DESIGN OF EXPERIMENTS OPTIMIZATION STUDY
ON THE POWERED ROLL GIN STAND: PART I

G. A. Holt

ABSTRACT. The powered roll gin stand has been evaluated in numerous studies evaluating its impact on production and fiber quality properties. The question remained as to what speed the various components of the powered roll gin stand should be operated at to optimize performance. The three main components of the power roll gin stand are the paddle roll, seed finger roll, and gin saw. This article presents the results of an optimization study conducted on a power roll gin stand operating at a commercial cotton gin during the 2003-2004 ginning season. The results are based on lint samples taken after the gin stand (before lint cleaning) and after one stage of lint cleaning, seed samples, and performance data. Of the 13 response variables evaluated, four variables resulted in significant models: fiber length, short fiber content, ginning rate, and Rd (reflectance). Several optimal solutions were obtained based on the input factors used in the evaluation. When including all response variables in the analysis, the optimal operational settings for a Continental Double Eagle 141 before and after lint cleaning were: paddle roll speed = 180 and 180 rpm, paddle roll loading = 25 and 23.8 amps, and seed finger speed = 18 and 40 rpm, respectively. The saw speed was held constant at 724 rpm.

Keywords. Cotton gin, Design of experiments, Ginning, Gin stand, Optimization.

The powered roll gin stand is USDA-ARS patented technology (Laird, 2000) initially developed to remove the residual fibers from cottonseed for the EASIflo process (Laird et al., 1997). Past studies have demonstrated that the powered roll gin stand has the potential means to improve the efficiency of ginning seed cotton without adversely affecting fiber properties (Laird et al., 2000; Laird et al., 2001; Holt et al., 2001; Laird et al., 2002; Holt et al., 2002; Laird and Holt, 2003; Holt, 2004). Results also revealed a number of operational settings that could further improve performance and fiber quality. These operational settings were for the three primary components of the powered roll gin stand, which are the saw, the paddle roll, and the seed finger roll (fig. 1).

The operational settings of interest were saw speed, paddle roll speed, seed finger roll speed, and paddle roll loading rate. An initial evaluation of the optimal operational settings for these three components, while ginning seed cotton, indicated speeds or loading rates that could potentially produce the best turnout, production rate, and/or fiber quality data for the ranges evaluated (Holt et al., 2001). Likewise, the initial optimal setting study was performed using a single variety of cotton that had been grown in one location and harvested using a cotton stripper without use of the field cleaner. Even though the initial study was a good screening evaluation, it could be considered a “one-factor-at-a-time” approach. Because each of these factors could have an impact on determining the ideal operational settings for a certain cotton variety grown in a certain area and harvested in a certain way, it is desirable to determine the operational settings such that they would be insensitive (i.e., robust) to all possible combinations of uncontrollable factors (i.e., noise), while maintaining reliable performance.

As of the 2004-2005 ginning season, 18 gin stands were retrofitted with the powered roll gin stand technology. The gin stands were located in seven cotton gins across the continental U.S. (cotton belt). Some of the cotton gins retrofitted all of their gin stands, while others opted to evaluate the powered roll technology by retrofitting only one stand while comparing its performance to the existing gin stands. Results detailing some of the comparisons can be found in Holt (2004). One of the cotton gins that modified all of its gin stands was Servico Incorporated in Courtland, Alabama. The primary concern was what speeds the various components should be operated at to best preserve the lint quality while maximizing turnout. Thus, the objectives of this research

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Figure 1. Schematic of the powered roll gin stand showing the paddle roll, gin saw, and seed finger roll.
were to: (1) determine which response variables have the greatest influence on the optimal solution(s); and (2) define and determine the optimal operational parameters of a powered roll gin stand operating in a commercial cotton gin in order to maximize cotton ginning processing rate, lint turnout, and fiber quality.

**MATERIALS AND METHODS**

**CONTINENTAL POWERED ROLL GIN STAND**

Servico Incorporated’s cotton gin is a three-stand plant comprised of Continental Double Eagle 141’s with 40.6 cm (16 in.) saws and a seed tube. Modifications to each gin stand included replacing the old front with a new paddle roll front. The specific modifications included:

- Removing the 10.2 cm (4 in.) outside-diameter seed tube and replacing it with a 19.69 cm (7.75 in.) paddle roll.
- Increasing the cross-sectional area of the roll box by 432.3 cm² (67 in.²) to accommodate the paddle roll.
- Replacing the original seed tube drive, which was powered from the saw motor, with a 22.4 kW (30 hp), 885 rpm motor driving the paddle roll through a 3:85:1 gear reduction for a maximum paddle roll speed of 230 rpm.
- Replacing the picker roll with a seed finger roll consisting of one hundred and forty-two 17.8 cm (7 in.) seed fingers extending 5.1 cm (2 in.) between the saws.
- Replacing the original seed tube drive, which was powered from the saw motor, with a 0.19 kW (1/4 hp), 1750 rpm DC motor that powered the seed finger roll through a 43.75:1 gear box and chain sprocket reducer for a maximum speed of 40 rpm.

The original drive system for the saw and doffing brush remained unchanged. The saw and doffing brush were powered by a 93.2 kW (125 hp) motor. Within the gin stand used for testing, the paddle and seed finger rolls were powered through variable-speed drives. The variable-frequency inverter driving the paddle roll motor was a 22.4 kW (30 hp) Allen Bradley model 1336 (Rockwell Automation, Milwaukee, Wisc.). The seed finger motor was driven by a Leeson DC drive (Leeson Electric Corp., Grafton, Wisc.). Even though saw speed is one of the parameters of interest, the saw motor speed was not adjusted during this study. The speed of the saw motor was set at 724 rpm based on preliminary evaluations. Therefore, for this gin stand, there were three independent variables: paddle roll speed, paddle roll loading rate, and seed finger speed. The paddle roll loading rate is correlated to gin stand feed rate because the feeder output is governed by the saw speed. The paddle roll loading rate was not adjusted during this study. The speed of the saw motor, with a 0.19 kW (1/4 hp), 1750 rpm DC motor that powered the seed finger roll through a 43.75:1 gear box and chain sprocket reducer for a maximum speed of 40 rpm.

The design consisted of six center points, two in each block, and 14 axial and factorial points. A face-centered design (FCD) is one in which the axial points are at the face of the cube portion on the design. The FCD was chosen because the region of interest and region of operability were the same. The physical limitations of the equipment were the primary factors in selecting the FCD. Table 1 shows the FCD matrix, listed by block, used for optimizing the Continental PRGS with the three independent variables in engineering units.

**EXPERIMENTAL DESIGN AND DATA COLLECTION**

The experimental design consisted of a face-centered central-composite design with three independent variables and 13 response variables. The independent variables and their associated range of operation for testing were: paddle roll speed (170 to 230 rpm), paddle roll load (16 to 25 amps), and seed finger speed (10 to 40 rpm).

The operational ranges for the independent variables were selected based on operational limits at which the equipment could operate, according to management at Servico Incorporated, without adversely affecting the ginning operation. The response variables were:

- Ginning rate (bales/h)
- AFIS length by weight (mm [in.])
- AFIS short fiber content (SFC) (%)
- AFIS nep (count/gm)
- AFIS upper quartile length (mm [in.])
- AFIS seed coat nep (count/gm)
- HVI length (mm [in.])
- HVI uniformity index (%)
- Reflectance (Rd)
- Yellowness (+b)
- Loan rate ($)
- Seed lint loss (%)
- Seed visible mechanical damage (%)

Turnout was not evaluated as a response variable for this testing because it would have required shutting down the other two gin stands and operating only the gin stand being evaluated. Because turnout was not measured by the conventional means of dividing the lint weight by the weight of seed cotton, the seed lint loss (described below) was used as a surrogate for turnout.

The Continental powered roll gin stand (PRGS) optimization study consisted of three blocks, for a total of 20 runs. Each run consisted of half a module (six to eight bales). There were six runs in the first two blocks and eight in the third block. The design was blocked by cotton variety. Varieties evaluated were: Delta and Pine Land 451, Paymaster 1218, and Stoneville 5599.

The design consisted of six center points, two in each block, and 14 axial and factorial points. A face-centered design (FCD) is one in which the axial points are at the face of the cube portion on the design. The FCD was chosen because the region of interest and region of operability were the same. The physical limitations of the equipment were the primary factors in selecting the FCD. Table 1 shows the FCD matrix, listed by block, used for optimizing the Continental PRGS with the three independent variables in engineering units.

**Table 1. The face-centered design matrix for the Continental paddle roll gin stand listed by block.**

<table>
<thead>
<tr>
<th>Block</th>
<th>Standard Order</th>
<th>Design Point Type</th>
<th>Paddle Roll Speed (rpm)</th>
<th>Paddle Roll Load (amps)</th>
<th>Seed Finger Speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>Factorial</td>
<td>230</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Center</td>
<td>200</td>
<td>20.5</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Factorial</td>
<td>230</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>Factorial</td>
<td>230</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Factorial</td>
<td>170</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>Factorial</td>
<td>230</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>17</td>
<td>Axial</td>
<td>200</td>
<td>20.5</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>Axial</td>
<td>200</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>18</td>
<td>14</td>
<td>Axial</td>
<td>230</td>
<td>20.5</td>
<td>25</td>
</tr>
<tr>
<td>19</td>
<td>13</td>
<td>Axial</td>
<td>200</td>
<td>20.5</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>Center</td>
<td>200</td>
<td>20.5</td>
<td>25</td>
</tr>
</tbody>
</table>

**REFERENCES**

1. [Title of Reference]
2. [Another Reference]

**Figure 1.** Diagram of Continental powered roll gin stand.

**Graph 1.** Graph showing response variable against parameter.

**Table 1.** Table listing results.

**Table 2.** Table listing experimental design.

**Table 3.** Table listing independent variables.

**Table 4.** Table listing response variables.

**Table 5.** Table listing operational ranges.

**Figure 2.** Diagram of experimental setup.

**Graph 2.** Graph showing comparison of results.

**Table 6.** Table listing summary of results.
When performing the analysis for the individual response variables in the optimization studies, the backward elimination procedure and hierarchy principle were used to determine the model coefficients. The level of significance was set at 10% (α = 0.1). The optimization analysis was performed using “desirability” functions, as detailed in Derringer and Suich (1980). Generally, functions that transform a set of properties into a single objective are known as desirability functions.

For each test run, the seed cotton and lint were processed through the same equipment: Module feeder, 243.8 cm (96 in.) Big J feed works, (split 243.8 cm [96 in.]) system 1st stage tower drier, 1st stage inclined cleaner, dual stick machine, 2nd stage inclined cleaner, distributing conveyor, gin stand, and one stage of lint cleaning (for the after lint cleaning [ALC] samples only). The sample locations (and type of sample) were: feeder apron (seed cotton), seed discharge from the gin stand (seed), before lint cleaner (lint), and lint slide (lint). The feeder apron sample (seed cotton) was analyzed for moisture in-house and dried according to Shepard (1972). Lint samples were analyzed utilizing the high-volume instrument (HVI) and the Advanced Fiber Information System (AFIS) at Cotton Incorporated’s facility in Cary, North Carolina. Seed samples were analyzed for lint loss and visible mechanical damage at the Delta and Pine Lands facility in Aiken, Texas. Lint loss refers to the amount of lint still remaining on the seed after ginning and is measured by weighing out a predetermined amount of seed, drying the seed, acid-delinting, drying the seed again, and then re-weighing the delinted seed. Lint loss is reported in percentage of seed weight.

Visible mechanical damage (VMD) is one means of evaluating ginning effectiveness in regards to seed quality. The seeds are acid-delinted and are evaluated for damage, which is classified into low, medium, and high severity. The sum of all the classifications is termed total VMD, and is the value used in this research. The VMD analysis was performed as described by McCarty and Baskin (1978).

The reason for sampling lint before and after lint cleaning was so that the fiber property results could be analyzed independently. The hypothesis was that the lint cleaner would influence the optimum settings. Because a gin stand is rarely, if ever, operated commercially without lint cleaning, the optimization should be inclusive of the whole system and not just one component, the gin stand. Even though situations exist where two lint cleaners are used in commercial cotton gins, this study was performed using one lint cleaner after the gin stand.

**RESULTS**

**REGRESSION AND MODEL ANALYSIS**

**Before Lint Cleaning (BLC)**

Table 2 shows the mean and standard deviation values for all the fiber property response variables evaluated based on samples collected BLC. The Continental-141 BLC analysis produced significant fitted models to four variables: AFIS length, SFC, ginning rate, and Rd. The ginning rate model is a reduced two-factor interaction. The other three variables are based on fiber quality analyses, with AFIS length and Rd being reduced linear models and SFC a reduced quadratic model. The SFC data were modified using the inverse square root transformation derived from the analysis software, Design-Expert (Stat-Ease, Inc., Minneapolis, Minn.).

Both the AFIS length and Rd models contained only the paddle roll load (PRL) factor. The short fiber content (SFC) model contained the following terms: paddle roll speed (PRS), PRL, seed finger speed (SFS), SFS², PRS*SFS, and PRL*SFS. As a result of hierarchy, two non-significant terms (P > 0.1) were contained in the SFC model, PRS (P = 0.39) and SFS (P = 0.62). The ginning rate model contained three terms: PRS, PRL, and PRS*PRL. Only PRS was included due to hierarchy (P = 0.71). Table 3 contains the mean, root mean square error (RMSE), R², adjusted R², predicted R², and signal-to-noise ratio for all four models. The signal-to-noise ratio is a metric that indicates adequate model discrimination of the response variable to noise. A ratio value greater than 4 is desirable and indicates adequate model discrimination (Whitcomb et al., 2003).

The R² values for SFC and ginning rate (0.90) were the best, with the other two models having R² values of 0.58 (AFIS length) and 0.72 (Rd). The predicted R² value for AFIS length indicates that the model has limited ability to predict

### Table 2. Mean, standard deviation (SD), and model terms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Mean</th>
<th>SD</th>
<th>Model Terms</th>
<th>Adjusted R²</th>
<th>Predicted R²</th>
<th>Signal-to-Noise Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFIS L(w)</td>
<td>cm</td>
<td>2.45</td>
<td>0.071</td>
<td>PRL</td>
<td>0.58</td>
<td>0.56</td>
<td>0.33</td>
</tr>
<tr>
<td>AFIS SFC(w)</td>
<td>%</td>
<td>9.40</td>
<td>2.64</td>
<td>PRL, SFS², PRS<em>SFS, PRL</em>SFS</td>
<td>0.90</td>
<td>0.85</td>
<td>0.76</td>
</tr>
<tr>
<td>AFIS neps</td>
<td>count/g</td>
<td>259</td>
<td>34.23</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>AFIS UQL</td>
<td>cm</td>
<td>2.98</td>
<td>0.043</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>AFIS seed coat neps</td>
<td>count/g</td>
<td>27.50</td>
<td>5.63</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>HVI length</td>
<td>cm</td>
<td>2.83</td>
<td>0.036</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>HVI uniformity</td>
<td>%</td>
<td>83.02</td>
<td>0.811</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rd</td>
<td>--</td>
<td>74.31</td>
<td>2.05</td>
<td>PRL</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>+b</td>
<td>--</td>
<td>7.55</td>
<td>0.312</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Loan rate</td>
<td>$</td>
<td>0.539</td>
<td>0.010</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

[a] AFIS = Advanced Fiber Information System, L(w) = length by weight, SFC(w) = short fiber content by weight, UQL = upper quartile length.

[b] Only statistically significant terms in the significant models are shown.
new observations (33%). The Rd model exhibited a mediocre predicted $R^2$ of 0.57, while the SFC and ginning rate models had a respectable 0.76 and 0.81, respectively. The signal-to-noise ratios for all models indicated adequate model discrimination from the noise in the data.

The models for the four variables from the BLC analyses were:

AFIS length = $2.675 - 1.072E^{-2}(PRL)$  \hspace{1cm} (1)

AFIS SFC (transformed) = $0.3706 + 1.2E^{-3}(PRS)$ \hspace{1cm} (2)

$- 7.2E^{-3}(PRL) + 9.0E^{-3}(SFS) + 1.0E^{-4}(SFS)^2$

$- 1.0E^{-4}(PRS \times SFS) - 2.0E^{-4}(PRL^2SFS)$

Ginning rate = $17.64 - 0.1471(PRS)$ \hspace{1cm} (3)

$- 0.3046(PRL) + 6.9E^{-3}(PRS^2PRL)$

Rd = $78.64 - 0.1991(PRL)$ \hspace{1cm} (4)

The majority of this article will focus on the results from the ALC samples, since it is unlikely that a commercial cotton gin would ever bypass the lint cleaners completely.

**After Lint Cleaning (ALC)**

Table 4 shows the mean and standard deviation values for all response variables evaluated. The fiber property values in table 4 are based on samples collected ALC. The Continental-141 ALC analysis produced significant fitted models to the same four variables as in the BLC analysis (AFIS length, SFC, ginning rate, and Rd). The ginning rate model was similar to the BLC analysis since the variable (ginning rate) was measured with the lint cleaner in operation as is not dependent on fiber property results obtained from any location in the process stream. The other models were similar to their BLC counterparts with the SFC data being similar to their BLC counterparts with the SFC data being similar to their BLC counterparts.

Similar to the BLC models, the AFIS length and Rd models contained only the PRL factor. However, the SFC model contained all the terms of the BLC model plus PRL$^2$. The non-significant (P > 0.1) SFC model terms included due to hierarchy were paddle roll speed (P = 0.64) and SFS (P = 0.27). Table 5 contains the mean, root mean square error (RMSE), $R^2$, adjusted $R^2$, predicted $R^2$, and signal-to-noise ratios for three of the four variables. The ginning rate model is excluded since it is the same as the one shown in table 3.

The $R^2$ value for SFC (0.94) was the best, with the other two models having $R^2$ values of 0.61 (AFIS length), and 0.70 (Rd). The predicted $R^2$ for AFIS length indicates that the model has only a 2.3% improvement in predicting new observations (35%) over the BLC model. The ALC Rd model had a predicted $R^2$ that was 3.8% lower than its BLC counterpart (53%). The predicted $R^2$ of the SFC model was 3.6% lower than it was for the BLC model but was still respectable (0.72). The signal-to-noise ratios for all models indicated adequate model discrimination from the noise in the data.

Overall, the AFIS length model was the weakest, creating concern as to whether inclusion of this variable in the optimization analysis would help or hurt the results.

Figures 2 through 8 contain three-dimensional (3-D) graphs and cube plots for all four models. These 3-D graphs show the effect that two factors have on the response, while the cube plots show the effect that three factors have on the response. Cube plots are useful for illustrating the effects of three factors at a time and are shown here using the minimum and maximum ranges of the factors in the plot. For example, the A+ in figure 5 is for the minimum PRL evaluated in the study (170 rpm), while the A+ is for the maximum PRL (230 rpm). It should be noted that the 3-D graphs are positioned to emphasize the curvature and shape of the response. Consequently, some of the graphs have the x- and/or y-axis increasing from the front-center to the edge of the graph, while others are decreasing. For example, figure 6 has the smallest x- and y-axis values in the front-center of the graph, while figure 3 has the smallest y-axis value (paddle roll speed) and largest x-axis value (seed finger speed) in the front-center of the graph.

The AFIS length graph was plotted using a paddle roll speed of 200 rpm. Figure 2 indicates decreasing fiber length as the load on the paddle roll increases. Because paddle roll density is directly related to seed roll density, increasing the density of the seed roll results in shorter fiber length. The reduction in fiber length, as a result of loading the gin stand (i.e., increasing throughput), follows the logic that “pushing” the equipment to its maximum production can adversely affect fiber quality. For a given PRL, seed finger speed did not alter AFIS length. The AFIS length model for the after-lint-cleaner analysis, in terms of the factors, was:

**Table 4. Mean, standard deviation (SD), and model terms for all response variables with the fiber property values based on samples collected after one stage of lint cleaning.**

<table>
<thead>
<tr>
<th>Variable$^a$</th>
<th>Units</th>
<th>Mean</th>
<th>SD</th>
<th>Model Terms$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFIS L(w)</td>
<td>cm</td>
<td>2.41</td>
<td>0.081</td>
<td>PRL, PRL$^2$</td>
</tr>
<tr>
<td>AFIS SFC(w)</td>
<td>%</td>
<td>10.12</td>
<td>2.90</td>
<td>PRL, PRL$^2$, SFS, PRL$^2$SFS, PRL$^2$SFS</td>
</tr>
<tr>
<td>AFIS neps</td>
<td>count/g</td>
<td>308</td>
<td>33.67</td>
<td>--</td>
</tr>
<tr>
<td>AFIS UQL</td>
<td>cm</td>
<td>2.95</td>
<td>0.043</td>
<td>--</td>
</tr>
<tr>
<td>AFIS seed coat neps</td>
<td>count/g</td>
<td>28.91</td>
<td>6.49</td>
<td>--</td>
</tr>
<tr>
<td>HVI length</td>
<td>cm</td>
<td>2.79</td>
<td>0.025</td>
<td>--</td>
</tr>
<tr>
<td>HVI uniformity</td>
<td>%</td>
<td>82.46</td>
<td>0.843</td>
<td>--</td>
</tr>
<tr>
<td>Ginning rate</td>
<td>bales/h</td>
<td>9.66</td>
<td>3.45</td>
<td>PRL, PRL$^2$</td>
</tr>
<tr>
<td>Rd</td>
<td>--</td>
<td>75.6</td>
<td>2.03</td>
<td>PRL</td>
</tr>
<tr>
<td>+b</td>
<td>--</td>
<td>7.68</td>
<td>0.323</td>
<td>--</td>
</tr>
<tr>
<td>Loan rate</td>
<td>$</td>
<td>0.544</td>
<td>0.007</td>
<td>--</td>
</tr>
<tr>
<td>Lint loss</td>
<td>%</td>
<td>12.99</td>
<td>1.30</td>
<td>--</td>
</tr>
<tr>
<td>Total VMD</td>
<td>count</td>
<td>11.28</td>
<td>4.10</td>
<td>--</td>
</tr>
</tbody>
</table>

[a] AFIS = Advanced Fiber Information System, L(w) = length by weight, SFC(w) = short fiber content by weight, UQL = upper quartile length, VMD = visible mechanical damage.

[b] Only statistically significant terms in the significant models are shown.

**Table 5. Model analysis data for AFIS length, short fiber content, and Rd response variables for the continental 141 power roll gin stand based on lint samples collected after lint cleaning.**

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Units</th>
<th>Mean</th>
<th>RMSE</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>Predicted $R^2$</th>
<th>Signal-to-Noise Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFIS length</td>
<td>cm</td>
<td>2.416</td>
<td>0.033</td>
<td>0.61</td>
<td>0.58</td>
<td>0.35</td>
<td>16.6</td>
</tr>
<tr>
<td>Short fiber content (SFC)</td>
<td>%</td>
<td>0.325</td>
<td>8.6E-3</td>
<td>0.94</td>
<td>0.90</td>
<td>0.72</td>
<td>29.2</td>
</tr>
<tr>
<td>Rd</td>
<td>--</td>
<td>75.6</td>
<td>0.510</td>
<td>0.70</td>
<td>0.68</td>
<td>0.53</td>
<td>28.0</td>
</tr>
</tbody>
</table>
AFIS length = $2.667 - 1.192 \times 10^{-2} \text{PRL}$ (5)

The SFC graphs are plotted using a paddle roll load of 20.5 amps (fig. 3) and a paddle roll speed of 200 rpm (fig. 4). Figure 3 shows a ridge of maximum SFC, with the greatest amount of short fiber (10.23%) occurring at the slowest paddle roll and seed finger speeds. The lowest SFC (6.46%) occurs when the paddle roll is in the 170 to 185 rpm range and the seed fingers are at 37 to 40 rpm.

As seen in figure 4, the largest SFC occurred at or near maximum load on the paddle roll regardless of SFS. The data presented in figure 2 coincide with the information seen in figure 3. That is, as the load increases, fiber length decreases. The figure also shows that as paddle roll load increases, so does SFC, regardless of the speed of either the paddle roll or seed fingers. Likewise, when the seed fingers were at their maximum speed, an increase in PRS increased SFC. Conversely, when the seed fingers were at their lowest speed, increases in paddle roll speed decreased SFC. The SFC model of the transformed data, in terms of the factors, was:

$$\text{AFIS SFC (transformed)} = 0.6143 + 5.7 \times 10^{-4} \text{PRS} - 0.0346 \text{PRL} + 5.4 \times 10^{-3} \text{SFS} + 7.6 \times 10^{-4} \text{PRL}^2 + 4.1 \times 10^{-5} \text{SFS}^2 - 2.5 \times 10^{-5} \text{PRS} \times \text{SFS} - 1.1 \times 10^{-4} \text{PRL} \times \text{SFS}$$

The ginning rate graph in figure 6 is based on an SFS of 25 rpm. Figure 7 shows the maximum ginning rate when the paddle roll speed and load are maximized, irrespective of seed finger speed. The lowest ginning rate, 3.53 bales/h, occurred at minimum load and maximum paddle roll speed, while the highest rate, 15.01 bales/h, was at the maximum paddle roll load and speed. The interaction between paddle roll load and speed is surprising because it was believed that an increase in either one would result in an increase in ginning rate. However, when the paddle roll load is at its minimum, and paddle roll speed is decreased, ginning rate increased from 3.53 to 6.47 bales/h. The results seen at the low paddle roll load may be due to the seed roll not being dense enough and turning too fast, thus not “pushing” the seed cotton fiber into the saw and thereby reducing ginning rate. The ginning rate model, in terms of the factors, was:

$$\text{Ginning Rate} = 8.18 + 10.59 \text{PRL} - 8.18 \text{PRS} + 6.46 \text{SFS} + 11.44 \text{PRL} \times \text{SFS}$$
Figure 6. Three-dimensional graph for ginning rate (bales/h) over the range of paddle roll loads (16 to 25 amps) and paddle roll speeds (170 to 230 rpm) evaluated.

\[
\text{Ginning rate} = 17.64 - 0.1471\text{(PRS)} - 0.3046\text{(PRL)} + 6.9 \times 10^{-3}\text{(PRS} \times \text{PRL)}
\]  

The Rd graph in figure 8 was plotted using a paddle roll speed of 200 rpm. The graph shows Rd decreasing as PRL increases, regardless of SFS. This result may seem surprising because the gin stand is not expected to have any influence on true color. However, other fiber quality factors evaluated (i.e., VMD and seed coat nep) and not evaluated in this study (i.e., dust and visible foreign matter) more than likely influenced the Rd results. As to the VMD and seed coat nep, both response variables had their highest values at the higher paddle roll loading rate. The model, in terms of the factors, was:

\[
\text{Rd} = 80.3 - 0.2178\text{(PRL)}
\]

**OPTIMIZATION**

For the optimization analysis, the response variables used in the analyses were weighted equally. For each set of lint quality data (BLC and ALC), different combinations of response variables (scenarios) were grouped together to determine how the inclusion or exclusion of certain response variables influenced optimal solution(s). In addition to the response variables, another factor included in the optimization was the propagation of error (POE). The POE is the amount of error in the response resulting from varying the factor (controllable variables) settings and can be determined for non-linear models. The POE was included in an effort to minimize error in the response variables and to evaluate its effect on the optimal solution(s).

**Before Lint Cleaning**

For the BLC samples, six scenarios were evaluated using desirability functions. Because the AFIS length analysis yielded a model with poor predictive capabilities (i.e., low predicted R^2), it was decided to remove the variable from some of the scenarios to determine its effect on the optimal solution(s). The scenarios consisted of constraining certain response variables within upper and lower bounds depending on the response variable. The response variables in each scenario (with their upper and lower constraints) were:

- **Scenario 1:** AFIS length (2.26 and 2.56), SFC (5.1 and 14.7), ginning rate (12 and 15), and Rd (70.9 and 77.2).
- **Scenario 2:** SFC (5.1 and 14.7), ginning rate (12 and 15), and Rd (70.9 and 77.2).
- **Scenario 3:** AFIS length (2.26 and 2.56), SFC (5.1 and 14.7), ginning rate (12 and 15), ginning rate POE, Rd (70.9 and 77.2).
- **Scenario 4:** SFC (5.1 and 14.7), SFC POE, ginning rate (12 and 15), ginning rate POE, Rd (70.9 and 77.2).
- **Scenario 5:** SFC POE and ginning rate POE.
- **Scenario 6:** All response variables and POEs. Same boundaries as those listed in scenario 1. The upper limit of VMD was constrained to 12.

The most desirable solutions for each scenario are shown in table 6. The results are carried out to one decimal place even though the values would be rounded when used in commercial facilities. Scenarios 1 and 2 and scenarios 3 and 4 resulted in similar optimal results except for SFS. The
difference between scenarios 1 and 2 and scenarios 3 and 4 was the inclusion of the AFIS length variable in the analysis. Due to the inclusion of AFIS length, scenario 1 had a 29.2% higher SFS than scenario 2, while scenario 3 had a 45.3% higher SFS than scenario 4. Scenarios 4 and 6 produced the same results, indicating that the addition of the other variables and their associated constraints were of no effect on the optimal solution. When just the POE variables were evaluated (scenario 5), the loading on the paddle roll motor decreased 17.6% from the loading rate seen in the other five scenarios.

After One Stage of Lint Cleaning

The same six scenarios evaluated for the BLC fiber quality data were used for the optimization analysis of the ALC fiber quality data. The response variables in each scenario (with their upper and lower constraints) were:

- Scenario 1: AFIS length (2.24 and 2.56), SFC (5.12 and 10), ginning rate (12 and 15), and Rd (72.3 and 78.9).
- Scenario 2: SFC (5.12 and 10), ginning rate (12 and 15), and Rd (72.3 and 78.9).
- Scenario 3: AFIS length (2.24 and 2.56), SFC (5.12 and 10), SFC POE, ginning rate (12 and 15), ginning rate POE, and Rd (72.3 and 78.9).
- Scenario 4: Same as scenario 3 with the exclusion of AFIS length.
- Scenario 5: SFC POE and ginning rate POE.
- Scenario 6: All response variables and POEs. Same as scenario 6 in the BLC analysis.

The most desirable solutions for each scenario are shown in table 7. Scenario 1 and 2 are the same regardless of whether or not AFIS length was included in the analysis. When the POE variables were added to the optimization analysis (scenario 3), the optimal settings with the largest options were PRS and SFS. The PRS went from 230 to 180 rpm, while the SFS went from 10 to 40 rpm. When AFIS length was excluded from the analyses with the POE variables (scenario 4), the PRS increased from 180 to 211 rpm and the SFS decreased from 40 to 10 rpm. The difference between the results for scenarios 3 and 4 emphasizes how one variable can alter the outcome. Likewise, because a single variable can have a dramatic impact on the final solution(s), the quality of the models predicting the response variables used in the optimization are crucial to obtaining meaningful results. In the case of AFIS length, the predicted R² of the model was only 0.349. Except for scenario 5, all seed finger speeds for the other setups are at either the minimum or maximum values of the ranges evaluated. Scenarios 1 and 2 have optimum settings for all three factors on the boundary limits for the ranges evaluated. Scenarios 3 and 6 are identical, implying that the inclusion of all the variables in the analysis (scenario 6) had no impact on the outcome.

The differences in the optimal solutions from the BLC to ALC analyses indicate the impact a single lint cleaner had on the optimal operational settings of the PRGS. When only the response variables of AFIS SFC, ginning rate, and Rd were used in the desirability functions, the results (scenario 2 in tables 6 and 7) indicate that the lint cleaner had no impact on the optimal solution. However, the impact of the lint cleaner was noticed when only the SFC and ginning rate POEs were used (scenario 5 in tables 6 and 7) due to changes in PRL and SFS. When all the variables were used in the optimization (scenario 6 in tables 6 and 7), the largest change resulting from the inclusion if the lint cleaner was associated with a 45% increase in SFS.

**Conclusion**

The powered roll gin stand is a new saw-type ginning technology that has shown promising results in studies evaluating its use in ginning seed cotton. Results from the various studies indicate a need to determine the optimal operational settings for various makes of gin stands. The various components of the PRGS have varying degrees of influence on production and/or fiber quality properties depending on their operational settings. The three primary components of the PRGS that need to be optimized are the paddle roll, saw, and seed finger roll speeds. Each of these factors has an effect on at least one variable of interest to a producer, cotton ginner, and/or textile mill.

Optimizing any multiple-response process involves a compromise among the response variables because improvements in one response may in turn adversely affect another. In the case of the PRGS, response surface methodology and desirability functions were used to evaluate the best overall settings of the gin stand’s three main components in order to produce the highest fiber quality possible while increasing ginning capacity and lint turnout. As is the case with most optimization studies involving multiple response variables, there is not a single optimal solution. Rather, the objective is to find the range of operational speeds that satisfy all the constraints based on the goals and objectives of the cotton gin’s management. For example, operational speeds that maximize fiber length and decrease short fiber content may in turn adversely affect some other factor of interest (i.e., turnout, ginning rate, and/or neps).

In this study, several optimal solutions were obtained for a powered roll gin stand installed and operated in a commercial cotton gin during the 2003-2004 ginning season. The optimal solutions varied depending on the response variables included in the analyses as well as the location (before or after the lint cleaner) at which the lint samples were collected. The response variables yielding reasonable mathematical models
were the same for the BLC and ALC samples: AFIS length, SFC, ginning rate, and Rd. When only these four variables were included in the optimization analysis, the optimal solutions were: PRS = 230 rpm, PRL = 25 amps, and SFS = 10 rpm for both the BLC and ALC analyses. When all response variables and propagation of error terms were included in the optimization analyses, the optimal solutions were: PRS = 180 rpm, PRL = 25 amps, and SFS = 18 rpm for BLC; and PRS = 180 rpm, PRL = 23.8 amps, and SFS = 40 rpm for ALC.

Additional studies to refine and further develop the mathematical models discovered in this study along with validation testing are currently being planned. Likewise, optimization studies for other makes and models of gin stands are being developed. Overall, the long-term potential for this technology is for the gin stand to become an integral part of a control system that adjusts settings, speeds, and ginning rates based on the variety and/or incoming quality of the seed cotton. The influence of the various components of the powered roll gin stand on production rate, turnout, and various fiber quality parameters need to be realized to a greater extent so control systems can be developed to take full advantage of this technology.

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