Twist Liveliness Measurement and Its Application to Predict Fabric Spirality

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Abstract

Twist liveliness is the tendency of a spun yarn to twist or untwist spontaneously in an attempt to release the residual torque. Generally, in the textile industry twist liveliness is considered a negative attribute of a spun yarn, which is responsible for many post-spinning problems, such as yarn snarling and fabric spirality. Despite its significance, systematic studies on yarn twist liveliness measurement and particularly its quantitative relationship with fabric spirality, have not been carried out. In the present study, the twist liveliness of 100% cotton ring yarns were measured using an improved testing methodology and apparatus based on the ISO Standard 03343-1984 where two ends of a known length of yarn are brought together and the number of snarls in the length of yarn is counted. The effects of the measured twist liveliness on the spirality of plain knits have been investigated. Mathematical tools have been used to determine the relationship between the measured twist liveliness and the degree of spirality of pure cotton fabrics. The results of the analyses reveal that the measurement of twist liveliness using the improved testing methodology and apparatus is significant in the prediction of knitted fabric spirality. The results of this work will be of interest to spinners, knitters or researchers investigating methods to monitor yarn twist liveliness and/or control fabric spirality.

Keywords: Twist liveliness; Spirality; Ring yarn; Single Jersey Fabric; Prediction

1. Introduction

Twist liveliness of a yarn is due to the twist insertion during the spinning process. During twist insertion a residual torque is generated in the fibres from stresses built up from the twisting. This residual torque results from the bending and torsional stresses in the fibres that have been imposed into some kind of helical configuration as well as the tensile forces acting on the fibres in the yarn. The yarn then has a tendency to untwist due to this residual torque which will result in snarls unless the yarn is constrained [1, 2]. Generally, in the textile industry twist liveliness is considered a negative attribute of a spun yarn as it has been identified as one of the major causes of the problems of spirality in fabrics and snarling in spun yarns [3, 4, 5].

Previously, various measurement devices and procedures relevant to the measurement of twist liveliness have been examined. They can be divided into three categories namely direct, semi-direct, and indirect measurements [2, 6]. Despite the fact that yarn twist liveliness is of practical importance in the textile manufacturing industry and to the study of developments to reduce twist liveliness, a standard measurement of twist liveliness has not been adopted. This is because there are conflicting opinions [7, 8] as to which technique is suitable. However, a standard technique is desirable as it could facilitate in developments to reduce the twist liveliness of yarns.

In earlier works [9, 10] we reported the development of a patented [11] improved testing methodology and apparatus to evaluate yarn twist liveliness. It is based on the ISO Standard 03343-1984 where two ends of a known length of yarn are brought together and the number of snarls in the length of yarn is counted. The propensity of the yarn to snarl indicates the level of twist liveliness. We investigated the application of the improved testing methodology and apparatus to assess the twist liveliness of a yarn spun using a modified ring spinning process called Nu-Torque^{TM} singles ring yarn in comparison with conventional ring yarns. This system was developed by Tao and Xu [12, 13] to directly balance the yarn torque in singles ring spun yarns during the spinning process and hence reduce the twist liveliness of the yarns. An advantage of this method is that the torque balancing process can be achieved in a single step hence saving processing time and reducing processing cost.

We found that by reducing the twist liveliness of the yarns the spirality of the single jersey fabrics knitted from these yarns could be reduced significantly. Although, it is generally agreed that twist liveliness is one of the main causes of fabric spirality no publications to determine its quantitative relationship with fabric spirality have been reported. However, by using the improved testing methodology and apparatus it makes it possible to quantitatively study the effects of the twist liveliness of yarns on fabric spirality.

Therefore, in this paper, we investigate the effects of the measured twist liveliness of 100% cotton yarns on the angle of spirality of single jersey knitted fabrics. Empirical relationships between the angle of spirality, the measured twist liveliness and other parameters also contributing to fabric spirality are established using statistical regression techniques.

2. Experimental

2.1 Yarn and fabric details

In this work a total of 48 data sets were used for the analysis. Several types of cotton yarns were collected including conventional ring yarns, Nu-Torque^{TM} ring yarns and plied yarns. The yarn count was limited to 29.5tex and the twist multiples of the conventional and Nu-Torque^{TM} yarns were from 1.9 to 3.6.

The yarns were then knitted into single jersey fabrics of various tightness factors by circular knitting machines rotating both in the clockwise and anti-clockwise directions. The number of feeders included a single feeder, 54 feeders and 90 feeders and the gauges of the machines were 20, 22 and 24npi. Some of the fabrics were then piece-dyed in the tubular form.

2.2 Measuring twist liveliness

The yarn samples from cones were tested for twist liveliness using the improved testing methodology and apparatus [14] and 30 readings were taken for each yarn tested. In the measurement, the twist liveliness was recorded as a positive value if the yarn snarled in the S direction and negative if the yarn snarled in the Z direction.

All yarns were conditioned for at least 24 hours prior to testing under standard atmospheric conditions (65 ± 2% RH, 20 ±2^{o}C).

2.4 Measuring knitted fabric spirality

Before undertaking any measurements on the samples, the fabrics were placed on a flat surface for at least 48 hours in standard atmospheric conditions of 20 ± 2°C and 65 ± 2% relative humidity (dry relaxed fabrics). All fabrics were then subjected to wash and dry relaxation treatment consisting of three 3A cycles of laundering and tumble drying. The washing temperature and drying temperatures were 60^{o}c and 65^{o}c respectively. After wash and dry relaxation treatment, the dried fabrics were again conditioned at standard atmospheric conditions for 24 hours (wash and dry relaxed fabrics).

The angle of spirality was measured in two stages, firstly at the dry relaxed state and secondly after the washing and drying procedure.

A modified IWS test method TM276 [15] was used to measure the fabric spirality both before and after the relaxation treatment. In this method, the angle between the wale line and the line parallel to the machine running direction was measured; in this case, the edge of the circular fabric as shown in Figure 1 and the angle of spirality was calculated using the following Equation:

$$\tan\Theta = \frac{W - W_1}{L_1} \qquad (1)$$

As can be seen four measurements were taken on each fabric sample by substituting W_1 with W_2, W_3 and W_4 and L_1 with L_{1+} L_2, L_{1+} $L_{2+}L_3$ and L_{1+} $L_{2+}L_3$ + L_4. The spirality angle for each sample was taken as the mean of the four measurements. In the measurement the degree of spirality was recorded as a positive value for the case of Z direction spirality and a negative value for S direction spirality.

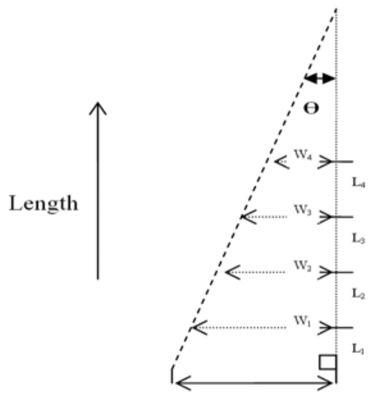

Fig. 1. Technique for measuring fabric spirality

3. Results and discussion

3.1 Relationship between twist liveliness and fabric spirality

As a preliminary analysis of the data, scatter plots were used to illustrate the correlation of the measured twist liveliness and the angle of spirality as shown in Figures 2a and 2b for the dry relaxed and wash and dry relaxed fabrics respectively.

Figures 2a and 2b indicate that the measured twist liveliness is strongly related to the angle of spirality. In general, it can be seen that if the yarns snarled in the S direction the fabrics spiralled in the Z direction and vice versa. It can also be seen that as the twist liveliness increased the angle of spirality increased in both directions.

Based on this range of data the results indicate that, to achieve zero spirality with the fabrics which are dry relaxed, the number of snarl turns of a yarn should be about 4 turns/cm. To achieve zero spirality after washing and tumble drying the fabrics the snarl turns should be around 3 turns/cm. However, the deviations of the present experimental points from the best fit line as shown in Figures 2a and 2b indicate that it is necessary to examine the effects of other parameters on fabric spirality.

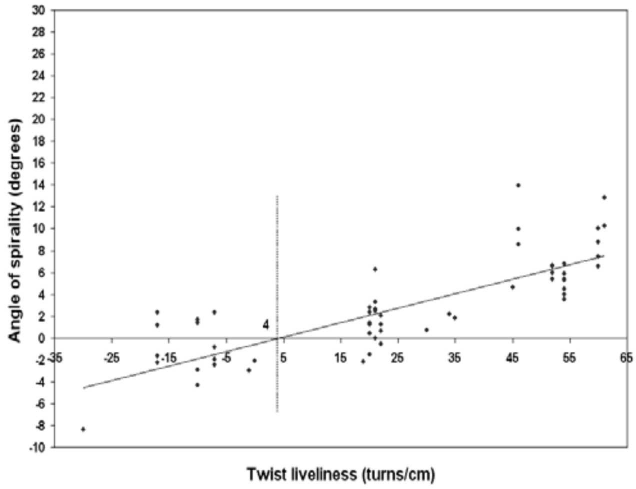

Fig. 2a. Relationship between the measured twist liveliness and angle of spirality of the dry relaxed fabrics

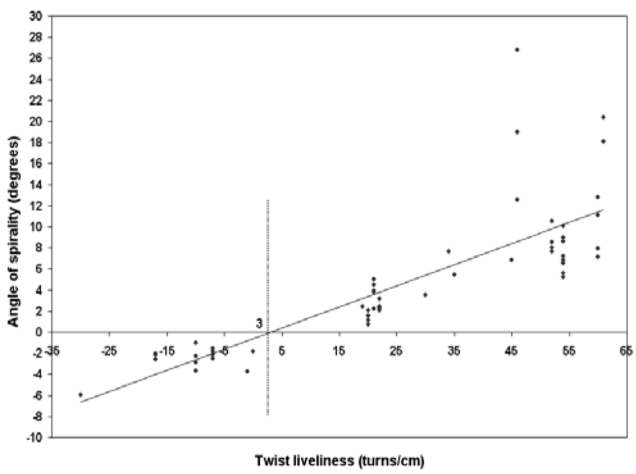

Fig. 2b. Relationship between the measured twist liveliness and angle of spirality of the wash and dry relaxed fabrics

3.2 Analysis of factors affecting fabric spirality

It is well known that fabric spirality is a complex phenomenon and that there are various other yarn, fabric and knitting machine parameters apart from twist liveliness that influence the angle of spirality [16, 17, 18]. Therefore, five additional factors namely tightness factor, the number of feeders on the knitting machine, the machine gauge (needles/inch), the rotational direction of the machine and whether the fabrics had been piece dyed or not were included in our investigation.

The ranges of the variables are in provided in Table 1:

For the discrete parameters, the different levels are defined as follows:

- Piece dyed: 0 = no, 1 = yes
- No. of feeders: 1 = 1 feeder, 2 = 54 feeders, 3 = 90 feeders
- Gauge: 1 = 20 gauge, 2 = 22 gauge, 3 = 24 gauge
- Rotational direction: 0 = clockwise, 1 = anti-clockwise

Table 1 Range of variables

Input parameters	**Min**	**Max**
Yarn and fabric parameters		
Yarn twist liveliness	**-17**	**61**
Tightness factor	**12.82**	**17.18**
Piece dyed	**0**	**1**
Knitting machine parameters:		
No. of feeders	**1**	**3**
Gauge	**1**	**3**
Rotational direction	**0**	**1**
Output parameters		
Degree of spirality (dry relaxed)	**-8.40**	**13.96**
Degree of spirality (wash and dry relaxed)	**-3.76**	**26.73**

In order to examine the inter-relationships of the angle of spirality and the yarn, fabric and machine variables the simple (bivariate) and partial correlation coefficients were analysed for both the dry relaxed and washed and dry relaxed fabrics. The computed correlation coefficients are given in Tables 2a to 3b.

Tables 2a and 2b reveal the bivariate correlation coefficients of the dry relaxed and washed and dry relaxed fabric respectively. It can be seen that there are strong positive correlations between the measured twist liveliness and angle of spirality for both the dry relaxed (Pearson correlation value r = 0.81) and wash and dry relaxed fabrics (Pearson correlation value r = 0.795). Tightness factor showed a moderate negative correlation with the angle of spirality in both the dry and wash and dry relaxed fabrics. For the dry relaxed fabrics the effect of the other parameters (number of feeders, gauge, rotational direction and piece dyed) on the angle of spirality were not significant at the 5% level. Whereas, for the wash and dry relaxed fabrics only the number of feeders and gauge showed weak correlations with the angle of spirality.

The method of partial correlation was used to examine the relationship between the angle of spirality and the individual variables when the effects of the other variables are kept constant. Table 3a presents the partial correlation coefficients of the various variables for the dry relaxed fabrics. It is clear that yarn twist liveliness and tightness factor are the most important variables and are strongly correlated to the angle of spirality. In Table 3b, the partial correlation coefficients of the various variables for the wash and dry relaxed fabrics show that in addition to twist liveliness and tightness factor, piece dyeing has a correlation with the angle of spirality at the 5% level although it is only a weak correlation.

It is interesting to compare the bivariate and partial correlation coefficients for the wash and dry relaxed fabrics in Tables 2b and 3b. It can be seen that the strong correlation between the twist liveliness and angle of spirality and the moderate correlation between the angle of spirality and tightness factor become much stronger when the effects of the other variables are kept constant.

It can therefore be confirmed that twist liveliness and tightness factor are the most important parameters influencing fabric spirality whereas the number of feeders, gauge, rotational direction and piece dyeing are less important.

Table 2a Simple correlation coefficients between spirality and various variables for dry relaxed fabrics

	Angle of spirality	**Twist liveliness**	**Number of feeders**	**Gauge**	**Rotational direction**	**Piece dyed**	**Tightness Factor**
Angle of spirality	1						
Twist liveliness	0.807	1					
Number of feeders	-0.234 (ns)	-0.080 (ns)	1				
Gauge	-0.249 (ns)	-0.109 (ns)	0.787	1			
Rotational direction	-0.149 (ns)	-0.103 (ns)	-0.235	0.056 (ns)	1		
Piece dyed	-0.169 (ns)	-0.059 (ns)	0.370	0.358	-0.091 (ns)	1	
Tightness Factor	-0.522	-0.202 (ns)	0.651	0.475	-0.171 (ns)	0.226 (ns)	1

ns: not significant at 5% level

Table 2b Simple correlation coefficients between spirality and various variables for wash and dry relaxed fabrics

	Angle of spirality	**Twist liveliness**	**Number of feeders**	**Gauge**	**Rotational direction**	**Piece dyed**	**Tightness Factor**
Angle of spirality	1						
Twist liveliness	0.795	1					
Number of feeders	-0.404	-0.080 (ns)	1				
Gauge	-0.325	-0.109 (ns)	0.787	1			
Rotational direction	0.053 (ns)	-0.103 (ns)	-0.235 (ns)	0.056 (ns)	1		
Piece dyed	-0.248 (ns)	-0.059 (ns)	0.370	0.358	-0.091 (ns)	1	
Tightness Factor	-0.696	-0.202 (ns)	0.010	0.475	-0.171 (ns)	0.226 (ns)	1

ns: not significant at 5% level

Table 3a Partial correlation coefficients of various variables for the dry relaxed fabrics

	Twist liveliness	No. of feeders	Gauge	Rot. direction	Piece dyed	Tightness Factor
Spirality Angle	0.846	0.174 (ns)	-0.050 (ns)	-0.248 (ns)	-0.166 (ns)	-0.628

ns: not significant at 5% level

Table 3b Partial correlation coefficients of various variables for the wash and dry relaxed fabrics

	Twist liveliness	No. of feeders	Gauge	Rot. direction	Piece dyed	Tightness Factor
Spirality Angle	0.938	0.135 (ns)	0.007 (ns)	0.115 (ns)	-0.357	-0.868

ns: not significant at 5% level

3.3 Prediction of fabric spirality by multiple regression

One approach to establish a quantitative relationship between the angle of spirality and the yarn and fabric variables is to use a multiple regression method on the data. Such an approach can estimate the relative contribution of each variable to the average angle of spirality.

A stepwise multiple regression analysis was first performed to predict the angle of spirality for the dry relaxed fabrics. The analysis was done using Minitab statistical software using a combination of forward selection and backward elimination. The stepwise regression technique inserts or removes variables into a regression model according to the default statistical inclusion criterion (5% level of significance) until a satisfactory regression equation is reached.

For the dry relaxed fabrics the results in Table 4a reveal that twist liveliness is the most important parameter and accounts for 65% of the variance in the angle of spirality. With the addition of the parameters tightness factor and rotational direction only 81% of the variance in the angle of spirality of the dry relaxed fabric is explained. This implies that the prediction results may not be very accurate if the resultant regression model is used for the dry relaxed fabrics.

A second stepwise multiple regression analysis was performed to predict the angle of spirality for the wash and dry relaxed fabrics as shown in Table 4b. Similarly, to the dry relaxed fabric the twist liveliness is the most important parameter than accounts for 63% of the variance in the data. Tightness factor is the other important parameter and together with twist liveliness they account for 93% of the variance in the angle of spirality. The parameter, piece dyed, did not account for a significant improvement in the variance of spirality (less than 1%) and therefore was not included in the resultant regression equation (for angle spirality after wash and dry relaxation) as given below:

$$Spirality = 68.63 + 0.167T - 4.08TF \qquad (2)$$

Where the units of spirality, twist liveliness (T) and tightness factor (TF) are degrees, turns/25cm, $tex^{1/2}\ cm^{-1}$, respectively and for piece dyed (P): 0 = no, 1 = yes

Table 4a Prediction of fabric spirality (dry relaxed) with an increasing number of yarn, fabric and knitting machine parameters (step-wise method)

Step	**Factors**	**Multiple correlation coefficient, R**	**Percentage variance explained, R^2**
1	Twist liveliness (T)	0.81	65.14
2	Tightness Factor (TF)	0.88	78.58
3	Rotational direction (R)	0.89	80.56

Table 4b Prediction of fabric spirality (wash and dry relaxed) with an increasing number of yarn, fabric and knitting machine parameters (step-wise method)

Step	**Factors**	**Multiple correlation coefficient, R**	**Percentage variance explained, R^2**
1	Twist liveliness (T)	0.79	63.12
2	Tightness Factor (TF)	0.96	93.04
3	Piece dyed (P)	0.97	93.74

In order to test the regression model results a set of data that had not been used to construct the model was used. This set of data included 11 fabrics with parameters shown in Table 5.

Table 5 Parameters of the test set

Sample No.	**Twist liveliness (turns/25cm)**	**Tightness Factor**	**Measured angle of spirality (degrees)**
1	21	16.74	2.19
2	-7	16.90	-1.54
3	-10	16.83	-2.27
4	-17	17.09	-2.56
5	21	16.96	4.45
6	-17	16.96	-2.15
7	22	16.96	2.29
8	22	17.03	3.17
9	20	17.03	0.70
10	0	17.03	-1.82
11	20	17.03	1.56

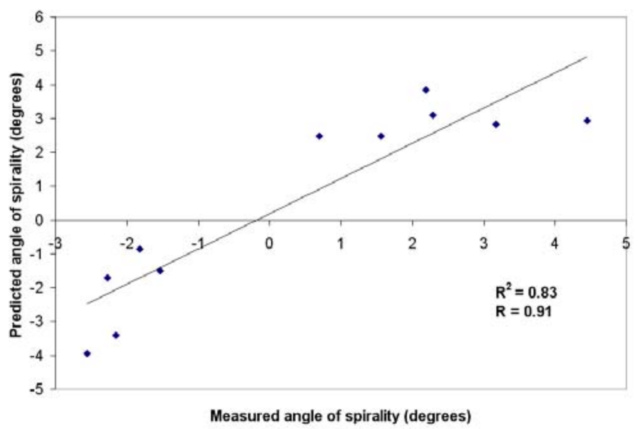

Fig. 3. Relationship between the predicted and measured angle of spirality after wash and dry relaxation

Figure 3 presents the agreement between the predicted angle of spirality after wash and dry relaxation from the regression model versus the 'target' measured values for the test data set. There is a relatively good agreement of linear relationship ($R=0.94$, at $p<0.001$) between the measured angle of spirality and the model's prediction observed.

4. Conclusion

An improved methodology and apparatus to measure twist liveliness has been applied to study the quantitative relationship between yarn twist liveliness and fabric spirality. Additional parameters including tightness factor, number of feeder, machine rotational direction, gauge and piece dyeing were incorporated in the analysis.

The results of the simple bivariate and partial analyses have demonstrated that twist liveliness is significantly correlated with fabric spirality. Tightness factor has a moderately negative correlation. Whereas, the other parameters do not have a significant effect on fabric spirality for both dry relaxed and wash and dry relaxed fabrics.

It was established that spirality could not be predicted with any reasonable degree of accuracy when using fabric samples in their dry relaxation state.

For wash and dry relaxation fabrics an empirical equation for the angle of spirality was derived by a stepwise multiple regression technique. The regression analyses can reveal the quantitative relationship between the angle of spirality and the twist liveliness and tightness factor. It showed that approximately 63% of the variance in the fabric spirality of the specimens tested is explained by yarn twist liveliness alone. With the inclusion of tightness factor, about 93% of the variance of fabric spirality can be explained. The derived empirical equation was tested on data that had not been used to develop the model. It was found that there was a relatively good agreement with the measured angle of spirality and the model's prediction.

Therefore we conclude that the application of the results obtained from the measurement of twist liveliness using the developed methodology and apparatus is effective in the prediction of fabric spirality after wash and dry relaxation processes.

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