DETERMINING SEED COTTON MASS FLOW RATE BY PRESSURE DROP ACROSS A BLOWBOX: GIN TESTING

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Abstract

A measurement of seed cotton mass flow rate would be useful to gin managers and enable the development of advanced process control systems for gins. A seed cotton mass flow rate sensing system was previously developed that performed well in the laboratory, but prediction errors were much higher when tested in a commercial-scale gin. Varying air leakage through the rotary valve above the blowbox was the likely source of increased error. The model for predicting mass flow rate was modified to incorporate an estimate of this air leakage. Mass flow rate was predicted based on the pressure drop across the blowbox; the air velocity, air density, and static pressure at the blowbox inlet, and the ambient air density (for negative pressure systems). The first- and second-stage seed cotton cleaning and drying systems of the commercial-scale gin at the Cotton Ginning Research Unit were instrumented to test the improved model. Air velocity, cultivar, dryer temperature, and seed cotton feed rate were varied to determine their effects on model accuracy. The mean absolute percentage errors in predicting mass flow rate were 5.32% and 2.46% for the first- and second-stage systems, respectively. Dryer temperature had a large effect and seed cotton feed rate had a smaller, but still significant, effect on the first-stage regression coefficients. The mass flow rate measurement system was installed in a commercial gin in 2014, and performed reliably. Much of the error observed at the commercial gin may have been due to the estimation of seed cotton weights from bale weights.

Introduction

Accurate, inexpensive measurement of seed cotton mass flow rate is both desired by cotton gin operators for proper management of the ginning process and needed as an input in improved process control systems for cotton gins. Optical mass flow rate sensors have been used on cotton harvesters, and some efforts have been made to develop this technology for use in cotton gins (Wilkerson, Moody, Hart, & Funk, 2001; Sui & Byler, 2012). However, these systems have not been tested in commercial gins. Practical disadvantages of optical systems in gins are the requirement to keep emitters and detectors clean and the need for multiple sensors at a single location in a large diameter duct. Furthermore, optical systems measure seed cotton mass flow rate by counting bolls or larger masses of seed cotton. Optical yield monitors for harvesters have been shown to have significantly different errors between cultivars (when compared to a reference scale) if not recalibrated (Taylor, et al., 2014). Likely sources of this error are differences in boll weight and the lint to seed ratio between cultivars. Because gins often do not know the cultivar being processed, and may switch cultivars frequently, optical systems may have large errors in measurements of seed cotton mass flow rate at gins that cannot be reduced by more frequent calibration.

Static pressure measurements are reliable, inexpensive, and currently used in many gins for process control. Consequently, several researchers have attempted to use pressure-based systems for mass flow measurement. Funk et al. (2000) showed that the differential static pressure in a vertical seed cotton conveying pipe was correlated to the mass flow rate. When this system was tested in a commercial gin, the model calibration R^2 was 0.95, while the model R^2 on a test set of data collected later in the season was 0.88 (Funk, Gillum, & Hughs, 2001). This testing was conducted on one-bale lots of cotton (approximately 635 kg [1400 lb] seed cotton), so some errors may average out with larger lot sizes. Additionally, no prediction error was given, and the effects of air velocity and temperature on the mass flow rate model were not tested. Mailander and Moriasi (2011) used the total static pressure at a specified location in a cotton harvester duct to predict mass flow rate, but the regression model errors were too large for use in a yield monitoring system. One drawback to either of these methods is that the variation in pressure due to changing mass flow rates would be small for the conditions occurring in a typical gin conveying pipe.

To address problems observed with other pressure-based systems, Hardin (2015) developed a mass flow measurement system based on the differential pressure across a blowbox, where seed cotton is fed into the conveying air and the pressure drop is largely due to the acceleration of the seed cotton. The regression model used accounted for differences in air velocity and temperature, and the mean absolute error in calibrating the model was 7.35%. The variation in the pressure drop across the blowbox over the expected range of mass flow rates was much larger than the variation in pressure measured by Funk et al. (2000; 2001) or Mailander and Moriasi (2011). Significantly more energy is required to accelerate the seed cotton than to overcome the friction of the air and seed cotton. However, when this system was tested in a commercial-scale gin, the mean absolute error in calibrating the model was higher, and air velocity, temperature, and seed cotton feed rate significantly affected the regression coefficients (R.G. Hardin IV, unpublished data). Further analysis indicated that varying air leakage through the rotary valve (commonly referred to as a vacuum dropper in the ginning industry) above the blowbox was the likely source of additional error, as the original model assumed that air leakage was proportional to the measured inlet air flow rate.

The objectives of this research were to:

- Develop an improved model for predicting mass flow rate, based on the pressure drop across a blowbox and incorporating an estimate of air leakage through the rotary valve
- Test the effects of feed rate, air velocity, dryer temperature, and cultivar on the improved mass flow rate model in a system similar to a commercial gin
- Identify further modifications needed to improve the accuracy of the seed cotton mass flow rate measurement system
- Evaluate the mass flow rate system in a commercial gin

Materials and Methods

Modeling

Equations have been developed to estimate air leakage through a rotary valve; however, these models have been developed for high, positive pressure systems (Dixon, 1981; Wypych, 2008). These models include variables describing the rotary valve geometry to apply generally and some are rather complicated. However, in these equations, the volumetric flow rate of air leaking through the valve is consistently proportional to the pressure difference across the dropper and inversely proportional to the density of the higher pressure air (the air that leaks through the valve):

$$Q_{leakage} = -\frac{k_{leakage}(SP)}{\rho^*} \tag{1}$$

where:

$Q_{leakage}$ = volumetric air flow rate into (positive) or out of (negative) rotary valve (m^3 s^{-1})
$k_{leakage}$ = leakage coefficient (m*s)
SP = pressure difference across rotary valve (Pa)
ρ^* = density of higher pressure air (kg m^{-3})

Because the mass flow rate model must be calibrated for each installation anyway, accurately describing the rotary valve geometry is not important for estimating air leakage. With an estimate of air leakage at the rotary valve, the mass flow rate and velocity of air through the blowbox can be calculated, using the measured inlet velocity and temperature. Density was calculated using the measured temperature, the standard atmospheric pressure adjusted for elevation, and dry air (at the temperature and humidity values found in gin conveying systems, this assumption introduces very little error).

$$v_{blowbox} = \frac{v_{inlet}\rho_{inlet}}{\rho_{blowbox}} - \frac{k_{leakage}(SP)}{A\rho_{blowbox}} \tag{2}$$

where:

$v_{blowbox}$ = air velocity through the blowbox (m s^{-1})
v_{inlet} = measured air velocity at the blowbox inlet (m s^{-1})
ρ_{inlet} = air density at the blowbox inlet (calculated from measured temperature, kg m^{-3})
$\rho_{blowbox}$ = air density in the blowbox (kg m^{-3})
A = cross-sectional area of pipe (m^2)

The density of air in the blowbox remains unknown, but was calculated. Because density was assumed to be inversely proportional to temperature (humidity and barometric pressure effects are small and ignored), the following expression results:

$$\frac{\rho_{blowbox}}{\rho_{inlet}} = \frac{T_{inlet}}{T_{blowbox}} \tag{3}$$

where:

T_{inlet} = measured air temperature at the blowbox inlet (K)
$T_{blowbox}$ = air temperature in the blowbox (K)

An expression for the temperature in the blowbox can be derived from the mass flow rates of the conveying air and air leakage across the rotary valve, and their respective temperatures:

$$T_{blowbox} = \frac{v_{inlet}\rho_{inlet}AT_{inlet} - k_{leakage}(SP)T^*}{v_{inlet}\rho_{inlet}A - k_{leakage}(SP)} \tag{4}$$

where:

T^* = temperature of higher pressure air (K)

If the static pressure in the conveying line below the rotary valve is more negative than above the valve, air at approximately ambient temperature leaks into the conveying pipe. If the conveying line is at higher pressure relative to the material infeed side of the valve, air leaks out of the conveying line, and the temperature and density of air in the blowbox will be approximately equal to the measured temperature and calculated density at the blowbox inlet.

The equation for the pressure drop through the blowbox was given by Hardin (2015, eq. 2), with the velocity and density used in the original equation measured at the blowbox inlet. The actual velocity and density at the blowbox should be used in the equation; however, the assumption was made that the measured inlet velocity was proportional to the blowbox velocity, so the difference in velocity would be accounted for in the regression analysis to specify model coefficients. Using the actual blowbox velocity and density results in the following equation:

$$\Delta p = \left(\frac{c}{v_{blowbox}} + \frac{k_s}{2}\right)\left(\frac{\dot{m}v_{blowbox}}{A}\right) + \frac{k_a\rho_{blowbox}v_{blowbox}^2}{2} \tag{5}$$

where:

Δp = total pressure drop across the blowbox (Pa)
c = maximum seed cotton velocity (m s^{-1})
k_s= friction loss factor for seed cotton through blowbox (dimensionless)
$\dot{m}$ = mass flow rate of seed cotton (kg s^{-1})
k_a = friction loss factor for air through blowbox (dimensionless)

Substituting equations 2, 3, and 4 into equation 5; solving for the mass flow rate of seed cotton; and combining constant terms (defined slightly differently than in Hardin (2015)) resulted in the following equation:

$$\dot{m} = \beta_1 \frac{\Delta p}{v_{inlet} - \beta_3 \frac{(SP)}{\rho^*}} - \beta_1\beta_2\rho_{inlet}v_{inlet} + \beta_1\beta_2\beta_3(SP) \tag{6}$$

where:

$\beta_1 = A/(c/v_{blowbox} + k_s/2)$
$\beta_2 = k_a/2$
$\beta_3 = k_{leakage}/A$

With no air leakage (SP = 0), equation 6 reduces to the equation derived by Hardin (2015). Because no reference method exists for measuring seed cotton mass flow rate, this equation must be integrated over the time that a known mass of seed cotton is conveyed through the system to determine the model parameters. Due to the β_3 term in the denominator, parameter values cannot be determined directly by integration and regression. A second-order Taylor polynomial was used to approximate the first term in equation 6 around SP = 0. The resulting equation was:

$$\dot{m} = \beta_1 \frac{\Delta p}{v_{inlet}} + \beta_1\beta_3 \frac{(\Delta p)(SP)}{(\rho^*)(v_{inlet}^2)} + \beta_1\beta_3^2 \frac{(\Delta p)(SP^2)}{(\rho^{*2})(v_{inlet}^3)} - \beta_1\beta_2\rho_{inlet}v_{inlet} + \beta_1\beta_2\beta_3(SP) \tag{7}$$

This equation could then be integrated over a test period, yielding the following equation for nonlinear regression analysis:

$$m = \beta_1 \Delta t \sum_{t=0}^{T} \frac{\Delta p}{v_{inlet}} + \beta_1 \beta_3 \Delta t \sum_{t=0}^{T} \frac{(\Delta p)(SP)}{(\rho^*)(v_{inlet}^2)} + \beta_1 \beta_3^2 \Delta t \sum_{t=0}^{T} \frac{(\Delta p)(SP^2)}{(\rho^{*2})(v_{inlet}^3)} - \beta_1 \beta_2 \Delta t \sum_{t=0}^{T} \rho_{inlet} v_{inlet} + \beta_1 \beta_2 \beta_3 \Delta t \sum_{t=0}^{T} (SP) \quad (8)$$

where:

m = total mass (kg) of seed cotton conveyed from time 0 to time T (s)
Δt = time interval between sensor readings (s)

Model performance was evaluated by comparing the known mass conveyed over a test period to the predicted mass conveyed over that time period (the integrated mass flow rate).

Ginning System and Instrumentation

Initial evaluation of the improved mass flow rate model was performed in the commercial-scale gin at the Cotton Ginning Research Unit (CGRU). A simplified schematic of the first-stage seed cotton cleaning and drying system is shown in Figure 1. An S-type pitot tube (160S-18; Dwyer Instruments, Inc.; Michigan City, IN) was installed in the center of the pipe from the burner outlet to the fan, as this was the closest location to the feed control with a sufficient length of straight pipe for an accurate measurement. Velocity pressure was measured with a Dwyer 607D-05 pressure transmitter. A type J thermocouple (NB1-ICIN-316U-12; Omega Engineering, Inc.; Stamford, Conn.) was installed after the pitot tube to measure the air temperature for calculating air density at the pitot tube and velocity. Because of the length of pipe and the fan between the pitot tube and blowbox, a second thermocouple was installed just prior to the blowbox to measure air temperature for calculating air density and velocity at the blowbox inlet. Static pressure taps were installed on the top side of the pipe at the blowbox inlet and outlet. The pressure drop across the blowbox was measured with a Dwyer 607D-06 pressure transmitter. While the model indicated that the pressure difference across the rotary valve should be measured (i.e. one tap in the blowbox and one in the feed control), preliminary data indicated that the model performed no better using this measurement than simply using the static pressure at the blowbox inlet. This result was likely due to near-atmospheric pressures above the rotary valve and turbulence induced by movement of the rotary valve. Consequently, the variable *SP* in the model was the static pressure at the blowbox inlet. A tee was installed in the tubing connected to this pressure tap, and the static pressure was measured using a pressure transmitter with bidirectional range (DPTA-20-15B; AutomationDirect; Cumming, GA.). A Dwyer RHP-2S11 temperature and relative humidity transmitter was installed near the burner inlet to record ambient conditions.

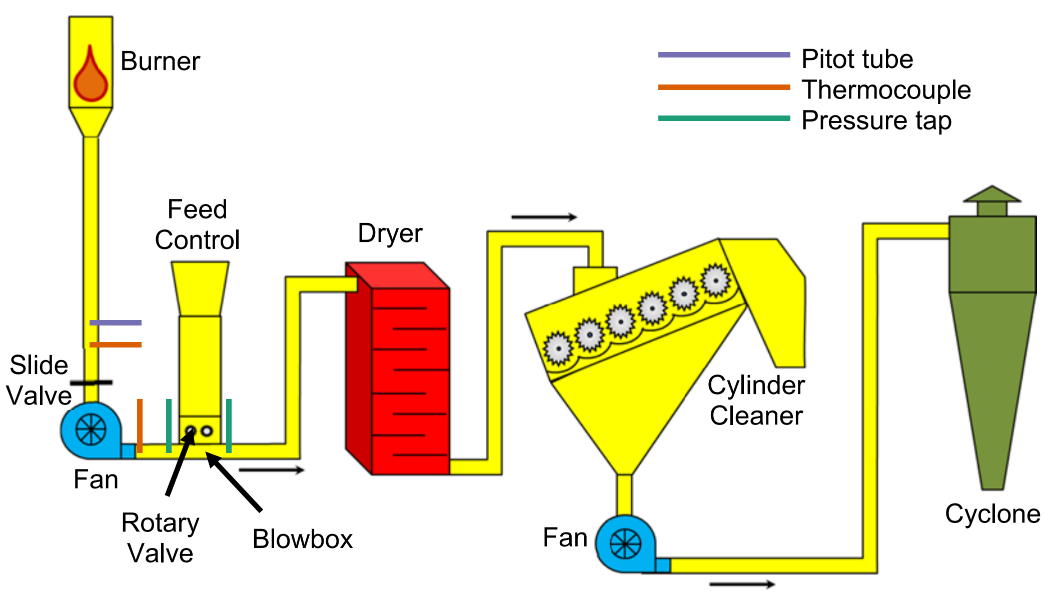

Figure 1. Schematic of the first-stage seed cotton cleaning and drying system in the CGRU commercial-scale gin.

The second-stage seed cotton cleaning and drying system was quite similar to the first-stage system. Seed cotton exited the stick machine (not shown, but located under the cylinder cleaner in Figure 1) and fell through a duct to the rotary valve. Therefore, a feed control was not needed. The first fan in the second-stage system was located farther from the blowbox; therefore, the pitot tube and thermocouple were installed closer to the blowbox and a second thermocouple was not needed. All other instrumentation was identical to the first-stage system. Sensor data was collected at 0.01 s intervals using the MATLAB Data Acquisition Toolbox (MATLAB R2014a; Mathworks, Inc.; Natick, Mass.) and a Measurement Computing USB-1616HS multifunction data acquisition device (Measurement Computing Corporation; Norton, Mass.).

Testing and Analysis

Conveying air velocity was varied by adjusting the slide valves in both the first- and second-stage systems. The two settings used on each slide valve corresponded to measured velocities of 17.8 and 22.9 m s^{-1} (3500 and 4500 ft min^{-1}) without cotton in the system and the dryers off. A hairy-leaf cultivar, ST 5458 B2RF (Bayer CropScience; Research Triangle Park, NC), and a semi-smooth-leaf cultivar, PHY 375 WRF (Dow AgroSciences, Indianapolis, IN), were used in this study. Two dryer temperatures (54 and 93°C [130 and 200°F]) and two seed cotton feed rates (averaging 59.4 and 97.8 kg min^{-1} [131.0 and 215.7 lb min^{-1}]) were tested. Each feed rate treatment corresponded to a specific feed control roller speed, so the actual feed rates varied slightly within a particular treatment level. The experiment was a split-plot design, with three replications used as main blocks, the air velocities as the sub-block, and a factorial combination of cultivar, dryer temperature, and feed rate tested within each sub-block. Air velocity was used as a sub-block because the valves were located in the gin basement and machinery had to be shut down to safely access the valves, requiring significant additional time.

Three samples were collected from each test lot for foreign matter and moisture content determination (Shepherd, 1972). The weight of each lot was randomly selected between 68.0 and 102.1 kg (150.0 and 225.0 lb) to provide a range of data for the regression analysis. The average weight of the test lots was 84.5 kg (186.4 lb), with a range of 71.0 to 100.4 kg (156.6 to 221.4 lb). All seed cotton in each test lot was conveyed to the feed control. The data acquisition system was started immediately prior to starting the feed control. Three moisture content samples were collected after the first-stage cylinder cleaner, to calculate moisture loss. Foreign matter removed by the first-stage cylinder cleaner and stick machine was collected and weighed. The amount of moisture and foreign matter removed was used to estimate the seed cotton weight entering the second-stage seed cotton cleaning and drying system. After all cotton in the test lot was processed through the second-stage blowbox (indicated by visual observation through a clear section of pipe farther downstream), the data acquisition system was stopped.

The five terms in equation 8 were calculated for each record and summated for the entire test run. Multiplying these values by the time interval between sensor readings produced the independent variables used in the subsequent regression analysis.

The nonlinear regression procedure (*PROC NLIN)* in SAS (SAS 9.2; SAS Institute, Inc.; Cary, NC) was used to generate estimates for the regression parameters β_1, β_2, and β_3. Predicted values for the total mass of seed cotton conveyed and the percent error in mass were calculated for each test lot. Model statistics, including R^2, root mean square error (RMSE), and mean absolute percentage error, were calculated to evaluate model accuracy. To examine the suitability of the model at predicting new values, the regression parameters were fit using two of the replications and the prediction error was calculated using the third replication. This cross-validation procedure was repeated using all three replications as the test dataset to provide an average value for the prediction error. A sum of squares reduction test (Hinds & Milliken, 1987) was used to determine if the models fit to data from individual treatment levels were significantly different. The residual errors for treatment levels of significantly different effects and the entire experiment were examined to identify any patterns that may indicate improvements needed to the model.

Commercial Gin Testing

The instrumentation for predicting mass flow rate was installed on the first-stage seed cotton cleaning and drying system at a commercial gin for the 2014 ginning season. Sensors were installed in the same locations as in the gin at the CGRU. Although the commercial gin had a negative pressure conveying system, the pitot tube was installed over 15 m (50 ft) from the blowbox due to the gin layout, and a second thermocouple was also used. Different ranges of pressure transmitters were used to measure the pressure drop across the blowbox (Dwyer 607D-05) and the static pressure at the blowbox inlet (Dwyer 607D-06). Sensor data was collected at 0.1 s intervals with a CR1000 data logger (Campbell Scientific, Inc.; Logan, UT).

The gin did not weigh modules or cottonseed; therefore, bale weights were used with an average turnout of 35% to estimate seed cotton weight for calibrating the model. Alternative values of turnout would scale the β_1 parameter, and do not affect the measures of model fit. If an incorrect average turnout value is used, subsequent application of the model to new data would result in erroneous predictions of seed cotton mass flow rate; however, these could be corrected by appropriately scaling the β_1 parameter if the correct turnout is determined.

Because gins process material continuously, total weights were calculated for periods of operation separated by at least five minutes of no seed cotton flow. An average estimated seed cotton weight of 78400 kg (172840 lb), with a range of 630 to 190840 kg (1390 to 420720 lb), was processed during a total of 41 of these periods. The gin frequently operated for several hours (in some cases, the entire shift) without stopping. When using this data alone to calibrate the model, the nonlinear regression procedure had difficulty converging on a solution and the model performed poorly at zero mass flow rate. Consequently, the dataset used for model calibration also included these shutdowns (25 total) for maintenance when the first-stage conveying fan was left on, but no seed cotton was processed. When the mass conveyed was zero, dividing both sides of equation 8 by β_1 removed the term from the model. The resulting equation was used in a nonlinear regression analysis to estimate β_2 and β_3. Using the data collected when material was conveyed and the estimates of β_2 and β_3, linear regression was used to estimate β_1. Similar to the test at the CGRU gin, model statistics were calculated.

Results and Discussion

The results of the regression analyses are shown in Table 1. The model predicted the conveyed mass more accurately for the second-stage system, despite the uncertainty in the initial mass due to estimating the moisture and foreign matter losses. Accounting for air leakage at the blowbox substantially improved model performance, as the mean absolute percentage errors were lower than the 7.35% reported in initial testing by Hardin (2015) or the testing of the original model in the commercial-scale gin (first-stage- 11.3%, second-stage- 10.4%; R.G. Hardin IV, unpublished data). Cross-validation errors were only slightly higher than the mean absolute percentage error calculated using all data. Frequent calibration may not be needed with the system, since results did not vary much between replications. Even though prediction accuracy was high for the first-stage system, R^2 was lower due to the limited range of weights used in fitting the model.

Table 1. Regression coefficients and model fit statistics.

Seed Cotton Cleaning and Drying System	β_1	β_2	β_3	R^2	RMSE (kg)	Mean Absolute % Error	Cross-Validation % Error
1st Stage	0.1057	0.5255	0.001129	0.574	5.71	5.32	5.37
2nd Stage	0.1154	0.4185	0.002036	0.904	2.60	2.46	2.57

Air velocity, dryer temperature, and seed cotton feed rate had significant effects (at the 5% level) on the regression model parameters for the first-stage system (Table 2). For the second-stage system, air velocity and seed cotton feed rate had significant effects on the regression model parameters. Similar to the previous study (Hardin, 2015), cultivar had no effect on the model.

Table 2. Effect of treatments on regression parameters.

Treatment	p-Value	
	1st Stage	2nd Stage
Air Velocity	0.0001	<0.0001
Cultivar	0.6066	0.4200
Dryer Temperature	<0.0001	0.0775
Feed Rate	<0.0001	<0.0001

While the effect of these treatments on the regression coefficients was statistically significant, only the dryer temperature and seed cotton feed rate for the first-stage system had a practically important effect, as evidenced by the mean residuals by treatment level (Table 3). The differences in the mean residuals of the treatment levels for air velocity with both systems or feed rate for the second-stage system were actually smaller than the differences in the mean residuals of the two cultivars (which had no statistically significant effect on the model parameters.

Table 3. Mean residuals (kg [lb]) by treatment level.

	1st Stage		2nd Stage	
	Low	High	Low	High
Air Velocity	0.23 (0.51)	0.69 (1.52)	0.35 (0.77)	-0.23 (-0.51)
Dryer Temperature	-3.97 (-8.75)	4.89 (10.78)	Not Significant	
Feed Rate	-0.95 (-2.10)	1.88 (4.14)	-0.07 (-0.15)	0.19 (0.41)

Plots of the residuals for the first-stage system by treatment level for air velocity, dryer temperature, and feed rate are shown in Figure 2, illustrating the differences in Table 3. No relationship between the residual values and lot weight was observed. The residuals for the second-stage system (not shown) exhibited no patterns in the residuals, either with lot weight or between treatment levels.

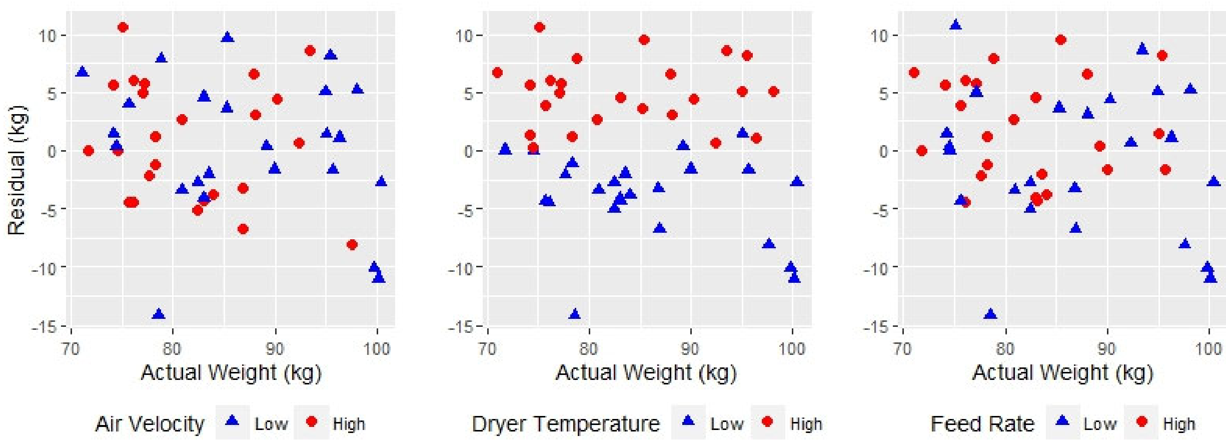

Figure 2. Residual plots by treatment level for the first-stage seed cotton cleaning and drying system.

A likely source of the remaining errors in model prediction was the difference between the blowbox air density value used in the model and the actual density in the blowbox. While the model accounted for air leakage into the blowbox, rapid heat exchange between the seed cotton and air was not considered. Heating the seed cotton and evaporating moisture will reduce the air temperature and increase the air density. This hypothesis is consistent with the improved model performance in the second-stage system because the seed cotton temperature is much closer to the air temperature and the moisture content is lower. A thermocouple can be installed in the blowbox to measure air temperature for calculating density. Incorporating the blowbox density requires slight modifications to the model; however, the form of the equation and the methods used to determine model parameters would not change. With a negative pressure conveying system, the measurement of ambient air temperature would no longer be needed, so the total number of sensors needed would not change. Further testing will be conducted to determine if measuring the blowbox temperature improves model performance.

Commercial Gin Testing

A plot of actual and predicted seed cotton weights is shown in figure 3. Model R^2 was 0.989 and the RMSE was 6850 kg (15100 lb). The mean absolute percentage error (only calculated for data points with mass flow) was 16.04%. However, the three data points with the largest percentage errors all consisted of less than five bales of cotton processed. While larger runs may average out some errors, much of the error on the smaller lots may be due to the difficulty in correlating bale and seed cotton weights (e.g. for a particular data point, the weights of three bales were associated with data collected from nearly four bales worth of seed cotton). Eliminating the four data points with less than five bales of data reduced the mean absolute percentage error to 7.73%. Much of the remaining error could be attributed to differences in turnout. For example, if the seed cotton weight was estimated at 150000 kg (330690 lb) with 35% turnout, the actual seed cotton weight would have been 138160 kg (304590 lb) if turnout was 38%, a difference of nearly 8%.

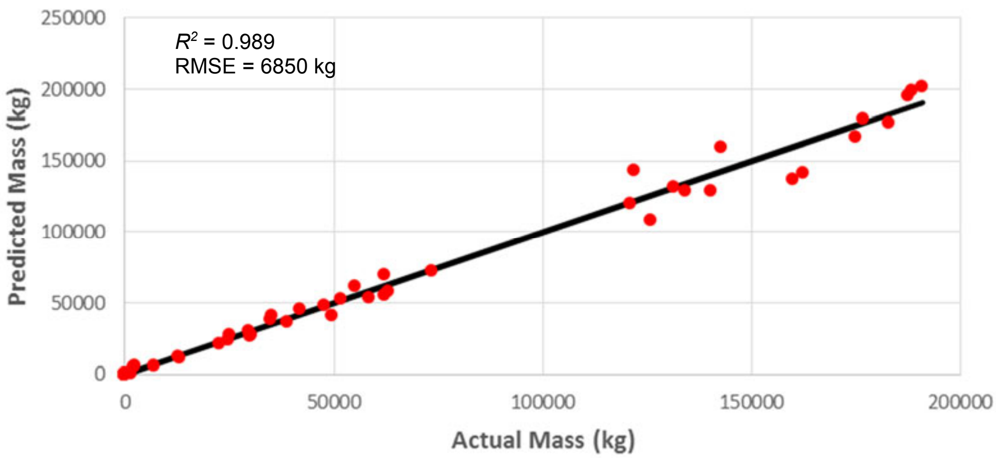

Figure 3. Predicted and actual weights (with 1:1 line displayed).

As expected, the system for predicting mass flow rate performed reliably during the ginning season, as thermocouples, pressure transmitters, and pitot tubes have been used in gin automation and control for many years. The two-step calibration procedure for the model may have additional benefits in installation of a commercial version. Programming a nonlinear regression procedure into an industrial controller may not be possible due to hardware or cost limitations. The initial calibration step could be done when installing the system during the off-season, as data could be collected for a range of air flow rates and dryer temperatures, without conveying seed cotton. The nonlinear regression could then be done using commercial computer software. The final calibration step is a simple linear regression and would be done by the controller once the gin operator had entered a sufficient number of module weights during the ginning season.

Conclusions

The mass flow model was modified to account for air leakage through the rotary valve at the blowbox. Model performance was significantly improved, as the mean absolute percentage errors were 5.32% and 2.46% for the first- and second-stage systems, respectively. Dryer temperature had a large effect and seed cotton feed rate had a smaller, but still significant, effect on the first-stage regression coefficients. A likely source of error was a lower air temperature and higher air density in the blowbox than estimated due to rapid heat exchange between the seed cotton and air. Additional testing will be conducted incorporating a measurement of the blowbox temperature. The system for predicting mass flow rate performed reliably in a commercial gin and much of the model error may have resulted from estimating seed cotton weights from bale weights. Further testing in commercial gins with module weights is needed to properly evaluate the system.

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Disclaimer

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