strand is almost wrapped up by the twist zone on another strand. Along

Figure 5. *Sample of in-phase (c = 0) ST yarn.*

Figure 6. *Sample of phased (0 < c < b) ST yarn.*

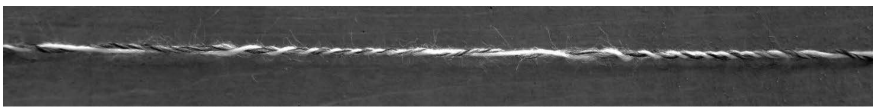

Figure 7. *Sample of phased (c = b) ST yarn.*

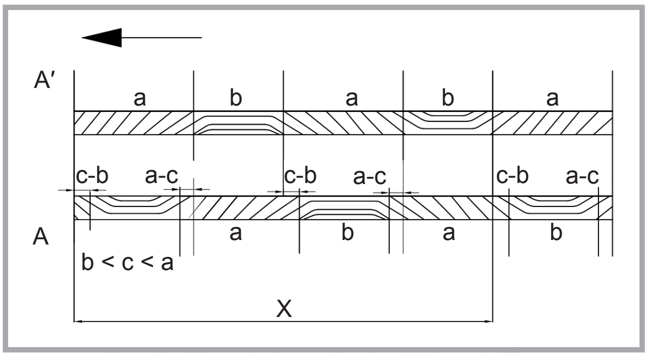

Figure 8. Schematic diagram for phased (b < c < a) ST yarn.

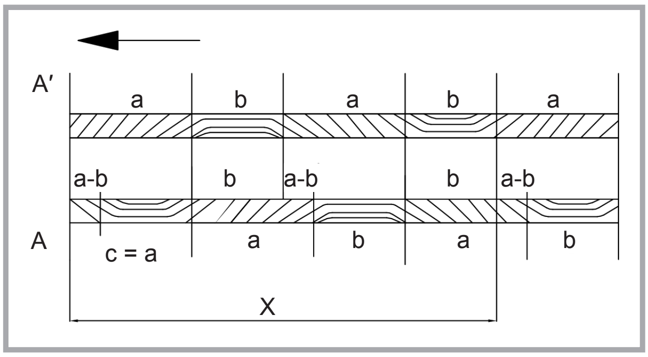

Figure 9. Schematic diagram for phased (c = a) ST yarn.

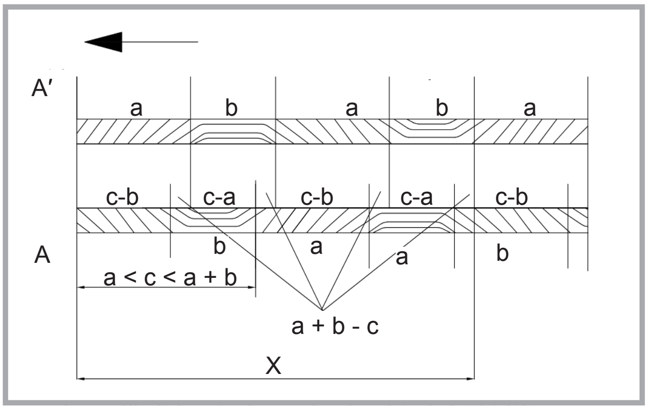

Figure 10. Schematic diagram for phased (a < c < a+ b) ST yarn.

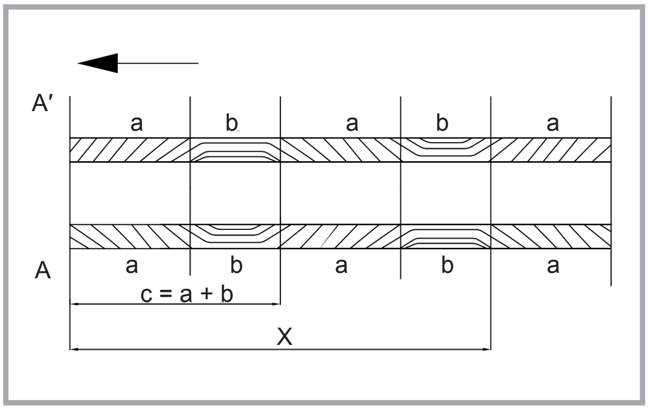

Figure 11. Schematic diagram for phased (c = a + b) ST yarn.

the whole ST yarn length, no weak twist zone exists. When the phase difference *c* is equal to the length *b*, the best performance of ST yarn can be obtained.

b < c < a

Figure 8 is a schematic diagram for phased ST yarn ($b < c < a$) in one cycle length X. Suppose AA' is the position of the convergence point of two strands. In ***Figure 8*** section *a* with S twist on the top strand meets sections *c-b* with Z twist, and section *b* with zero twist meets sections *a-c* with S twist. Since the opposite twist directions cannot form ST yarn, the untwisting torque on the top strand can make the zero twist and S twist zone form ST yarn. When section *b* with zero twist on the top strand meets the twist zone on the bottom strand, the properties of this ST yarn are slightly weaker than the yarn in 2.3. The length of the opposite twist direction in one cycle length is *2(c-b)*.

c = a

Figure 9 is a schematic diagram for phased ST yarn ($c = a$) in one cycle length X. Suppose AA' is the position of the convergence point of two strands. It is shown in ***Figure 9*** that when the phase difference *c* is equal to the length of the twist zone, each zero twist zone on each strand coincides with the twist zone on another strand, but the two opposite twist direction zones meet. We should pay attention to the fact that along the ST yarn length, a no twist-twist zone exists and therefore has an influence on the properties of the yarn. The length of the opposite twist direction in one cycle length is *2(c-b)*.

a < c < a + b

Figure 10 is a schematic diagram for phased ST yarn ($a < c < a + b$) in one cycle length X. Suppose AA' is the position of the convergence point of two strands. It is shown in ***Figure 10*** that along the ST yarn length, not only does the coincidence of the two opposite twist direction zones exist, but also that of the two zero twist zones, which will disadvantage the ST process. The length of the opposite twist direction or zero twist zone in one cycle length is *2(c-b)+2(c-a)*.

c = a + b

Figure 11 is a schematic diagram for phased ST yarn ($c = a + b$) in one cycle length X. Suppose AA' is the position of the convergence point of two strands. It is shown in ***Figure 10*** that when the phase difference *c* is equal to the half cycle length $a + b$, two strands are exactly staggered a half cycle length. In their coincidence length, they have the same twist but the twist direction is opposite, in which case the ST phenomenon cannot occur.

Table 1. *Length of three yarn zones in seven phased ST yarn.*

Seven phases	twist-twist	twist-notwist	notwist-notwist
In-phase yarn (c = 0)	2a	0	2b
Phased yarn 1 (0 < c < b)	2(a-c)	4c	2(b-c)
Phased yarn 2 (c = b)	2(a-b)	4b	0
Phased yarn 3 (b < c < a)	2(a-c)	4b	2(c-b)
Phased yarn 4 (c = a)	0	2b	2(c-b)
Phased yarn 5 (a < c < a + b)	0	4(a+b-c)	2(c-b)+2(c-a)
Phased yarn 6 (c = a + b)	0	0	2(a+b)

Table 2. *Comparison of twist structure and strength of in-phase with phased ST yarn.*

Yarn count tex	226 tex					98.8 tex				
Yarn type Items	In-phase yarn	Phased yarn 1	Increase or decrease rate %	Phased yarn 2	Increase or decrease rate %	In-phase yarn	Phased yarn 1	Increase or decrease rate %	Phased yarn 2	Increase or decrease rate %
Cycle length, mm	210.5	204.5	-2.9	204.5	-2.9	211.0	209	-0.9	209.0	-0.9
Length of S twist zone, mm	54.5	57.5	5.5	60.0	10.1	57.5	57.5	0.0	62.0	7.8
Length of zero twist zone (next to S twist zone), mm	47.0	45.0	-4.3	42.0	-10.6	44.0	40.5	-8.0	37.0	-15.9
Length of Z twist zone, mm	51.5	55.0	6.8	60.0	16.5	61.5	66	7.3	68.0	10.6
Length of zero twist zone (next to Z twist zone), mm	51.5	45.5	-11.7	42.5	-17.5	48.0	42.5	-11.5	40.5	-15.6
Tenacity, $cN \cdot tex^{-1}$	4.1	4.7	14.6	5.2	26.8	3.5	5.5	57.1	6.1	74.3
Elongation at break, %	6.1	6.3	3.3	6.7	9.8	2.5	3.7	48.0	4.6	84.0

Twist distribution statistics of seven phased yarn in one cycle length

When the top and bottom strands have both the same twist directions, it is called the twist-twist zone. When the twist zone of one strand meets the zero twist zone of another strand, it is called the twist-notwist zone, and when two strands are both a twistless zone or have two opposite twist directions, it is called a notwist-notwist zone. It is obvious that the strength of the three kinds of zones is as follows: twist-twist > twist-notwist > notwist-notwist. The phase difference of the notwist-notwist zone will improve the properties of the ST yarn. ***Table 1*** is statistical data of the length of three yarn zones in seven phased ST yarn.

We can see from ***Table 1***, except phased yarn 6, that the length of the notwist-notwist of in-phase yarn is greatest, which can increase the unevenness of making the tenacity. From phased yarn 1 to phased yarn 3, when the phased difference *c* is very close to the length *b* of the zero twist zone, the structure of ST yarns is very close to that of phased yarn 2, which possesses the best yarn properties. The length of the twist-twist zone is zero from phased yarn 4 to phased yarn 6, which is disadvantageous to the tenacity of yarn; hence its phase differences are seldom applied in production.

Comparison of the properties of in-phase with phased ST yarn

A comparison of the twist structure and strength of in-phase yarn with phased yarn 1 ($c = 19$ *mm*) and with phased yarn 2 ($c = 43$ *mm*) is given in ***Table 2***.

As shown in ***Table 2***, the length of the S twist and Z twist zones as well as the tenacity and elongation at break of phased yarn are greater than those of in-phase yarn, but the length of the zero twist zone of two phased yarns is less than that of in-phase yarn. The main reason for the improved breaking properties is the increment of the length of the twist zone and the decrement of the zero twist zone. When the actual length *b* of the zero twist zone is close to the phase difference *c* ($c = 43$ *mm*), the tenacity of phased yarn 1 and phased yarn 2 will increase by *26.8%* and *74.3%,* respectively, and the elongation at break of phased yarn 1 and phased yarn 2 by *9.8%* and *84%*, respectively, It is thus clear that the properties of ST yarn are considerably improved by changing the phase difference.

Conclusions

According to the structure feature of ST yarn, there are three kinds of yarn zone in one cycle length, namely, the twist-twist zone, twist-notwist zone and notwist-notwist zero zone. The existence of a phase difference can minimise the length of the notwist-notwist zone.

When the phase difference *c* is close to or equal to the length *b* of the zero twist zone, the length of the zero twist zone is zero, and along the ST length there is a twist-twist zone and twist-notwist zone. In theory, this kind of ST yarn possesses the best properties.

By comparing in-phase with phased ST yarn in spinning, as seen from the results, due to the existence of the phase difference, the zones of S twist and Z twist are lengthened but the zero twist zone is shortened, which is the main reason that the tenacity and elongation at break in phased ST yarn are superior to those in in-phase ST yarn.

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