PROCESS OPTIMIZATION OF YARN HAIRINESS, YARN STRENGTH AND COST FOR STAPLE-YARN

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Abstract: It is generally desirable to reduce yarn hairiness as much as possible since it causes important problems in both yarn production and use of yarn in subsequent textile operations. On the other hand, yarn production cost should be minimized while maintaining yarn hairiness and yarn strength within required limits. In this study, a multiple response optimization model based on empirical regression models is developed to determine the best processing conditions for spindle speed, yarn twist, and number of traveller as yarn hairiness, yarn strength and production cost being multiple responses. Experimental levels for process variables are selected according to a statistical Central Composite Design (CCD) due to its good statistical properties such as orthogonality and rotatability. Regression analysis of experimental results indicates that the second-order regression model adequately represents yarn hairiness in terms of process variables. Finally, yarn production cost model and regression models for yarn hairiness and yarn strength are combined in a multiple response optimization model to determine optimum processing conditions for different yarn quality levels.

Keywords: *Process Optimization, Yarn Production, Hairiness, Yarn Cost*

1. Introduction

In yarn production, yarn hairiness is to be kept low as much as possible except for few special cases. High yarn hairiness causes important problems in both yarn production and use of yarn in subsequent textile operations. Such problems include higher friction during spinning, greater fly fiber, increased yan breaking during weawing (Barella & Manich, 1997). A study published in Textile World (1989) states that 46% of yarn breakings in weawing are due to high yarn hairiness. Another adverse effect of hairiness in weawing is greater pilling in fabric. Differences in hairiness properties of weft yarns result in band forming in fabric. High hairiness in bobin machines results in loss of productivity and dark lines form where high hairiness exists in warp yarn (Barella & Manich, 1997). These examples show that it is critical to reduce yarn hairiness in order to improve quality of yarn used in knitting, weawing and finishing operations. This also brings significant cost reductions in production of yarn by eliminating additioanl operations to reduce hairiness.

On the other hand, yarn production cost should be minimized while maintaining yarn hairiness and yarn strength within desirable limits. In this study, an optimization model based on empirical regression models is developed to determine the best processing conditions for spindle speed, yarn twist, and number of traveller as yarn hairiness, yarn strength and production cost being multiple responses (Morris, Rennel & Merkin, 1997). Regression analysis is used to build response surface models for yarn hairiness, yarn cost and yarn strength as a function of the process variables of interest (Myers & Montgomery, 2002).

2. Optimization Approach

Basic steps of the multiple-response optimizaton approach used in this study are summarized in a flowchart as shown in Figure 1. A pure cotton blend is prepared to produce Ne 40/1 staple yarn on the ring machines. Experimental levels for process variables are selected according to a statistical Central Composite Design (CCD) due to its good statistical properties such as orthogonality and rotatability. This design has 15 different design points for combinations of process variables. Produced yarns are tested on Uster Tester 4 and Uster Tensorapid 3 testing equipment.

Yarn production cost at each design point is estimated in order to build a regression model that defines relationship between yarn cost and process variables of interest. Design Expert software is used for all statistical analysis and optimization in this study (Stat-Ease, Inc.)

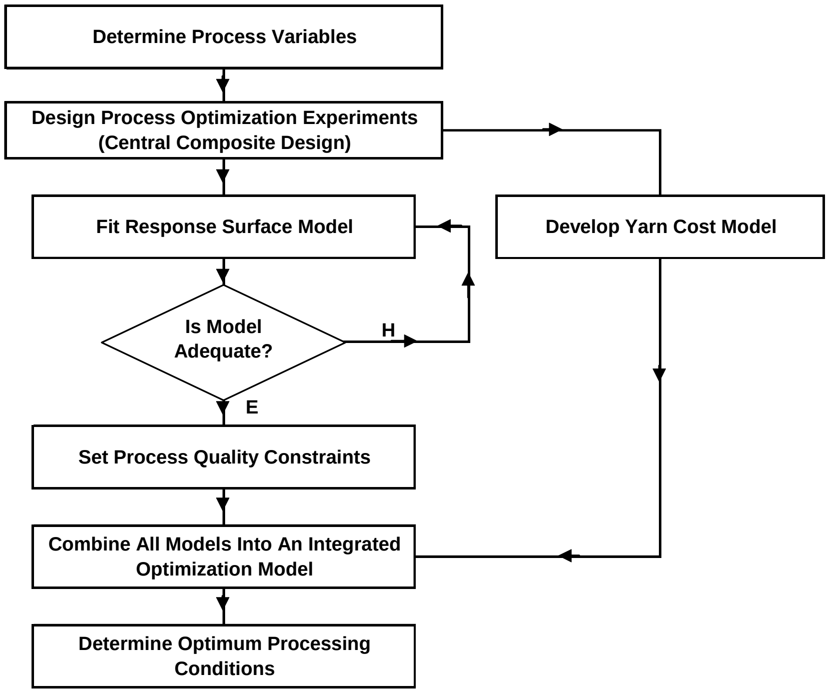

Figure 1. Steps of multiple response process optimization approach

A useful approach to optimization of m multiple responses proposed by Derringer and Suich (1980) makes use of desirability functions. In this approach, each response y_i is expressed in terms of an individual desirability function d_i that takes values in the following range

$$0 \le d_i \le 1 \quad i = 1, 2, \ldots, m$$

When the response is at its goal or target, $d_i = 1$, and if the response is outside an acceptable range, $d_i = 0$. The process variables are set to levels such that the following overall desirability function is maximized,

$$D = (d_1 d_2 \ldots\ldots\ldots d_m)^{1/m}$$

For yarn hairiness the desirability function is

$$d = \begin{cases} 1 & y < T \\ \left(\dfrac{U - y}{U - T}\right)^r & T \le y \le U \\ 0 & y > U \end{cases}$$

where T and U is target value and upper limit for yarn hairiness respectively. In this equation, r is the weight assigned to the response variable. Choosing $r > 1$ places greater importance on being close to the target value, and choosing $0 < r < 1$ makes this less important.

In a similar way, as yarn strength should be maximized, the desirability function should be:

$$d = \begin{cases} 1 & y < T \\ \left(\dfrac{y - L}{T - L}\right)^r & T \le y \le U \\ 0 & y > U \end{cases}$$

where L is lower limit for yarn strength. Upper and lower limits for the response variables are selected from Uster statistics published in 2001 for quality of yarn produced worldwide.

3. Research Findings and Discussion

Regression analysis of experimental results incidates that the second-order regression models adequately represent yarn haireness and yarn strength in terms of process variables. (*p*-values for model significance are 0.0037 and 0.0087 for yarn haireness and yarn strength respectively). Regression equations are as follows:

$$y_{hairiness} = -19.56 - 0{,}00109x_1 + 0{,}0762x_2 - 0{,}7655x_3 - 0{,}00027x_3^2 + 0{,}00039x_1x_3$$

$$y_{strength} = +14.97 - 0{,}0004x_1 + 0{,}0386x_2 + 0{,}378x_3 - 0{,}0183x_2^2 + 0{,}0008x_2x_3$$

$$y_{\cos t} = 4.135 - 0{,}00016x_1 + 0{,}0031x_2 - 0{,}0185x_3$$

Response models for all three response variables are combined into a single multiple-response optimzation model. Quality constraints for different quality levels of yarn produced throughout the world (top 75%, 50%, 25% and 5%) are published regularly by Uster (2001). Table 1 summarizes optimizastion results for various quality levels.

Table 1. Optimum processing conditions for different quality levels

Quality level (%)	Optimum processing conditions			Optimum values for response variables		
	x_1	x_2	x_3	$y_{\text{haireness}}$	y_{cost} [USD/kg]	y_{strength} [cN/tex]
75	11038.96	1017.61	37.97	3.75	4.78	19.238
50	12696.12	1011.41	33.29	4.57	4.57	18.330
25	10365.50	1012.57	37.91	3.53	4.87	19.820
5	9820.00	1011.40	38.05	3.39	4.96	20.612

x_1 : spindle speed (rpm); x_2 : yarn twist (T/m); x_3 : number of traveller

As shown in Table 1, there is no feasible solution for 75% quality level. Therefore, we conclude that as the quality of raw material is high, it is not possisble to produce low quality yarn from this batch. At the lowest level of yarn twist, when spindle speed and number of traveller levels are close to the center of the design, it is possible to produce 50% yarn quality.

4. Conclusions

In this study, yarn production cost model and regression models for yarn hairiness and yarn strength are combined in a multiple-criteria decision model to determine optimum processing conditions for different quality levels punlished by Uster. Optimization model indicates that low spindle speed and yarn twist along with high number of traveller should be selected to reduce yarn haireness and production cost while maintaining high yarn strength.

For further study, other process variables (e.g., applied draw, ring diameter, temperature and humidity at workplace) not included in this study might be considered. Moreover, process optimization approach used here can be repeated for yarn produced in other spinning systems such as open-end. In such a study, other quality parameters (e.g., yarn evenness, breaking force, thin places) could be incorporated into the optimization model.

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