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RESULTS FROM OPTIMIZATION STUDIES PERFORMED ON THE POWERED ROLL GIN STAND - REPORT I

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Abstract

The powered roll gin stand has been evaluated in numerous studies in regards to increases in lint turnout and ginning rate without adversely affecting fiber quality properties. In some cases improvements in fiber quality over conventional gin stands were noted. However, the question remained as to what speed the various components of the power roll gin stand should be operated to optimize performance. The three main components of the power roll gin stand are: paddle roll, seed finger roll, and saw speed. This paper presents the results of an optimization study conducted on a power roll gin stand operating at a commercial cotton gin during the 2003-04 ginning season. The results are based on lint samples taken after one stage of lint cleaning, seed samples, and performance data. Of the thirteen 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 were: paddle roll speed = 180 rpm, paddle roll loading = 23.8 amps and seed finger speed = 40 rpm. The saw speed was held constant at 724 rpm.

Introduction

The Powered Roll Gin Stand is USDA-ARS patented technology (Laird, 2000) initially developed to remove the residual fibers from cottonseed for the EASI*flo*™ process (Laird et al., 1997). Various research studies have demonstrated the power roll gin stand as a potential means of improving 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: 1) the saw, 2) the paddle roll, and 3) the seed finger roll (Figure 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. Since each of these factors, and more, could have an impact in determining the ideal operational settings for a certain varietal cotton grown in a certain area and harvested 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.

During the 2003 season, eighteen gin stands were retrofitted with the power roll gin stand technology. The gin stands were located in seven cotton gins across the Continental United States (cottonbelt). Some of the cotton gins retrofitted all of their gin stands while others opted to evaluate the power 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 their gin stands was Servico Incorporated in Courtland, AL. 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 were: 1) 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; and 2) Define the response variables that have the greatest influence on the optimal solution(s).

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 16-inch 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:

1) Removing the 4 - inch, outside diameter, seed tube and replacing it with a 7 ¾ -inch paddle roll.
2) Cross-sectional area of the roll box was increased by 67 in^2 to accommodate the paddle roll.
3) Replaced the original seed tube drive, which was powered from the saw motor, with a 30 hp, 885 rpm North American Electric motor driving the paddle roll through a 3.85 to 1 gear reduction for a maximum paddle roll speed of 230 rpm.
4) Replaced the picker roll with a seed finger roll consisting of one hundred and forty-two 7-inch seed fingers which extended 2-inches in between the saws.
5) Replace picker roll drive, which was powered from the saw motor, with a 1750 rpm ¼ hp Baldor DC motor that powered the seed finger roll through a 43.75 to 1 gear box and chain sprocket reducer for a maximum speed of 40 rpm.

The original drive system for the saw and doffing brush were unchanged. The saw and doffing brush were powered by a 125 hp Elektrim motor. On 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 30 hp Allen Bradley, Model 1336. The seed finger motor was driven by a Leeson DC drive. 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 research conducted during the previous year (2002-03 ginning season). Therefore, for this gin stand, there were three independent variables: 1) paddle roll speed, 2) paddle roll loading rate, and 3) seed finger speed. The paddle roll loading rate is correlated to gin stand feed rate since the feeder output is governed by the load (amps) on the paddle roll and not the saw.

Experimental Design and Data Collection

The experimental design consisted of a face-centered central-composite design with three independent variables and thirteen response variables. The independent variables and their associated range of operation for testing were: 1) paddle roll speed (170 to 230 rpm), 2) paddle roll load (16 to 25 amps), and 3) seed finger speed (10 to 40 rpm). The operational ranges for the independent variables were selected based on operational limits the management at Servico Inc. felt the equipment could operate at without adversely affecting the ginning operation. The response variables were: 1) Ginning rate (lb/hr), 2) AFIS length by weight (inches), 3) AFIS short fiber content (%), 4) AFIS neps (count/gram), 5) AFIS upper quartile length (inches), 6) AFIS seed coat neps (count/gram), 7) HVI length (inches), 8) HVI uniformity index (%), 9) Reflectance (Rd), 10) Yellowness (+b), 11) Loan rate ($), 12) Seed lint loss (%), and 13) Seed visible mechanical damage (%). Turnout was not evaluated as a response variable for this testing since it would have required shutting down the other two gin stands and performing testing only on the gin stand being evaluated. Since turnout was not measured by the conventional means of dividing the lint weight by the weight of seed cotton, the seed lint loss was used as a surrogate for turnout.

The Continental power roll gin stand (PRGS) optimization study consisted of three blocks for a total of twenty runs. There were six runs in the first two blocks and eight in the third. The design was blocked by cotton variety. The varieties evaluated were: 1) Delta and Pine Land 451, 2) Paymaster 1218, and 3) Stoneville 5599. The design consisted of six center points, two in each block, and fourteen 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 due to the fact that the region of interest and region of operability were the same. Table 1 shows the FCD matrix, listed by block, used for optimizing the Continental PRGS with the three independent variables in engineering units. When performing the analysis for the individual response variables in the optimization studies, the backward elimination procedure and hierarchy principle was used to determine the model coefficients. The level of significance was set at 10 percent (i.e. alpha (a) = 0.1). A 90 percent confidence interval was selected because the risk associated with a 95 percent confidence interval, for this initial optimization study, was deemed to be too strict. The term risk is used in regards to not including a particular parameter in the model based on a p-value higher than 0.05. The optimization analysis was performed using Desirability Functions as detailed in Derringer and Suich (1980). Generically, 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 basic equipment layout: Module feeder, 96-inch Big J feedworks, (split 96-inch 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. The sample locations and type of sample taken were: 1) feeder apron – moisture can, 2) seed discharge from the gin stand – seed sample, 3) before lint cleaner – lint sample, and 4) lint slide – lint sample. The seed cotton in the moisture cans was analyzed in-house and dried using the 5-hour procedure listed in Shepard (1972). Lint samples were analyzed via the High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) at Cotton Incorporated's facility in Cary, North Carolina, and at the International Textile Center in Lubbock, Texas. Seed samples were analyzed for lint loss and visible mechanical damage at Delta and Pine Lands's 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 re-weighing the delinted seed. Lint loss is reported in percent 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 classes of 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 using the matrix in Table 1. The hypothesis was that the lint cleaner would influence the optimum settings. Since a gin stand is rarely, if ever, operated commercially without any 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 only one lint cleaner after the gin stand.

The procedures used for testing were as follows:

1) A phone conversation was held with the gin manager to explain what was going to take place, how long it might take, when the best possible date for testing might be, what would be required from them, what operational ranges of the three components would be used in the testing, and to determine the cotton varieties they would like to see the process optimized for in the event that the optimization was not robust for all the varieties they currently gin.
2) Upon arrival at the plant, the following conditions were verified prior to testing: check to ensure that they could spare the labor necessary to take samples, the test procedure, operational ranges of the equipment, cotton varieties to be used, plan of attack for completing the test in the timeframe specified, and a contingency plan in the event of a plant upset or other unforeseeable circumstance occurred.
3) A day before testing, the current ginning rate and setting of all three gin stands were documented, while ginning the three varieties to be used for the study, to obtain a baseline at which the other two gin stands would operate during the test. This was done so that the only gin stand that would be varied during testing would be the one being evaluated. Since ginning rate of the individual gin stands was not able to be obtained directly, this pretest procedure was carried out in an effort to calculate ginning rate of the gin stand being tested.
4) Prior to testing, assignments were given to each member of the "sampling team" which included: collecting lint and moisture samples, recording motor amps and kilowatts for the saw and paddle roll motors, recording the module number, variety of cotton, grower, number of bales obtained from the module, and time to gin the module;
5) Prior to the first test module entering the system, the speeds and loading rate were set for each of the three components with the speeds being validated by a hand-held Shimpo model DT-205B tachometer (Nidec-Shimpo America Corp., Itasca, Illinois);
6) Since Servico gins cotton in large blocks by grower (i.e. several modules from the same grower), the sample bags and cans associated with each block were set up at the assigned sampling locations prior to the arrival of the first module to be used in the test;
7) The ginner notified the sampling team when the first module of the test was starting to enter the system so that the individual manning the stopwatch could start timing;
8) The sampling team waited until the first bale from the selected module exited the press and then three samples for the first run were collected over a three bale period of time; three samples were collected for each run;
9) After ginning another two bales, samples for the second run were collected.
10) After each block of runs were completed, all the samples were collected and stored in a central location;
11) After all runs were completed, the samples were bagged and shipped to the USDA-ARS ginning laboratory in Lubbock, Texas.

Results

Regression and Model Analysis

Even though lint samples were collected before and after lint cleaning, this report will focus on the results based on the after lint cleaning (ALC) data. The Continental-141 ALC analysis produced 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 was modified using the inverse square root transformation.

Both the AFIS length and Rd models contained only the paddle roll load (PRL) factor. The SFC model contained the following terms: paddle roll speed (PRS), PRL, seed finger speed (SFS), SFS^2, PRS*SFS, and PRL*SFS. As a result of hierarchy, two nonsignificant terms ($P > 0.1$) were contained in the SFC model, paddle roll speed ($P = 0.6441$) and SFS ($P = 0.2716$). The ginning rate model contained three terms: PRS, PRL, and PRS*PRL. Only PRS was included due to hierarchy ($P = 0.7101$). Table 2 contains the mean, standard deviation, R-square, adjusted R-square, predicted R-square, 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 four (4) is desirable and indicates adequate model discrimination (Stat-Ease Inc., 2000).

The R-square term for SFC (0.94) is the best with the other three models having R-square values of 0.899 (ginning rate), 0.609 (AFIS length), and 0.698 (Rd). The predicted R-square for AFIS length indicates the model has limited ability to predict new observations (34.9%). The Rd model exhibited a mediocre predicted R-square of 0.53, while the SFC and ginning rate models had a respectable 0.72 and 0.81, respectively. 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 or not inclusion of this variable in the optimization analysis would help or hurt the results.

Figures 2 to 8 contain the three-dimensional (3-D) graphs and cube plots for all four models. In figures 2 through 8, the 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 in this report using the minimum and maximum ranges of the factors in the plot. For example, the A- in Figure 5 is for the minimum PRS evaluated in the study (170 rpm) while A+ is for the maximum PRS (230 rpm). It should be noted that the 3-dimensional graphs are positioned in such a way so as to emphasize 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 7 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. Since 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:

$$AFIS\ Length = 1.050 - 4.691E\text{-}3(PRL). \qquad (1)$$

The SFC graphs are plotted using a paddle roll load of 20.5 amps (Figure 3) and a paddle roll speed of 200 rpm (Figure 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 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 4 coincides with the information seen in Figure 2, as the load increases fiber quality suffers. Figure 5 shows the cube plot for the three factors evaluated. Figure 5 shows that as paddle roll load increases, so does SFC regardless of 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:

$$\begin{aligned} AFIS\ SFC\ (transformed) = {} & 0.6143 + 5.7E\text{-}4(PRS) - 0.0346(PRL) \\ & + 5.4E\text{-}3(SFS) + 7.6E\text{-}4(PRL)^2 + 4.1E\text{-}5(SFS)^2 \\ & - 2.5E\text{-}5(PRS * SFS) - 1.1E\text{-}4(PRL * SFS). \qquad (2) \end{aligned}$$

The ginning rate graph in Figure 6 is based on a 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/hr, occurred at minimum load and maximum paddle roll speed while the highest rate, 15.01 bales/hr, was at the maximum paddle roll loading and speed. The interaction between paddle roll load and speed is surprising since 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 the speed of the paddle roll is decreased, ginning rate increased from 3.53 to 6.47 bales/hr. The results seen at the low paddle roll load may be resulting from 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 is:

$$\begin{aligned} \textit{Ginning Rate} = {} & 17.64 - 0.1471(PRS) - 0.3046(PRL) \\ & + 6.9E\text{-}3(PRS * PRL). \end{aligned} \tag{3}$$

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 since the gin stand is not expected to have any influence on true color. However, other fiber quality factors evaluated (VMD and seed coat neps) and not evaluated in this study (dust and visible foreign matter) more than likely influenced the Rd results. As to the VMD and seed coat neps, both response variables had their highest values at the higher paddle roll loading rate. The model in terms of the factors is:

$$Rd = 80.3 - 0.2178(PRL). \tag{4}$$

Optimization – After One Stage of Lint Cleaning

In this study, six separate setups were evaluated using desirability functions. Since the AFIS length analysis yielded a questionable model, it was decided to evaluate several scenarios including various response variables in the analyses to see if it resulted in different optimal solutions. 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. Thus, AFIS length and Rd do not have POE's. This factor was included since it is desirable to minimize error in the response variables and to see how its inclusion influenced the optimal solution(s). The variables used in each scenario were:

1) Setup 1 – AFIS Length, SFC, Ginning Rate, and Rd.
2) Setup 2 – SFC, Ginning Rate, and Rd.
3) Setup 3 – AFIS Length, SFC, SFC POE, Ginning Rate, Ginning Rate POE, Rd.
4) Setup 4 – Same as Setup 3 with the exclusion of AFIS Length.
5) Setup 5 – SFC POE and Ginning Rate POE.
6) Setup 6 - All response variables and POE's.

The most desirable solutions for each setup configuration are shown in Table 3. The results are carried out to one decimal place even though the values would be rounded when used in commercial facilities. Setup 1 and 2 are the same regardless of whether or not AFIS length was included in the analysis (PRS = 230 rpm, PRL=25 amps, SFS=10 rpm). When the POE variables were added to the optimization analysis (Setup 3), the optimal settings with the largest changes were the PRS and SFS. The PRS went from 230 rpm to 180 rpm while the SFS went from 10 rpm to 40 rpm. When AFIS length was excluded from the analyses with the POE variables (Setup 4), the PRS increased from 180 to 211 rpm and the SFS decreased from 40 to 10 rpm. The difference between the results of Setup 3 and Setup 4 emphasizes how one variable can alter the outcome. Likewise, since 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 R-square of the model was only 0.349. Except for Setup 5, all seed finger speeds for the other setups are at either the minimum or maximum values of the range evaluated. Setups 1 and 2 have optimum settings for all three factors on the boundary limits for the ranges evaluated. Setups 3 and 6 are identical (PRS=180 rpm, PRL=23.8 amps, and SFS = 40 rpm), implying that the inclusion of all the variables in the analysis (Setup 6) had no impact on the outcome.

Conclusions

The power 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: 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 between the response variables since 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 power roll gin stand installed and operated in a commercial cotton gin during the 2003-04 ginning season. The response variables yielding reasonable mathematical models were: AFIS length, SFC, ginning rate, and Rd. When only these four variables were included in the optimization analysis, the optimal solution was: PRS = 230 rpm, PRL = 25 amps, SFS = 10 rpm. When all response variables and propagation of error terms were included in the optimization analysis, the optimal solution was: PRS = 180 rpm, PRL = 23.8 amps, SFS = 40 rpm. The optimal results were based on fiber quality results obtained after one stage of lint cleaning as well as production data. Three varieties were used in the study in an effort to create optimal solutions that were robust to varietal changes in cotton.

Additional studies to develop better mathematical models for other fiber quality parameters of interest are currently being planned. Likewise, optimization studies for other makes and models of gin stands are being developed. The next optimization report will emphasize the results from a study of a Lummus 116 gin stand retrofitted with the power roll gin stand technology. 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. If the only purpose in evaluating the powered roll gin stand is so that it can be set at specific operational speeds and loads regardless of the variety of seed cotton being ginned, the long-term potential of this technology would be missed. 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 the technology.

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Disclaimer

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

Standard Order	Block	Type	Paddle Roll Speed (rpm)	Paddle Roll Load (amps)	Seed Finger Speed (rpm)
2	1	Fact	230	16	40
3		Fact	170	25	40
6		Center	200	20.5	25
5		Center	200	20.5	25
4		Fact	230	25	10
1		Fact	170	16	10
10	2	Fact	230	25	40
9		Fact	170	25	10
8		Fact	230	16	10
11		Center	200	20.5	25
7		Fact	170	16	40
12		Center	200	20.5	25
17	3	Axial	200	20.5	10
15		Axial	200	16	25
16		Axial	200	25	25
18		Axial	200	20.5	40
14		Axial	230	20.5	25
19		Center	200	20.5	25
13		Axial	170	20.5	25
20		Center	200	20.5	25

Table 2. Model analysis data for the afis length, short fiber content, ginning rate, and rd response variables for the continental 141 power roll gin stand based on lint samples collected after lint cleaning.

Response Variable	Units	Model Data					
		Mean	Standard Deviation	R^2	Adjusted R^2	Predicted R^2	Signal to Noise Ratio
AFIS Length	Inches	0.951	0.013	0.609	0.584	0.349	16.55
Short Fiber Content (SFC)	%	0.325	8.6E-3	0.940	0.898	0.720	29.15
Ginning Rate	Bales/hr	9.66	1.30	0.899	0.879	0.807	15.86
Rd		75.6	0.510	0.698	0.679	0.530	28.02

Table 3. Most desirable optimum solutions for the setup scenarios evaluated for the continental-141, after lint cleaning.

Setup	Paddle Roll Speed (rpm)	Paddle Roll Load (amps)	Seed Finger Speed (rpm)
1	230	25.0	10.0
2	230	25.0	10.0
3	180.0	23.8	40.0
4	210.6	25.0	10.0
5	180.0	23.7	20.4
6	180.0	23.8	40.0

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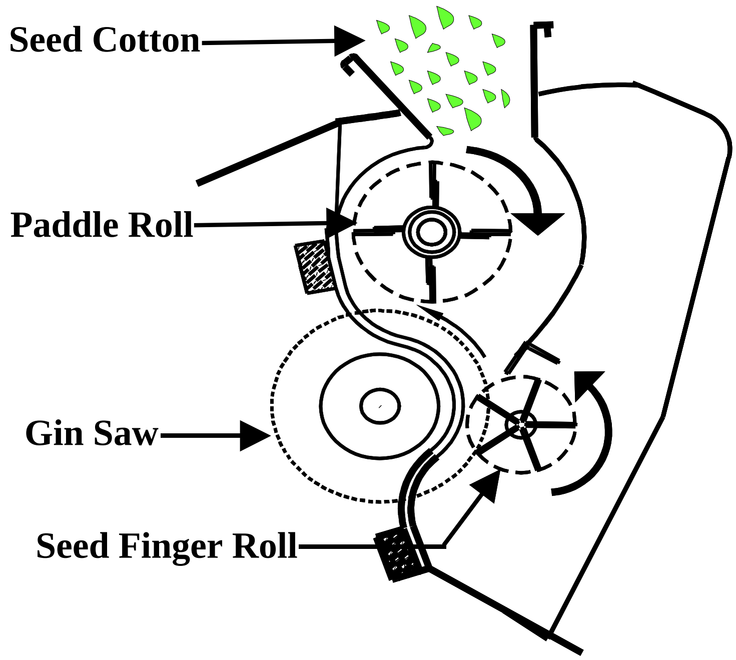

Figure 1. Schematic of the powered roll gin stand showing the paddle roll, gin saw, and seed finger roll components.

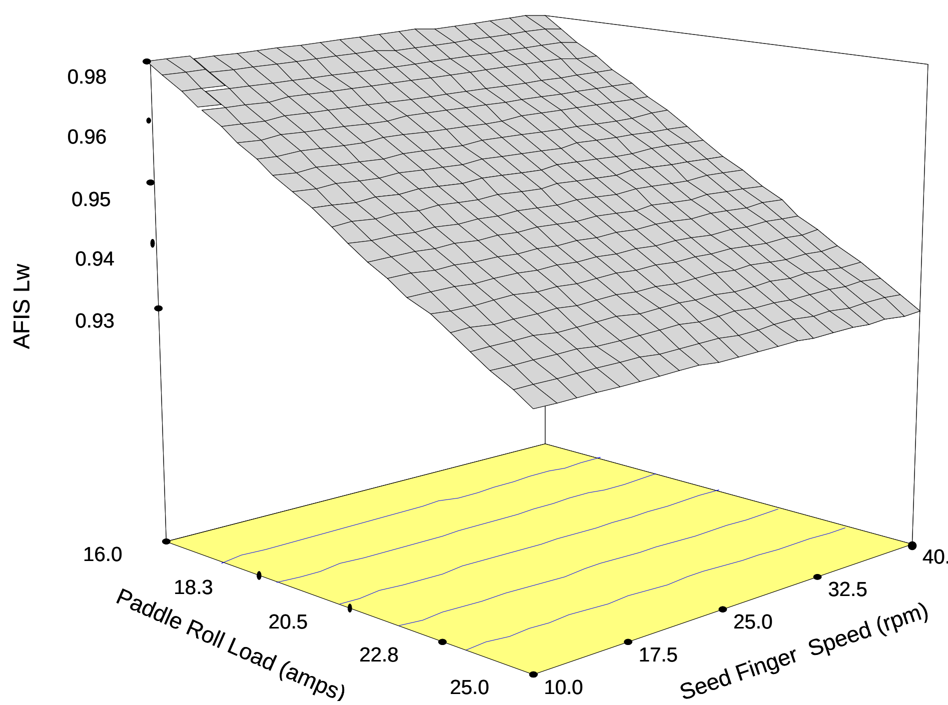

Figure 2. Three-dimensional graph for AFIS length over the range of paddle roll loads and seed finger speeds evaluated.

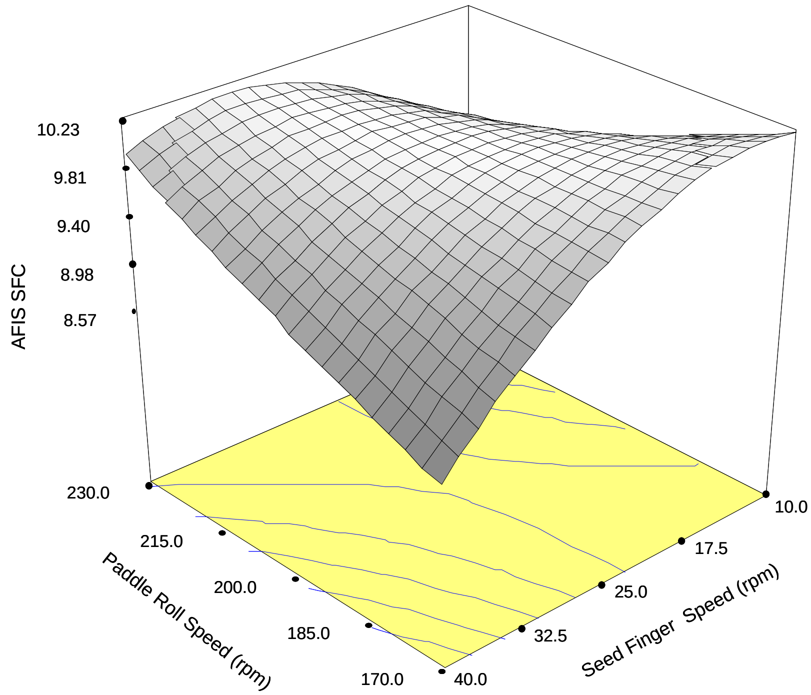

Figure 3. Three-dimensional graph for short fiber content over the range of paddle roll and seed finger speeds evaluated.

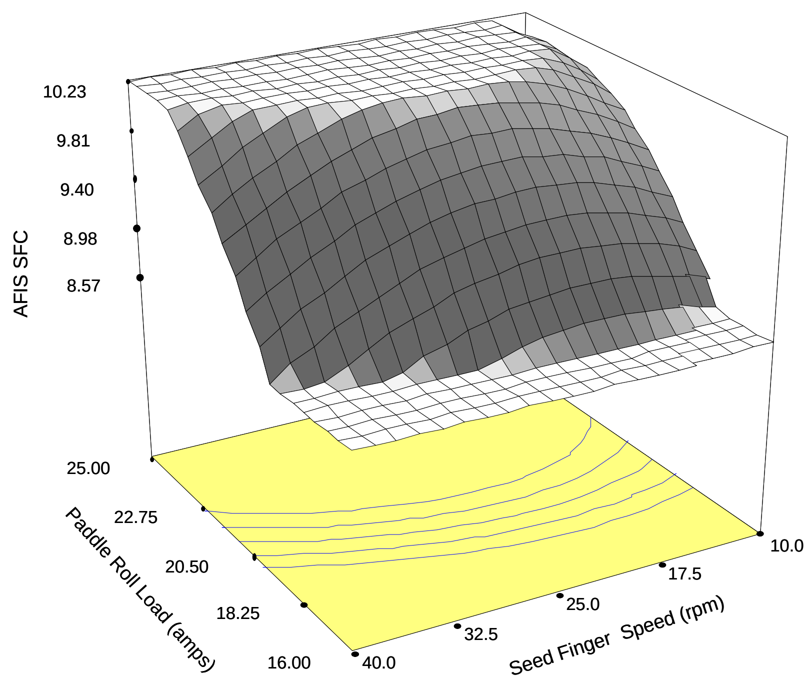

Figure 4. Three-dimensional graph for short fiber content over the range of paddle roll loads and seed finger speeds evaluated.

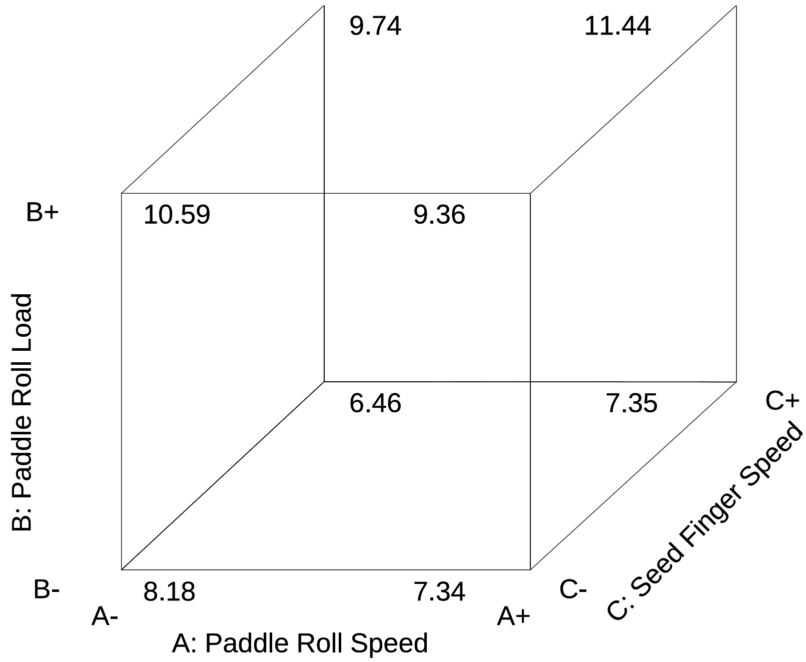

Figure 5. Cube plot for short fiber content over the range of paddle roll loads, paddle roll speeds, and seed finger speeds evaluated.

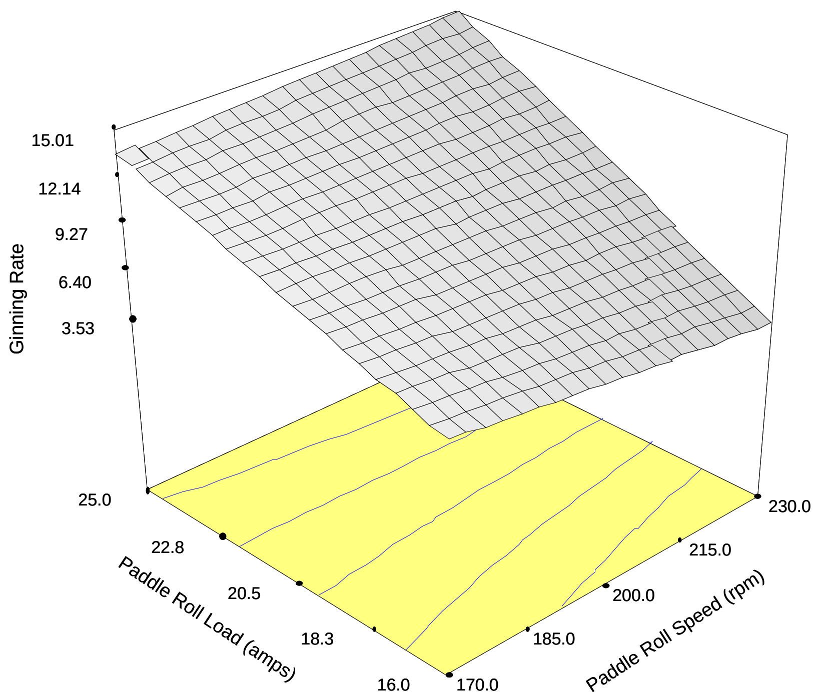

Figure 6. Three-dimensional graph for ginning rate over the range of paddle roll loads and paddle roll speeds evaluated.

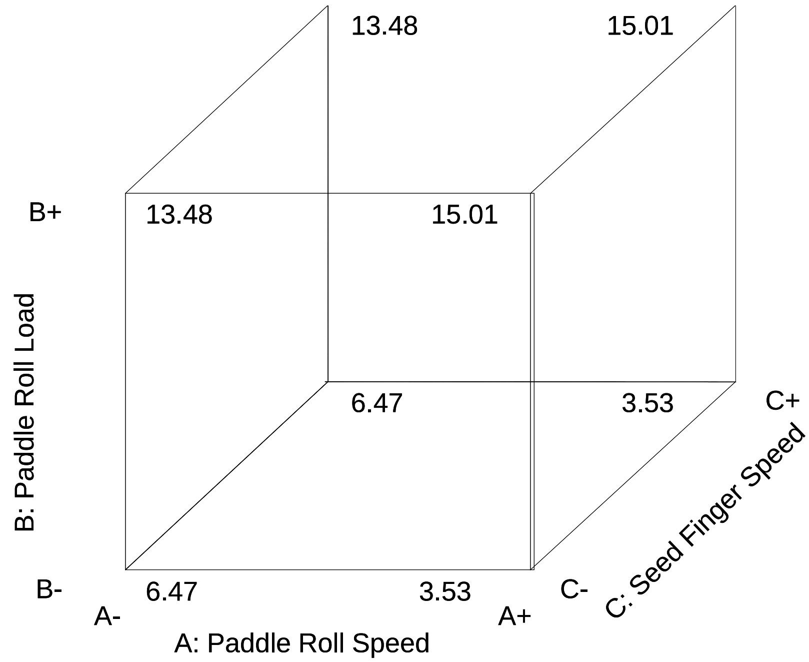

Figure 7. Cube plot for ginning rate over the range of paddle roll loads, seed finger speeds, and paddle roll speeds evaluated.

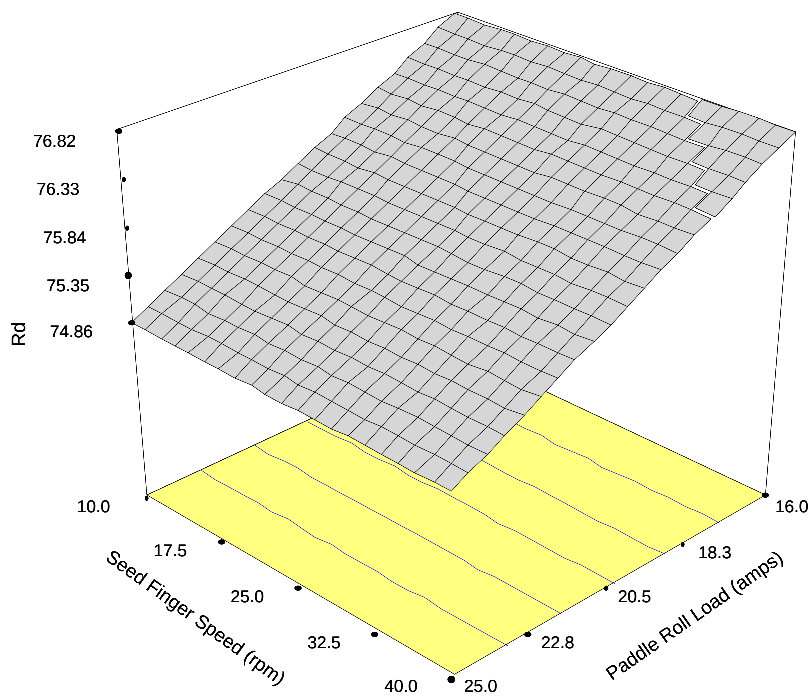

Figure 8. Three-dimensional graph for Rd over the range of paddle roll loads and seed finger speeds evaluated.