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ENGINEERING AND GINNING

Screening for Optimal Operating Parameters for the Powered Roll Gin Stand Using Taguchi's Robust Design

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ABSTRACT

The Powered Roll Gin Stand (PRGS) is a new saw-type ginning technology that has shown increased production and turnout without adversely effecting fiber properties. In some cases, improvements in fiber properties over a conventional gin stand were demonstrated. The new gin stand has three primary components: paddle roll, saw, and seed finger roll. The operational settings of these components have been shown to affect both production rates and fiber characteristics of the seed cotton being ginned. This research focused on screening for the optimal speeds and loading rates for the paddle roll, saw, and seed finger roll components of the PRGS, based on combinations of turnout, processing rate, and fiber quality data. An experiment using stripper-harvested seed cotton, with and without field cleaners, from two different fields (different growers) was evaluated using Taguchi's Method. Nine different operational setting configurations were selected for the gin stand's components. Evaluation was based on 11 response variables involving processing rate, turnout, and fiber quality measurements. In addition to screening for the optimum operational settings based on individual response variables, six different combinations of response variables were evaluated. Results varied depending on the response variable of interest. Overall, results indicated the most "robust" configuration included the 900 rpm saw speed. Other parameters of paddle roll speed, seed finger roll speed, and paddle roll loading rate varied based on the response variables. The results emphasized the potential application of this gin stand to a real-time dynamic control system that regulates operational parameters based on processing rate, turnout, and fiber quality goals and objectives.

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The Powered Roll Gin Stand (PRGS) is a patented design (Laird, 2000) that was initially developed to remove the residual fibers from cottonseed for the EASI*flo* process (Laird et al., 1997). It has been evaluated for use in ginning seed cotton (Laird et al., 2000; Laird et al., 2001). Results from the initial studies evaluating the effectiveness of the powered roll gin stand at ginning seed cotton demonstrated improved turnout and increased production rate per unit width. In addition to production and processing improvements, some fiber characteristics, such as staple length and length uniformity, were more favorable with the PRGS than with a conventional saw gin stand.

In addition to the previous research studies demonstrating the PRGS as a viable means of ginning seed cotton without adversely affecting fiber properties, results also revealed a number of operational settings that could further improve performance and fiber quality. The operational settings were for the saw, paddle roll, and seed finger roll, the three primary components of the PRGS. Figure 1 shows a cutaway schematic view of the three primary components. An initial evaluation of the optimal operational settings for these three components during ginning 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). The initial optimal setting study was performed with a single cultivar of cotton grown in one location and harvested with a cotton stripper without the use of a field cleaner. Even though the initial study was informative, it could be considered a "one-factor-at-a-time" approach. Because a variety of factors have the potential to influence the ideal operational settings of this new technology, it was decided to conduct an initial screening to determine which response variables might be beneficial in determining the optimum operational settings, so they would be insensitive (i.e. robust) to uncontrollable "noise" factors while maintaining high performance.

For this initial multivariate evaluation to determine the most robust operational settings for the PRGS, the Taguchi Method was used as the experimental design. Taguchi methodology has been widely practiced and documented (Taguchi and Wu, 1980; Box and Bisgaard, 1988; Phadke and Taguchi, 1988; Taguchi and Clausing, 1990; Kacker et al., 1991; McConnell and McPherson, 1997; Wilkins, 2000). In Taguchi's Method, the index of quality is measured according to the deviation of a characteristic from its target value (Mitra, 1998). These deviations from the target value are attributed to poor designs (i.e. combinations of controllable settings and materials) and disruptions from uncontrollable factors known as noise factors. The result is a loss of time and money to both manufacturer and customer. Taguchi believed that the loss of quality resulted in an ultimate cost to society. The Taguchi Method seeks to minimize the effect of noise while determining the optimal levels of the controllable factors based on the concept of robustness or Robust Design. Robust Design results in a product or process that is insensitive to the effects of sources of variability even when the sources themselves have not been eliminated. Robust Design requires the evaluation of controllable products or process control factors in the noisy environment from which the classical Design of Experiment (DOE) method seeks isolation (Fowlkes and Creveling, 1995). The objective is to create a product or process design that is insensitive to noise factors while being cost and performance efficient as a result of setting the key controllable factors at defined levels.

The main aspects of Taguchi's Method are essentially 1) the loss function, 2) the design array, and 3) the signal to noise ratio (Hsiang et al., 1997). Based on a Taylor Series approximation, the loss function increases as the quality characteristic deviates on either side of the target value. An important aspect of the loss function is that it maps deviations from the target into a financial measure (Schmidt and Launsby, 2000). The design array used by Taguchi is an orthogonal array that has its basis in fractional-factorials, Plackett-Burman, latin square, and mixed designs. The signal-to-noise ratio is the primary metric used for product or process optimization and represents the ratio of sensitivity to variability (Taguchi et al., 2005). The ratio can be used to determine quality or compare performance and is used to optimize the robustness of a product or process (Fowlkes and Creveling, 1995).

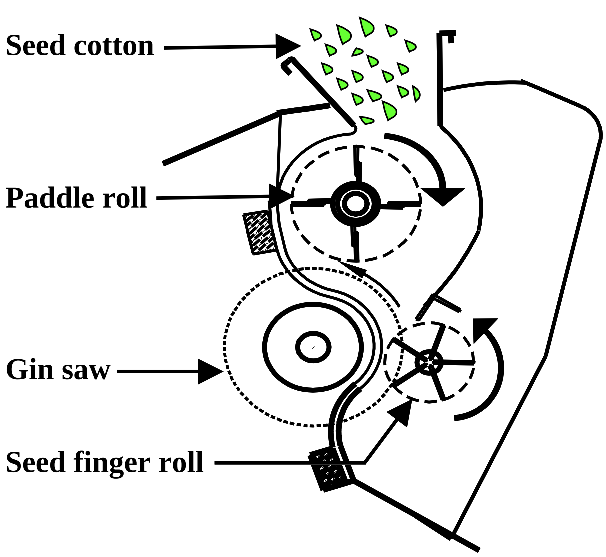

Figure 1. Schematic cutaway view of the powered roll gin stand showing the location of the paddle roll and seed finger roll relative to the gin saw.

Given variables, such as cultivar of cotton grown, harvest method, environmental conditions experienced by the crop during the season, fertilizer and chemical applications, etc., seed cotton received by a gin can vary tremendously in its quality and the ease with which it is processed. Because the PRGS is a new design recently introduced into industry, it was prudent to incorporate robustness into the initial screening of the optimal operational settings. An experiment was designed to determine the optimal operational settings using two commonly encountered noise factors when ginning stripper harvested seed cotton.

The objective of this study was to use Taguchi's Method as a screening tool to determine the most robust (insensitive to uncontrollable factors) settings for the paddle roll, saw, and seed finger roll components of the PRGS, while ginning stripper-harvested seed cotton based on production rate, turnout, and fiber quality measurements.

MATERIALS AND METHODS

Equipment. The first prototype PRGS was constructed by modifying a conventional 90- saw gin stand equipped with 30.5-cm (12-in) saws. The paddle roll consisted of four rubber strip paddles mounted on a 6.4-cm (2.5-in) schedule 80 pipe core resulting in a 21.6-cm (8.5-in) tip diameter. The paddle roll was installed in the center of the roll box. The gin stand was modified by making new rib rails and replacing the original ribs with narrower ribs to get a closer 1.59 cm (5/8 in) saw spacing. The saw spacers were trimmed to fit the narrow rib spacing, and 110 saws were installed on the original saw mandrel. The original gin stand roll box had a flattened oval shape. The modified roll box was pivoted up and back about 2.5 cm (1 in) at the top to give a shape that more closely matched the shape of the paddle roll. A new front was constructed for the gin roll box to replace the conventional huller front. The new front roll box shape was designed to allow a greater area of the saw to come in contact with the cotton. A driven rotating seed finger mechanism, known as the seed finger roll, was developed to improve the presentation of the cotton to the gin saws to allow increased contact and capture of the lint by the saws. The seed finger roll also aided in regulating the seed discharge from the gin stand.

The gin saw was powered by a 56 kW (75 hp) motor controlled by a variable frequency inverter. The 21.6-cm (8.5-in) diameter paddle roll was powered by a 11.2 kW (15 hp) motor, through an 8 to 1 gear reducer, attached to a variable frequency inverter. The 13.9-cm (5.5-in) diameter seed finger roll was attached to a variable speed drive powered by a 62.2 W (1/12 hp) motor through a 20 to 1 speed reducer.

Taguchi's method. The Taguchi Method is applied at the parameter design stage to establish optimal process settings or design parameters. Objectives of Taguchi's parameter design are 1) to make products and processes insensitive to environmental variations, 2) to make products and processes insensitive to manufacturing variations or imperfections, 3) to make products insensitive to product deterioration, and 4) to make products insensitive to unit-to-unit variations (Rowlands et al., 2000). To accomplish this, the signal-to-noise (S/N) ratio is the metric used to study the output quality characteristic in the presence of noise. Mathematical expressions of the S/N ratio are dependent on three situations: target is best, smaller is better, and larger is better (Mitra, 1998). The S/N ratio (ŋ) equations used for this study were the "smaller-is-better" and "larger-is-better" formulas as follows:

$$\text{smaller-is-better} \quad \eta = -10\log_{10}\left(\frac{1}{9}\sum_{i=1}^{9} y_i^{\,2}\right) \qquad (1)$$

$$\text{larger-is-better} \quad \eta = -10\log_{10}\left(\frac{1}{9}\sum_{i=1}^{9} \frac{1}{y_i^{\,2}}\right) \qquad (2)$$

where y_i was one of the nine observations.

The use of either smaller-is-better or larger-is-better was dependent on the response variable in question. The goal was to determine the operational settings that would maximize the relevant performance statistic.

To perform Taguchi's Method in the determination of optimal operating parameters for the PRGS, both controllable and noise factors had to be determined. Based on previous work (Holt et al., 2001), four controllable factors were chosen and varied over three levels. The controllable factors and their alternatives were as follows: 1) saw speed (550, 725, and 900 rpm), 2) paddle roll speed (120, 160, and 200 rpm), 3) seed finger roll speed (7.5, 10.5, and 13.5 rpm), and 4) paddle roll loading rate (16, 18, and 20 amps). A Taguchi's L_9 array was used to generate nine different operational setting configurations for the controllable factors. The L_9 array represents a design in which four factors are varied at three levels and is a fractional replicate of a full factorial design that needs 81 (3^4) experiments. Each of the nine operational configurations generated for the L_9 array were randomized (Table 1). Two noise factors, each varied over two levels, were selected for this

Table 1. Operational configuration for the selected levels of four controllable variables tested in this study (based on a Taguchi Method L_9 array)

Operational configuration	Paddle roll speed (rpm)	Saw speed (rpm)	Paddle roll loading (amps)	Seed finger roll speed (rpm)
1	120	550	16	7.5
2	160	725	20	7.5
3	200	550	20	10.5
4	120	900	20	13.5
5	200	900	18	7.5
6	160	550	18	13.5
7	200	725	16	13.5
8	160	900	16	10.5
9	120	725	18	10.5

study (Table 2). The noise factors and their levels were 1) where the crop was grown (field 1 or field 2) and 2) the method of stripper harvesting (with or without use of a field cleaner). The first factor "noise" was due to the fact that the fields were 4.8 km (3 mi) apart and operated by different producers using different production practices (i.e one producer took a "maximum" irrigation approach, while the other took a "minimum" irrigation approach to growing the crop). Since the primary variable influenced by the use of a field cleaner is trash level of the incoming seed cotton, the field cleaner "noise" was the condition of the seed cotton. Table 3 shows an example of the design matrix used for this study using the ginning rate data.

Even though other uncontrollable factors exist that can influence ginning, these factors were deemed to be prevalent for stripper-harvested cotton and for the most part uncontrollable. The uncontrollable nature of the location factor, variability resulting from two producers using different production practices, is self-explanatory. Some might argue, however, that the use of a field cleaner is controllable, and such arguments may be plausible under controlled laboratory conditions. Even though the use of a field cleaner is controllable, it is not cost effective for a gin to dictate to producers (their customers) whether or not they should use their field cleaners, if they have them, when harvesting their crop. Such a mandate could result in the loss of customers. The use of field cleaners is not solely based on whether or not producers have new or old equipment but on the preference of the producer. Thus, use of field cleaners is a physically controllable variable that is currently economically unfeasible to control.

Setup, testing, and data collection. The cotton cultivar used in this study was PayMaster 2326RR (Delta and Pine Land Co.; Scott, MS). The cotton

Table 2. Uncontrollable noise variables and their respective levels used in this study

Condition	Harvest equipment	Field location[z]
1	No field cleaner	Field 1
2	No field cleaner	Field 2
3	Field cleaner	Field 1
4	Field cleaner	Field 2

[z] The fields were operated by different producers approximately 4.8 km apart using different production practices.

Table 3. Ginning rate data shown in the design matrix (inner and outer arrays) used for each response variable evaluated in this study

Operational configuration	Ginning rate (bales/h)							
	Inner array[z]				Outer array[y]			
					1	1	2	2
	PRS	SS	PRL	SFS	1	2	1	2
1	1	1	1	1	5.91	5.51	5.48	6.03
2	2	2	3	1	6.79	6.89	6.49	7.72
3	3	1	3	2	5.36	5.64	7.04	6.34
4	1	3	3	3	6.39	7.12	7.57	7.42
5	3	3	2	1	7.46	7.53	7.58	7.57
6	2	1	2	3	5.59	5.91	6.52	5.74
7	3	2	1	3	6.32	7.24	7.25	6.69
8	2	3	1	2	6.67	7.30	8.61	6.74
9	1	2	2	2	6.49	6.50	6.47	7.26

[z] PRS = paddle roll speed, SS = saw speed, PRL = paddle roll load, SFS = seed finger roll speed. 1 = minimum operational level, 2 = mid-range operational level, 3 = maximum operational level.

[y] Outer array variables: 1 = no field cleaner for the top row and field 1 for the second row, 2 = field cleaner for the top row and field 2 for the second row.

was stored in a dry area and did not require drying prior to ginning. The average moisture content (dry basis) of the seed cotton at the feeder apron was 7.9% with a standard deviation of 1.3%. Moisture content was determined using the methods of Shepard (1972).

The machinery sequence for all pre-cleaning of the seed cotton and post cleaning of the lint was identical throughout the experiment. Seed cotton test lots, consisting of approximately 363 kg (800 lb) of non-field cleaned seed cotton and 249 kg (550 lb) of field cleaned seed cotton, were fed from the feed control bin at a constant rate through an inclined cleaner and stick machine, a second inclined cleaner and stick machine, and then to the distributing conveyor over the feeder above the PRGS. Upon exiting the gin stand, the lint proceeded through two saw-type lint cleaners. Three lint samples were obtained for each of the nine operational setting configurations after the gin stand and from the lint slide feeding the press.

Before each run, the variable frequency invertors operating the saw, paddle roll, and seed finger roll were set to the desired operational speeds (Table 1). The paddle roll loading rate was used as the set point for the control system. During the run, the control system regulated the feed rate from the gin stand feeder based on the paddle roll loading rate set point. In addition to controlling the seed cotton feed rate, the control system doubled as the data acquisition system and recorded information every 4 s. The data recorded included 1) saw and paddle roll motor power (kW), 2) saw and paddle roll motor current (A), 3) time of day, 4) saw and paddle roll motor frequency (Hz), 5) alarms (if any), and 6) set points for all speeds and loading rates. The seed finger roll was the only component that was not included in the control and data acquisition system. To control the seed finger roll, a variable speed control was manually set and the speed recorded with a hand-held tachometer.

Each lint sample was weighed and analyzed with the Advanced Fiber Information System (AFIS) and High Volume Instrument (HVI) fiber measurement systems at the Texas Tech University International Textile Center.

The following response variables were used for this study: 1) ginning rate (bales/h), 2) turnout (%), 3) AFIS length by weight (mm), 4) AFIS short fiber content (SFC) by weight (%), 5) AFIS upper quartile length (UQL)-wt (mm), 6) AFIS neps (count/g), 7) AFIS visible foreign matter (VFM) (%), 8) HVI length (mm), 9) HVI uniformity (%), 10) HVI Rd (grayness), and 11) HVI +b (yellowness). Even though lint samples were collected before and after lint cleaning, the results presented are only on those lint samples collected after the gin stand (i.e. before lint cleaning). Since this is the initial study using design of experiments to screen for optimal operational settings of the powered roll gin stand, it was decided to concentrate on the lint samples influenced by the gin stand alone and not those influenced by both the gin stand and the lint cleaners. Results from the after lint cleaning samples are planned for a future manuscript.

Even though other measurements, such as strength and micronaire, are important in determining the value of cotton, they were not deemed to be of primary significance as far as the gin stand itself is concerned. Strength and micronaire are minimally affected by the gin stand and are primarily determined by the cultivar planted and the growing conditions of the crop. Even though strength can be adversely affected by the overall ginning process, this is primarily due to excessive drying and/or improper moisture content of the seed cotton prior to ginning (Anthony and Griffin, 2001) and not the gin stand. The gin stands contribution to reducing strength can be reflected as an increase in SFC, which was used in the optimization analysis.

The value of lint in the bale, commonly referred to in terms of Commodity Credit Corporation (CCC) loan rate, is important to the producer. Since the loan rate value is based on multiple fiber properties (strength, micronaire, length, color, etc.) coupled with this study's focus on fiber properties based on lint samples obtained prior to lint cleaning (higher trash levels), it was decided not to use it as a response variable for this initial study. The loan rate value was used, however, to determine Taguchi's quality loss for a larger-is-better output response. The average quality loss function for a larger-is-better output response is as follows (Fowlkes and Creveling, 1995):

$$\overline{L(y)} = k\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad k = A_o y_o^2 \tag{3}$$

where:

A_o = customer loss ($)
y_o = customer tolerance ($)
y_i = one of the four observations for the respective operational configuration (OC).

Data analysis. The results were analyzed separately for every response variable. The response variables using the smaller-is-better performance statistic were SFC, neps, VFM, and +b. The remaining performance characteristics used the larger-is-better statistic. In addition to obtaining the individual S/N ratios, it was desirable to obtain optimal settings for combinations of the response variables that would include various combinations of all the response variables evaluated. For example, a cotton gin operator would want to maximize ginning rate and turnout while getting the best fiber properties possible. The response variable combinations (RVC) evaluated are shown in Table 4. The RVC mean and S/N ratios values obtained by normalizing the mean and S/N ratio for each response variable in the combination, multiplying them by a weighting factor, and summing the products of the response variables of interest (Equation 4). For each RVC evaluated, the response variables were equally weighted depending on the number of response variables in that particular combination. For example, the weighted S/N ratio for the first operational configuration (OC) (Table 1) in the second RVC (Table 4) was determined by inserting the corresponding S/N ratio values for ginning rate (GR), turnout (TO), HVI length (Lgt), uniformity (Unif), Rd, and +b into Equation 4.

Weighted S/N for OC 1 in the 2^{nd} RVC =
WF*(GR S/N 1÷GR S/N mean) +
WF*(TO S/N 1÷ TO S/N mean) +
WF*(Lgt S/N 1÷ Lgt S/N mean) +
WF*(Unif S/N 1÷ Unif S/N mean) +
WF*(Rd S/N 1÷ Rd S/N mean) +
WF*(+b S/N 1÷ +b S/N mean). (4)

where:

WF = weighting factor, determined by taking the inverse of the number of variables in the combination.

S/N 1 = S/N ratio for the 1^{st} OC of the corresponding variable

S/N mean = mean S/N value for the associated response variable

Once the normalized mean and S/N were calculated, the OC producing the highest S/N ratio was selected as the best OC for that RVC.

Table 4. Response variable combinations evaluated in this study

Response variable combination	Response variables in combination[z]
1	Ginning rate and turnout
2	Ginning rate, turnout, HVI (length, uniformity, Rd, +b)
3	Ginning rate, turnout, AFIS (length, SFC, UQL)
4	Ginning rate, turnout, AFIS (length, SFC, UQL, neps, VFM)
5	Ginning rate, turnout, HVI (length, uniformity), AFIS- SFC
6	Overall - all eleven individual variables listed above

[z] HVI = high volume instrumentation, AFIS = advanced fiber information system, SFC = short fiber content, UQL = upper quartile length, VFM = visible foreign matter. AFIS length, SFC, and UQL are by weight.

RESULTS AND DISCUSSION

Individual response variables. The optimal mean and S/N ratio for each response variable along with the observation that produced the corresponding peak value is shown in Table 5. The optimal value refers to the best or peak value for the given criteria used. For example, ginning rate was maximized (larger-is-better) whereas SFC was minimized (smaller-is-better). Of the eleven response variables evaluated, only turnout had different optimal operational settings for the mean and S/N ratio. All other response variables had the same operational configuration for both the optimal mean and S/N ratio. The difference in configuration between the mean and S/N ratio of the turnout indicated that even though OC 8 (Table 1) provided higher turnout (highest mean value), OC 5 resulted in a better combination of overall performance consistency (highest S/N ratio). For turnout, the operational settings for OC 8 had a slower paddle roll speed, higher seed finger roll speed, and a lower loading rate of the paddle roll than did the more robust OC 5. The saw speed, however, was the same (900 rpm).

In Table 5, the operational settings in the peak mean and peak S/N ratio columns that are the same color produced the same optimum operational settings for the individual response variables. Ginning rate and HVI uniformity had their peak mean at the same operational settings. Peak mean for ginning rate and turnout occurred at different operational settings with turnout having a slower paddle roll speed and lower paddle roll loading than ginning rate.

Ginning rate, turnout, and HVI uniformity had their peak S/N ratio at the same settings. The importance of knowing which variables may be maximized at the same operating conditions can help direct future research by potentially reducing the number of response variables, especially those that may take excess time and/or money to record.

Table 5 indicates that a variety of desirable OC's can exist depending on the response variable of interest. Rarely, however, would one of the response variables be singled out without consideration of other variables; therefore, it is of interest to know what role each component played in arriving at the peak S/N ratio operational settings shown in Table 5. Table 6 shows the relative effect (%) for each control factor on the variability of each response variable. This relative effect was calculated with the formula as follows:

$$\text{Relative effect (\%)} = \left(\frac{SS_{factor}}{totalSS}\right)*100 \qquad (5)$$

where:

SS_{factor} = sum of squares for the independent variable (factor)

total SS = total sum of squares

Saw speed had a large effect on seven of the eleven response variables evaluated: ginning rate, turnout, AFIS length, AFIS SFC, AFIS VFM, HVI Rd, and HVI +b (Table 6). The remaining response variables had either the paddle roll speed or paddle roll loading rate as the component with the largest effect in obtaining the peak S/N ratio. The paddle roll speed was the largest contributor to AFIS neps and HVI uniformity. Paddle roll loading rate had the largest contribution to AFIS UQL and HVI length. Even though seed finger speed was not the primary contributor to any of the response variables, it was the second largest influence on turnout and HVI uniformity. Table 6 does not indicate the direction of influence for the control factors on the response variables, only the amount of influence, in percentage, each factor had on the response variable in question. For example, turnout was primarily influenced by saw speed (56.1%), secondly by seed finger speed (36%), thirdly by paddle roll speed (6.9%), and minimally by paddle roll load (1%).

Table 7 shows how overall (all runs) mean and standard deviation for each response variable compares with the mean and standard deviation of the OC from Table 1, which resulted in the highest S/N ratio.

Response variable combinations. The normalized results corresponding to the RVC shown in Table 4 are shown in Figures 2 through 7. The figures indicate OC 5 is the most robust (highest S/N ratio) for all combinations except for OC 4 (Fig. 7). In addition to having the highest S/N ratio in five of the six combinations evaluated, OC 5 had the best overall mean for all the RVC evaluated. Whether or not the true optimal condition(s), or in this case the predicted optimum(s), was one of the OC evaluated or one of the other 72

Table 5. The best mean and peak signal-to-noise ratios for all the individual response variables evaluated in this study and the corresponding operational settings producing those values

Response variable[z]	Units of mean	Best mean	Operational settings for peak mean[y]	Peak S/N ratio[x]	Operational settings for peak S/N ratio
Ginning rate	bale/h	7.5	200, 900, 18, 7.5	17.5	200, 900, 18, 7.5
Turnout	%	29.2	160, 900, 16, 10.5	29.1	200, 900, 18, 7.5
AFIS length	mm (in)	23.5 (0.925)	160, 900, 16, 10.5	-0.678	160, 900, 16, 10.5
AFIS SFC	%	7.43	160, 900, 16, 10.5	-17.44	160, 900, 16, 10.5
AFIS UQL	mm (in)	27.9 (1.10)	120, 900, 20, 13.5	0.799	120, 900, 20, 13.5
AFIS neps	count/g	183.5	120, 725, 18, 10.5	-45.28	120, 725, 18, 10.5
AFIS VFM	%	2.61	120, 550, 18, 13.5	-8.54	120, 550, 18, 13.5
HVI length	mm (in)	26.8 (1.054)	120, 900, 20, 13.5	0.453	120, 900, 20, 13.5
HVI uniformity	%	83.14	200, 900, 18, 7.5	38.40	200, 900, 18, 7.5
HVI Rd	--	74.12	160, 550, 18, 13.5	37.40	160, 550, 18, 13.5
HVI +b	--	8.27	160, 550, 18, 13.5	-18.35	160, 550, 18, 13.5

[z] AFIS length, short fiber content (SFC), and upper quartile length (UQL) are by weight. VFM = visible foreign matter.

[y] The operational settings listed for both the mean and S/N ratios are for paddle roll speed, saw speed, paddle roll loading rate, and seed finger roll speed, respectively. Cells highlighted with the same color within a column have the same operational settings.

[x] S/N Ratio = signal-to-noise ratio.

configurations that comprise the full-factorial not evaluated needed to be determined. To determine the predicted optimum, the maximum normalized S/N ratio was selected for each component at the level where the maximum occurred. The results in Table 8 show the predicted optimums for each RVC compared with the optimal OC (Fig. 2 through 7) obtained with the fractional factorial design (L_9) used in this study. Table 8 shows that only the optimum for RVC 1 was equal to the predicted optimum. The predicted optimum for RVC 4 had a lower PRS and higher PRL than the OC shown in Figure 5. The other four RVC (RVC 2, 3, 5, and 6) had one independent variable in their OC, which was different from their predicted optimum.

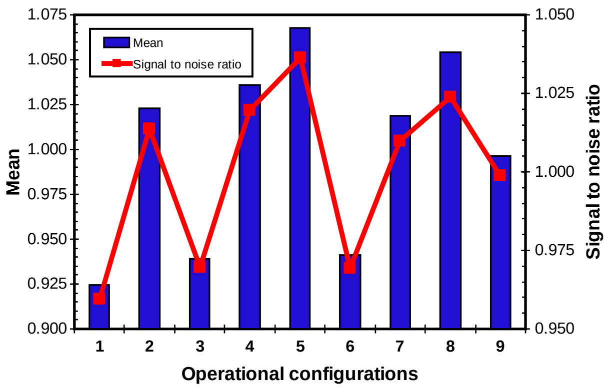

Figure 2. Weighted means and weighted signal-to-noise ratios for ginning rate and turnout (response variable combination number 1).

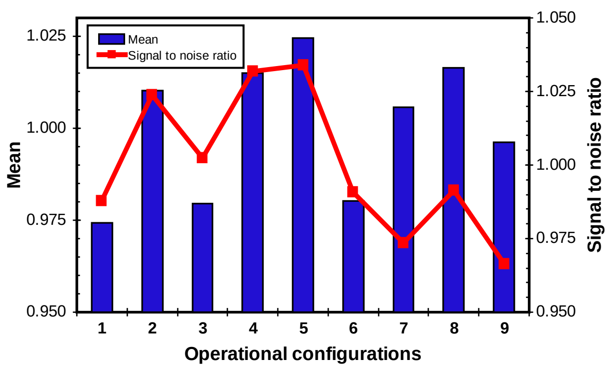

Figure 3. Weighted means and weighted signal-to-noise ratios for ginning rate, turnout, HVI length, HVI uniformity, HVI Rd, and HVI +b (response variable combination number 2).

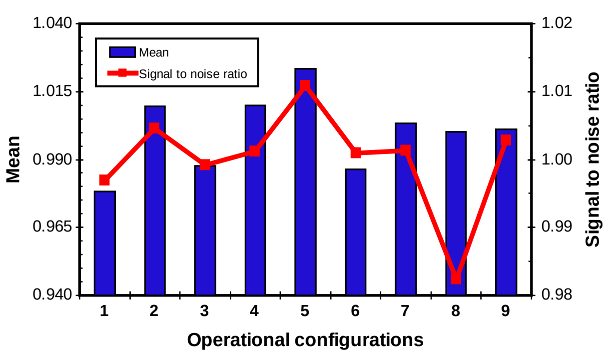

Figure 4. Weighted means and weighted signal-to-noise ratios for ginning rate, turnout, AFIS length, AFIS short fiber content, and AFIS upper quartile length (response variable combination number 3).

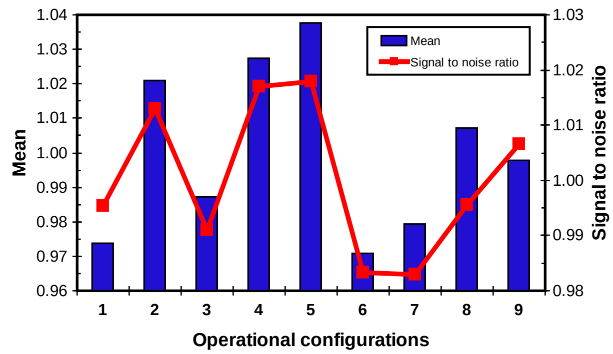

Figure 5. Weighted means and weighted signal-to-noise ratios for ginning rate, turnout, AFIS length, AFIS short fiber content, AFIS upper quartile length, AFIS neps, and AFIS visible foreign matter (response variable combination number 4).

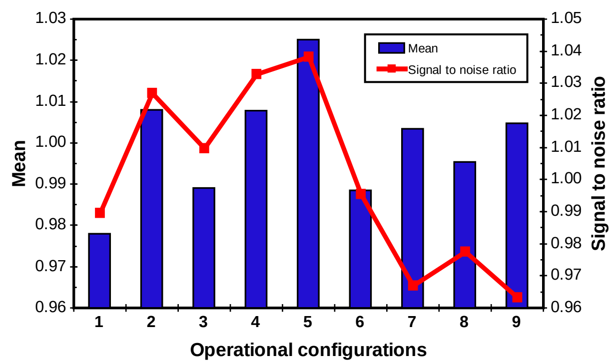

Figure 6. Weighted means and weighted signal-to-noise ratios for ginning rate, turnout, HVI length, HVI uniformity, and AFIS short fiber content (response variable combination number 5).

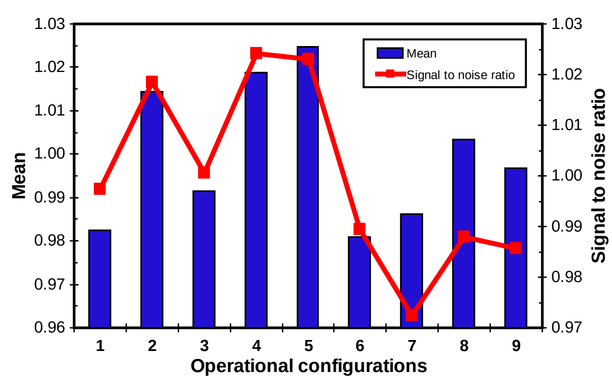

Figure 7. Weighted means and weighted signal-to-noise ratios for all eleven response variables evaluated (response variable combination number 6).

Table 6. The relative effect (in percentage) of each control factor on the variability of the measured response variable

Response variable	Paddle roll speed	Saw speed	Paddle roll loading	Seed finger roll speed
Ginning rate	4.29	94.65	0.59	0.45
Turnout	6.89	56.11	0.98	36.01
AFIS length	10.40	44.56	39.92	5.11
AFIS SFC	9.09	70.87	19.03	0.99
AFIS UQL	7.01	23.85	49.88	19.25
AFIS neps	38.55	11.12	36.65	13.66
AFIS VFM	22.17	52.46	8.62	16.74
HVI length	0.84	26.80	45.70	26.64
HVI uniformity	35.22	20.72	18.49	25.55
HVI Rd	23.45	56.64	2.74	17.15
HVI +b	13.23	77.16	1.18	8.40

Table 7. Mean and standard deviation of all the runs (overall) and the optimal operational configuration for each response variable

Response variable[z]	Units of mean	Overall mean[y]	Overall standard deviation	Optimal mean[x]	Optimal standard deviation
Ginning rate	bale/h	6.7	0.48	7.5	0.05
Turnout	%	28.8	4.40	29.2	4.94
AFIS length	mm (in)	23.2 (0.915)	0.201 (0.008)	23.5 (0.925)	0.270 (0.011)
AFIS SFC	%	8.5	0.46	7.4	0.65
AFIS UQL	mm (in)	27.6 (1.09)	0.238 (0.009)	27.9 (1.10)	0.273 (0.011)
AFIS neps	count/g	195.3	13.53	183.5	7.10
AFIS VFM	%	3.04	0.526	2.6	0.653
HVI length	mm (in)	26.6 (1.05)	0.246 (0.010)	26.8 (1.054)	0.309 (0.012)
HVI uniformity	%	82.8	0.47	83.1	0.64
HVI Rd	--	72.7	1.46	74.1	1.06
HVI +b	--	8.5	0.21	8.3	0.15

[z] AFIS length, short fiber content (SFC), and upper quartile length (UQL) are by weight. VFM = visible foreign matter.

[y] The overall mean and standard deviation for all runs.

[x] The optimal mean and standard deviation obtained from the operational condition with the highest signal-to-noise ratio.

It is interesting to note that all combinations (Table 8) have the seed finger roll at the minimum speed and all but RVC 3 (ginning rate, turnout, and AFIS length, AFIS SFC, and AFIS UQL) have the saw speed at the maximum of 900 rpm. The results in Table 8 further illustrate how operational settings of the gin stand can vary according to the emphasis placed on specific response variables, so various optimal operational settings could result based on the objective of the gin. For example,

1) If the emphasis is on ginning rate, turnout, HVI length, uniformity, Rd, and +b, the optimal setting may be a paddle roll speed of 200 rpm, saw speed of 900 rpm, paddle roll loading rate of 20 amps [100% of load for the 11.2 kW (15 hp) motor used to power the paddle roll], and a seed finger roll speed of 7.5 rpm.

2) If the emphasis was on ginning rate, turnout, AFIS length, short fiber content, and upper quartile length, the optimal setting may be a paddle roll speed of 200 rpm, saw speed of 725 rpm, paddle roll loading rate of 18 amps (90% of load), and a seed finger roll speed of 7.5 rpm. A total of six variable combinations were evaluated. These optimums are based on current design, tolerance limits of the components in the gin stand, and ranges of the parameters tested. Essential dimensions and design aspects of the PRGS are detailed in Laird et al. (2002).

Table 8. Predicted optimal operational configurations, based on the signal-to-noise ratio, of the six combinations evaluated in this study compared to the optimal operational configurations obtained from the fractional factorial (L_9) design used in this study

Response variable combination	Predicted optimums				Predicted results equal study results[z]	Variation of predicted results from study results[y]
	Paddle roll speed (rpm)	Saw speed (rpm)	Paddle roll loading (amps)	Seed finger roll speed (rpm)		
1	200	900	18	7.5	Yes	--
2	200	900	20	7.5	No	Higher PRL
3	200	725	18	7.5	No	Lower SS
4	120	900	20	7.5	No	Lower PRS and higher PRL
5	200	900	20	7.5	No	Higher PRL
6	120	900	20	7.5	No	Lower SFS

[z] Affirmation of whether or not the predicted optimal operational configuration was the same as that obtained from using the fractional factorial (L_9) design used in this study.

[y] How the predicted optimal operational configuration varied from the one obtained using the fractional factorial (L_9) design used in this study. PRS = paddle roll speed, SS = saw speed, PRL = paddle roll loading, SFS = seed finger roll speed.

Overall, the analyses indicated several potential optimal operational configurations depending on the variables of interest within the ranges of the parameters tested. The variation in the optimal operational settings, based on which production and fiber quality measurements were of interest, further emphasized the potential application of this gin stand to real-time gin process control. Real-time dynamic control of the gin stand to influence fiber grade and production is currently not being done in the ginning industry. Greene (1998) reported on the marketing advantage of using gin process control to add value to the spinner and thus add profits to the grower. Furthermore, McAlister (2001) reported on a study in which gin plant process control resulted in improvements in length, uniformity, strength, short fiber content, and neps.

One of the interesting findings of this study was that of the six optimal combinations evaluated only one did not indicate the optimal saw speed of 900 rpm. The importance of this would be setting the saw speed at 900 rpm and avoiding the costs associated with installing variable frequency inverters on saw motors 75 kW (100 hp) or greater. The data present in this study, however, was the initial evaluation. Future studies may indicate that any benefit of varying the saw speed outweighs costs associated with large frequency inverters.

Because the optimal saw speed of 900 rpm was at the upper limit of the range evaluated, it is important for future studies to validate whether or not the optimum saw speed is 900 rpm or higher. The reason for using 900 rpm as the upper limit was due to limitations of the existing equipment. Future evaluations are needed to verify that the optimum speeds and loading rates for the PRGS have been properly bracketed.

Taguchi quality loss function (larger-is-better). Figure 8 shows the mean quality loss ($) of each OC compared with the quality loss associated with the base loan value (Plains Cotton Growers, Inc., 2006). The customer loss in Equation 3 was calculated by taking the maximum ginning rate from Table 5 and multiplying by the amount of lint in a bale [227 kg (500 lb)], then multiplying by the base loan rate [$ 0.00113/g ($ 0.5160/lb)]. The customer tolerance was determined by taking the difference between the base loan rate at 41-4 and the value of the next leaf grad at 41-5 [$ 0.00108/g ($ 0.4940/lb). The results show OC 3 has smallest loss ($ 4.39) associated with quality (Fig. 8). Had the loan rate values for each of the four responses associated with each OC been at the base loan value [$ 0.00113/g ($ 0.5160/lb)], the loss would have been $ 4.56. Only two of the nine OC had higher quality losses than the base value, OC 8 ($ 4.58) and OC 9 ($ 4.73) (Fig. 8). The base loan line was included to give a reference point for the values and does not imply that operation of the powered roll gin stand using the seven OC that were lower would result in loan rates better than the base for all seed cotton. It is interesting to note that OC 3 does not correspond to optimal settings for any of the response variables in Table 5 or any RVC in Table 8, which illustrates the compromises necessary to obtain goals that may work in opposition to each other. For example, maximizing ginning rate and turnout may not produce the best fiber properties or result in the highest lint value.

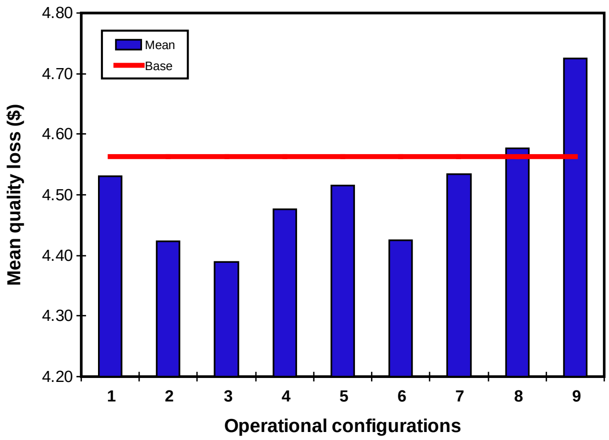

Figure 8. Average quality loss ($) for each operational configuration evaluated compared with the base loan value for the 2005-06 crop using Taguchi's larger-is-better case.

SUMMARY AND CONCLUSIONS

The powered roll gin stand (PRGS) is a new saw type ginning technology that has shown promising results in the initial studies evaluating its use in ginning seed cotton. To prepare this technology for transfer to industry, the optimal operational settings for the gin stand's three primary components need to be determined. The objective of this study was to conduct an initial screening that could provide groundwork necessary to determine the most robust operational settings for the paddle roll (speed and loading rate), saw (speed), and seed finger roll (speed). Each of these factors has an effect on at least one variable of interest to a producer or cotton ginner.

In this study response variables, such as ginning rate, turnout, HVI fiber properties, and AFIS fiber properties, were evaluated using Taguchi's Method. The response variables were evaluated individually and in six different select combinations. Taguchi's Method incorporates the variability (noise) brought about by input changes into the analysis of the design in order to design a system or process that is insensitive ('robust') to environmental conditions or component variations. The noise variables evaluated in this study included harvesting with and without a field cleaner and field location.

The most robust operational settings based on the individual response variables covered the spectrum of the speeds and loads evaluated. The most robust operating range seen, based on the operating ranges and conditions evaluated in this study, in a majority of the select combination of response variables was as follows: 1) paddle roll speed (rpm) = 200, 2) saw speed (rpm) = 900, 3) paddle roll loading = 100% of load (20 amps), and 4) seed finger roll speed (rpm) = 7.5. When lint value ($) was used to determine the quality loss associated with the operating conditions evaluated, the condition with the smallest loss was as follows: 1) paddle roll speed (rpm) = 200, 2) saw speed (rpm) = 550, 3) paddle roll loading = 100% of load (20 amps), and 4) seed finger roll speed (rpm) = 10.5. It should be noted that the solutions obtained in this study for the "select combinations" were based on equal weighting of each response variable and do not imply the "optimum" operating range for the PRGS. As the weighting of the response variables change, so do the "most robust" operating ranges. Findings in this study show that the "optimum" operational ranges for the PRGS are dynamic and primarily determined by the value placed on individual response variables. The wide range of response variables evaluated in this study helped focus the approach for future studies. Also, the results indicated the potential of the PRGS to be the first dynamically controlled gin stand using mathematical relationships of operational and fiber property parameters as part of a control algorithm tailored to gin cotton as close to customer specifications as possible given the state of the incoming seed cotton.

Based on the findings of this research and the growing importance of obtaining maximum production without compromising fiber quality, further research is needed to define mathematical relationships between production and fiber quality properties of interest and the operational settings of the powered roll gin stands components. In addition to defining the mathematical relationships, inclusion of other noise factors, such as cultivar, should be incorporated into future studies. These mathematical relationships in conjunction with the appropriate economic factors and/or Taguchi's loss function could potentially result in higher production rates, greater turnout, less fiber damage during ginning, and greater profits for the cotton gin and producer.

DISCLAIMER

Mention of product or trade names does not constitute an endorsement by the USDA-ARS over other comparable products. Products or trade names are listed for reference only.

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