A COMPARATIVE QUALITY OPTIMISATION BETWEEN RING SPUN AND SLUB YARNS
BY USING DESIRABILITY FUNCTION

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Abstract:
The present study was conducted to develop a credible approach to determine the quality of ring spun and slub yarns by virtue of criteria incorporating combinations of the fundamental fiber characteristics. Critical yarn parameters are to be investigated. The values of these tested properties were introduced into a database that ranked the quality of the yarn against industry standards. The paper investigates the possibilities of using the global optimization superimposed diagram response surface methodology in order to identify the spinner feasibility conditions across the customer yarn quality requirements. The spinner approach consists of optimizing the yarn count and twist. We have also studied the customer approach to optimize the yarn responses simultaneously by the use of the desirability functions. The response optimizer searches for a combination of input variables that jointly optimize the set of the responses by satisfying the customer requirements for each response in the set.

Keywords:
Ring spun, slub yarn, desirability function

Introduction
Developments in spinning have generated many yarns structures intend for different domains and end use. In fact, the annual production of fancy yarns is roughly estimated as more than 100000 tons [1]. In denim industry, the production of slub yarns is becoming increasingly useful and prevailing compared to the conventional yarn [2]. This increase is reported to the fabric effect gotten with slub yarn. Therefore, this fancy yarn type which consists of two parts, the slubs (or flames) and the spacings (figure 1), confers an aesthetic aspect which provides the initial impulse of attraction and may be the only factor that influences the decision to buy. This innovation is beneficial economically for yarn manufacturers that find it difficult to compete in standard products [3] and also for the customer who find a decorative effect and a better texture imparted to the product.

Figure 1. Slub yarn configuration.

This novelty generates a change in yarn properties compared to the conventional yarn. In this study, we have searched to assess slub yarn quality with comparison to that one of the conventional ring spun yarn. Traditionally, manufacturers have used yarn strength as a major measure of yarn quality [4, 5, and 6]. Here, we have quantified the level of satisfaction of customer all quality criterions simultaneously by using the desirability approach. The slub yarn studied in this paper is produced on the ring spinning system equipped with the Amsler device [7]. We predicted the ring spun and slub yarn global quality upon an experimental data base, which includes several properties.

The second aim of the present study is to find a compromise zone for the spinner and customer by using the diagrams of superimposed contours. Indeed, this prediction should help the spinner to estimate whether the yarn that is produced will match the customer taste and the spinning parameters to reach the desired quality.

Materials and methods
In this survey, we study the following yarn aspects (Table 1):

<table>
<thead>
<tr>
<th>Yarn properties</th>
<th>Instrument</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity (CN/ Tex)</td>
<td>Uster tensionrapid 3</td>
<td>RKM</td>
</tr>
<tr>
<td>Tenacity evenness (%)</td>
<td>Uster tensionrapid 3</td>
<td>CVRKM</td>
</tr>
<tr>
<td>Breaking elongation (%)</td>
<td>Uster tensionrapid 3</td>
<td>E%</td>
</tr>
<tr>
<td>Breaking work (Joule)</td>
<td>Uster tensionrapid 3</td>
<td>TR</td>
</tr>
<tr>
<td>Regularity (%)</td>
<td>Uster tester 3</td>
<td>U%</td>
</tr>
<tr>
<td>Number of thick points</td>
<td>Uster tester 3</td>
<td>THIK</td>
</tr>
<tr>
<td>Number of thin points</td>
<td>Uster tester 3</td>
<td>THIN</td>
</tr>
<tr>
<td>Number of neps</td>
<td>Uster tester 3</td>
<td>BOUT</td>
</tr>
<tr>
<td>Hairiness</td>
<td>Uster tester 3</td>
<td>PILO</td>
</tr>
</tbody>
</table>

These characteristics are measured according to international standards and represent the database outputs.

For the database inputs, we used different spinning production parameters, which are related to fibers' characteristics. These parameters were also evaluated according to international standards and were measured using the High Volume Instrument (HVI) testing system. The fibers' properties, which cover wide range of HVI fiber property values, are summarized in Table 2.

A statistical summary of all fiber property measurements (mean, standard deviation, minimum, and maximum) is given in Table 3.
The fibers’ characteristics are common for ring spun and slub (flame) yarns as they both preserve the same blow room spinning process. The statistical summary of ring spun and slub yarns properties measurements are given respectively in tables 4-a and 4-b. For the slub yarn, the properties U%, THIK, THIN, BOUT and PILO were not measured as the flame yarn presents provocative irregularities in its construction. The borderlines of the slub yarn properties cover the different sizes of the flames presented in the database of the present industry.

Optimising ring spun and slub yarns quality with overlaid contour plot

The present method consists of giving an objective and an acceptance zone for each yarn property. The goal of this study is to find the suitable and feasible ranges of the metric yarn count (Nm) and twists that the spinner can apply while holding the properties restrain imposed by the consumer at certain settings.

The graphics are two overlaid contour plots (Figure 2) drawn by using “Minitab” software for data analysis. Contour plots belonging to the interval [14.17; 17.78] and twist (rd/m) belonging to the interval [351; 629]. The common properties of the two yarns type are imposed to the same ranges setting (RKM ∈ [16 ; 22]; CVRKM ∈ [5 ; 10]; E%∈ [6 ; 9]; TR ∈ [2 ; 4]). For the slub yarn, the zone of feasibility (or compromise zone) is obtained with yarn count (Nm) belonging to the interval [9.47; 16.54] and a twist belonging to the interval [390; 664]. We can conclude that the ring spun yarn quality is obtained for a yarn count (Nm) higher than that one of the slub yarn. Effectively, due to its irregular structure composed with flames and thinnesses, the slub yarn should have lower values of yarn count compared to the ring spun yarn to reach a higher quality.

If we change yarn properties values according to customer demands, the spinner would have other optimal couples of yarn count and twist.

Optimizing ring spun and slub yarns quality with desirability approach

In desirability approach to optimization, each of the response values is transformed using a specific desirability function that reflects the yarn quality level. The steps followed in desirability approach are:

### Table 2. Fiber properties.

<table>
<thead>
<tr>
<th>Fiber property</th>
<th>Instrument</th>
<th>symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micronaire index</td>
<td>HVI</td>
<td>Mic</td>
</tr>
<tr>
<td>Maturity</td>
<td>HVI</td>
<td>Mat</td>
</tr>
<tr>
<td>Upper Half Mean Length (UHML)</td>
<td>HVI</td>
<td>Len</td>
</tr>
<tr>
<td>Length Uniformity</td>
<td>HVI</td>
<td>Unif</td>
</tr>
<tr>
<td>Short Fiber index</td>
<td>HVI</td>
<td>Sfi</td>
</tr>
<tr>
<td>Strength</td>
<td>HVI</td>
<td>Str</td>
</tr>
<tr>
<td>Elongation</td>
<td>HVI</td>
<td>Elg</td>
</tr>
<tr>
<td>Trash count</td>
<td>HVI</td>
<td>Tr cnt</td>
</tr>
<tr>
<td>Trash area</td>
<td>HVI</td>
<td>Tr area</td>
</tr>
<tr>
<td>Trash grade</td>
<td>HVI</td>
<td>Tr grade</td>
</tr>
<tr>
<td>Greyness ( color reflectance)</td>
<td>HVI</td>
<td>Rd</td>
</tr>
<tr>
<td>Yellowness</td>
<td>HVI</td>
<td>+b</td>
</tr>
</tbody>
</table>

### Table 3. Summary statistics for fiber properties.

#### Table 4-a. Summary statistics for ring spun yarn properties.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>RKM</th>
<th>CVRKM</th>
<th>E%</th>
<th>TR</th>
<th>U%</th>
<th>THIK</th>
<th>THIN</th>
<th>BOUT</th>
<th>PILO</th>
<th>Nm</th>
<th>Twist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum value</td>
<td>14.64</td>
<td>4.54</td>
<td>6.27</td>
<td>1.27</td>
<td>7.37</td>
<td>2.75</td>
<td>2.00</td>
<td>0.45</td>
<td>6.62</td>
<td>10.10</td>
<td>364</td>
</tr>
<tr>
<td>Maximum value</td>
<td>22.12</td>
<td>7.96</td>
<td>9.72</td>
<td>6.58</td>
<td>12.32</td>
<td>19.50</td>
<td>19.43</td>
<td>220.20</td>
<td>13.17</td>
<td>629</td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.23</td>
<td>3.17</td>
<td>0.77</td>
<td>0.85</td>
<td>1.34</td>
<td>1.78</td>
<td>8.20</td>
<td>6.42</td>
<td>1.18</td>
<td>1.51</td>
<td>1.42</td>
</tr>
<tr>
<td>Mean</td>
<td>17.32</td>
<td>6.85</td>
<td>7.87</td>
<td>2.83</td>
<td>9.92</td>
<td>54.29</td>
<td>1.46</td>
<td>64.09</td>
<td>9.74</td>
<td>13.07</td>
<td>463</td>
</tr>
</tbody>
</table>

#### Table 4-b. Summary statistics for slub yarn properties.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>RKM</th>
<th>CVRKM</th>
<th>E%</th>
<th>TR</th>
<th>Nm</th>
<th>Twist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum value</td>
<td>12.26</td>
<td>4.61</td>
<td>6.01</td>
<td>1.13</td>
<td>9.38</td>
<td>408</td>
</tr>
<tr>
<td>Maximum value</td>
<td>16.97</td>
<td>15.00</td>
<td>8.66</td>
<td>6.24</td>
<td>17.83</td>
<td>698</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.03</td>
<td>2.06</td>
<td>0.83</td>
<td>0.69</td>
<td>4.42</td>
<td>80</td>
</tr>
<tr>
<td>Mean</td>
<td>16.77</td>
<td>8.22</td>
<td>7.70</td>
<td>2.39</td>
<td>14.49</td>
<td>536</td>
</tr>
</tbody>
</table>

The fibers’ characteristics are common for ring spun and slub (flame) yarns as they both preserve the same blow room spinning process. The statistical summary of ring spun and slub yarns properties measurements are given respectively in tables 4-a and 4-b. For the slub yarn, the properties U%, THIK, THIN, BOUT and PILO were not measured as the flame yarn presents provocative irregularities in its construction.

The borderlines of the slub yarn properties cover the different sizes of the flames presented in the database of the present industry.
First, we obtain Derringer and Suich [8, 9] individual desirability function \(d_i\) for each response using the provided goals and boundaries. There are three goals to choose from:

- to target the response (target is best)
- to minimize the response (smaller is better)
- to maximize the response (larger is better)

To target a response such as the yarn count and twist, we use the following formula.

\[
\begin{align*}
&d_i = \begin{cases} 
\left( \frac{Y_i - LIT_i}{LST_i - LIT_i} \right)^p & \text{if } LIT_i \leq Y_i \leq \mu_i \\
\left( \frac{Y_i - LST_i}{\mu_i - LST_i} \right)^q & \text{if } \mu_i \leq Y_i \leq LST_i \\
1 & \text{if } Y_i = \mu_i \\
0 & \text{if } Y_i \leq LIT_i \text{ or } Y_i \geq LST_i
\end{cases}
\end{align*}
\]

The notation used in the formula 1 is:

- \(Y_i\) = predicted value of \(i^{th}\) response
- \(\mu_i\) = target value for \(i^{th}\) response
- \(LIT_i\) = lowest acceptable value for \(i^{th}\) response
- \(LST_i\) = highest acceptable value for \(i^{th}\) response
- \(p, q\) = weight of desirability function of \(i^{th}\) response: two different requirement levels to make less or more importance to the response when it is lower or higher than the target. For instance, the customer can be more rigorous when the elongation is lower than the target. In this study, we took \(p=1\) and \(q=1\) which means that we have the same requirement if it is under or upper the target.

If we want to maximize a response such as tenacity (RKM), regularity (U %) or breaking work energy (TR), we use the desirability function according to equation 2 as follow:

\[
\begin{align*}
&d_i = \begin{cases} 
0 & \text{if } Y_i \leq LIT_i \\
\left( \frac{Y_i - LIT_i}{\mu_i - LIT_i} \right)^p & \text{if } LIT_i \leq Y_i \leq \mu_i \\
1 & \text{if } Y_i \geq \mu_i
\end{cases}
\end{align*}
\]

2/ After calculating an individual desirability for each response, they are combined to provide a measure of the composite or overall desirability \(D\) of the multi-response system. This measure of the composite desirability \(D\) (equation 4) is the weighted geometric mean of the individual desirabilities \(d_i\) for the responses.

\[
D = \sqrt[\sum w_i]{d_i^n \times d_i^m \times \cdots \times d_i^w}
\]

The individual and the composite desirabilities for all responses have both a range of zero to one. One represents the ideal case; zero indicates that one or more responses are outside their acceptable limits.

3/ Maximizing the composite desirability and identifying the optimal input variable settings

The global desirability \(D\) was optimized by using an excel algorithm, which is modified when the definition of yarn quality is changed.

The setting parameters that maximize the yarn quality are modified with the customer demands. As an example, we set these properties for both ring spun and slub yarns respectively as follow in Tables 5-a and 5-b:

The weight values are accorded to make less emphasis on the target or to place more emphasis on the target. If some responses are more important than others, we can incorporate this information into the optimal solution by setting unequal importance values. In our case, we chose a weight value equal to one which places equal importance between responses.

The illustrations below (Table 6) show the global desirability for ring spun and slub yarns.
For interpreting the desirability values found, we have followed Harrington’s rating system [8]. The ring spun composite desirability (Table 6) ranges between 0.40 and 0.60. In Harrington standards, this borderline specifies that the product quality is acceptable to the specification limits but improvement is desired. Effectively, for the ring spun yarn, the individual desirability of the response CVRKM is satisfied (equal to 0.86). Whereas the individual desirabilities of uniformity (U %) and Hairiness of the same yarn are unacceptable (respectively equal to 0.21 and 0.24).

For the slub yarn (Table 6), the global desirability value is equal to 0.82 which lies between 0.8 and 1. This interval provides a relatively acceptable and excellent quality according to Harrington standards. For this yarn, the specifications for RKM,Nm and Twist have been easily met, whereas, the specification for CVRKM, TR and E(%) are barely satisfied.

For the slub yarn, the algorithm optimises in addition to the predicted responses the most convenient program of flames that should be manipulated in the Amsler unit. In this example, the adequate program to maximize the composite desirability involves the following specifications:

- The number of flames per meter = 2.505

The following step consists of setting the optimal input variable levels that have maximized the yarns composite desirabilities. That is, the fiber optimum parameters would be set as mentioned in Tables 5a and 5b. In this case, the two yarn types fairly show a similar global solution (Table 7).

## Conclusion

The idea in this article is to develop a composite yarn quality index by using the global desirability function and the individual desirability function of each property in order to aid in multicriterion yarn quality optimization. This will closely depict the perception of yarn quality as preferred by the consumers. For this case, an excel program was developed to predict the level of the customer quality satisfaction. In this program, we can vary the objectives, the tolerance intervals and the corresponding weights of the yarn properties as required by the customer. Face to the customers’ quality constraints, the spinner can predict the feasibility and the suitable ranges of ring spun and slub yarns counts and twists by studying the
compromise zone using the diagrams of superimposed contours.

Nevertheless, the possibility of finding an optimal solution that satisfies simultaneously all required responses remains a little bit limited. The benefits from deriving these alternative desirability functions are limited by the fact that if only one of the individual desirabilities is null, then the global desirability will be null.

References