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METHOD OF ESTIMATING BALE MOISTURE CONTENT AFTER MOISTURE RESTORATION

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Abstract

Proper control of the moisture restored to ginned lint before it is baled in commercial gins requires accurate moisture sensors. In this study two resistance-based moisture content (mc) indicators were used, one located before moisture was added and the other after moisture was added with humidified air. Regression relationships that predicted the mc of samples measured by the oven method within ±0.24% were developed. The algorithm was verified using additional data collected at a later date.

Introduction

Moisture has been intentionally added to lint after ginning for at least 50 years (Griffin and Harrell, 1957). Griffin and Harrell achieved different levels of moisture restoration, but measured the moisture content (mc) by the oven method and thus could not control it while ginning. More recently Anthony and Byler (1997) documented the use of a microwave-based instrument to measure the mc in cotton bales and Anthony (1998) described a method to use the bale geometry and force required to form the bale in the press to estimate the fiber mc.

Interest in restoring moisture to lint after it is ginned has grown over the past few years. Until recently only a small amount of moisture could be added to the lint so control of the moisture addition was not an issue. Improved humidification equipment capable of adding more moisture than before coupled with the desire to achieve higher mc levels in the bale have created a situation where control of the moisture addition is essential. No process can be controlled which cannot be measured, so a system to quickly and accurately measure the mc of lint after the moisture addition is needed. In current systems the moisture is added either before it reaches the lint slide or on the lint slide, so the mc could possibly be measured as the bale is being formed or soon after it is formed. A reliable and accurate bale mc sensor could be used for feedback to automatically change the control settings of the device that provides the moisture or could be used as an indicator that the ginner would use to optimize the settings. For control of the moisture addition, multiple readings per bale would be preferred to one reading per bale and the sooner the measurement is made after the moisture addition the better.

A resistance-based lint mc sensor developed by the Agricultural Research Service (Byler and Anthony, 1995; Byler and Anthony, 1996) has been used for several years with the “Intelligin” gin control system marketed by Zellweger Uster, Inc. This sensor has been used successfully to control the drying performed in gins (Byler and Anthony, 1997). Each resistance-based mc sensor used in this project consisted of multiple stainless steel strips embedded in a plastic base, figure 1, and connected to appropriate electronics. The resistance between these strips while they were pressed against the cotton sample indicated the sample mc. The sensors are highly sensitive to the surface moisture of the lint. Restoring moisture to cotton with humidified air results in moisture predominately on the surface of the fiber that results in an incorrectly high mc reading with these sensors.

Two of these mc sensors were used in this study; one located between the gin stand and the lint cleaners before moisture restoration, and the other on the bale press tramper after moisture restoration. Different cotton is contacted for each stroke of the tramper while ginning, making this an excellent approach to sampling the cotton. The tramper produces very good contact between the cotton and the sensor during the second half of each bale but measurements are unavailable during the first half of each bale. For a “typical” gin with 30 bale per hour operating speed this cycle of approximate one minute of no data and one minute of available data should not present a problem for the slow adjustment of moisture addition with proper software.

The purpose of this study was to develop a method of predicting the final mc of lint after moisture restoration with humidified air.

Materials and Methods

The data collection for the algorithm development was conducted on Feb. 22 and 23, 2001 in the "full size" gin at the US Cotton Ginning Laboratory at Stoneville, MS. A Continental 93 Double Eagle gin stand was used at 6.7 bale per hour ginning rate. A 9-foot long lint slide grid, figure 2, was installed in the gin with ducting from a Samuel Jackson Humidaire moist air generator, figure 3, to the grid to add moisture to the lint as desired. An additional Humidaire unit previously installed in place of the burner for the second stage drying was used to add moisture prior to fiber-seed separation when desired. This system of moisture addition was used to generate different moisture regimes during the test. It was theorized that the resistance moisture meter installed on the tramper would respond differently to moisture located on the surface of the lint fibers compared to moisture held within the fibers and that resistance-based sensors located before and after the moisture addition could be used to predict the lint mc. These moisture control regimes were designed to test this theory. During the formation of three bales the lint was wetted with a water spray on the lint slide (Mangialardi and Griffin, 1965; Hughs, et al., 1994).

After the algorithm was developed based on the data collected Feb. 22 and 23, additional data were collected on May 15 and 16 to verify and refine this measurement approach. During this period various humidity levels of air were used to condition the lint after the lint cleaners, but no moisture was added in the second tower.

Test Design and Sampling

The algorithm development was conducted using a randomized complete block experimental design with three varieties as blocks and moisture treatments as the main effect. Two bales were ginned consecutively as observations within each replication. The varieties used were Stoneville BXN 47, Stoneville 4892 BR and Suregrow 747. Each of the bales consisted of about 1500 lb of seed cotton to achieve about 500 lb of lint. All cotton used for the study was grown in Washington Co., MS and had been spindle harvested.

For the algorithm testing, seed cotton of varieties Deltapine 5409 and Stoneville BXN 47 were used. Varying amounts of moisture was added to the lint after the lint cleaner, including three bales when no moisture was added.

The sampling was the same for both portions of the study. Physical samples (5 per bale) were taken for the determination of initial seed cotton mc at the feed control and lint mc by the oven method (Shepherd, 1972) in the charge hopper at the end of the lint slide after moisture addition. All mc readings were calculated wet basis.

Data Collection Equipment and Software

A lint sampling station was located between the gin stand and the lint cleaners that measured the lint mc by the resistance method, similar to the system used by the "Intelligin" system, figure 4.

The resistance moisture sensor located in the tramper, figure 5, was controlled with a digital signal and replied with a pulse for each of eight channels, the width of which was related to the mc of the lint pressed against the electrodes. The area of the moisture sensor was 24 in^2 and a force transducer, with maximum rated capacity of 1000 lb, was installed between the moisture sensor and the tramper to measure the force exerted on the lint during mc measurement. The AC output from the bale press controller, which activated the hydraulic solenoid causing the tramper to compress the lint, was connected to the data logging system.

The counter/timer board had 20 16-bit counters. These were configured as eight 32-bit counters, with four 16-bit counters left unused. These eight 32-bit counter/timers were used to time the eight separate pulses from the resistance moisture meter by counting a 1MHz clock available on the board. The output of the force transducer was recorded with the use of a 12-bit A/D converter board.

The purpose of the software was to provide control of the data collection process, to display basic data for monitoring of the system, and for logging of the data for subsequent analysis. The mc sensor was set to begin measuring when the force on the moisture sensor exceeded 100 lb. The mc measurement ended when all 8 channels of the resistance moisture meter were complete or when the force decreased to less than 80 lb to ensure that no measurements would be made with inadequate contact between the lint and the electrodes.

The calibration of the resistance moisture meter predicting the mc based on the pulse width was adjusted because of known changes in the hardware. This calibration was used to linearize the input data to predict an indicated mc. The theoretical indicated range of the meter was from 20.3% (with a pulse of about 19 microseconds) down to about 4.7% (with a pulse of about 1 second). The mc sensor was checked with two calibration blocks equipped with resistors for each channel. These blocks had been used with standard Intelligin resistance moisture meters and had been found to be functional and accurate. The check showed that all channels of the meter were functional and agreed with the others to within ±0.25%.

Air at 200°F was used for all bales in the test at the first drier. If moisture was not added in the second drier the air temperature before the mix point was set to 150°F. If moisture was being added in the second drier the Humidaire water temperature was set to 97°F and the air temperature before the mix point was set to 105°F. When moisture was being added at the lint slide the air temperature was set to 105°F and the water temperature was set to 102°F.

Results

The data logged by the data collection system were examined to determine which data went with which bale and was further analyzed to determine the mean of the readings for each set bale ginned. No observations made while ginning the test bales were removed from the data set.

Control of MC of Material

The mc of the seed cotton used to develop the model entering the gin was 8.7% and did not vary significantly during the test. The lint mc data for the two locations ahead of the moisture restoration at the lint slide were averaged across all similar conditions to produce Table 1. The data included 12 bales for no moisture added at the second drier and 12 bales when moisture was added to the seed cotton at the second drier. The data showed that a measurable difference (1.4%) in moisture was achieved in the lint before the lint cleaners.

Table 2 shows the means of the measurements of lint taken from the charge hopper of the bale press. One of the goals of the experimental procedure was to get different mc levels under controlled conditions. The means in this table were different from each other based on the controlled conditions (within columns), so this goal was met.

The mc of the seed cotton used in the first 15 bales ginned in May averaged 8.5% and the last two averaged 11.2%.

Measurement of Lint Moisture in the Bale Press

The mean of the mc measurements made by the resistance meter on the tramper by humidity treatment were compared to those made by the oven method, Table 2. There were between 250 and 350 individual resistance based measurements per bale in the data set. When no moisture was added at the lint slide, the reading by the resistance method was about 1% higher than that made by the oven method and this difference was the same whether moisture was added in the second drier or not. The reason why the reading was so much higher with the resistance meter may have been related to the force exerted by the tramper on the sample. Increasing the contact force is known to increase the mc reading for the resistance meter. When a portable resistance moisture meter using a 15 lb dead weight was used to measure the mc, the mean of the readings with only drying were 4.5% and when humidification was used at the second drier and no humidification was employed at the lint slide the mean was 5.4%. These results compare well with the data by the oven method.

The oven-based mc data showed that the lint mc was about 0.7% higher at the lint slide when moisture was added at the second drier. Based on the oven-based mc, about the same difference due to moisture added in the second stage of drying was evident in this data as in the data where no moisture was added at the lint slide, 4.4 raised to 5.1 and 5.5 raised to 6.2. For the data when moisture was added at the lint slide the means of the data obtained with the meter on the tramper were about 5.4% higher than those from the oven method. When the data for the two treatments for which moisture was added at the lint slide were examined, the relationship between the data for the resistance moisture meter and the oven method were very different.

The measurements at the different locations were compared by regression. The mc measured by the oven method of samples obtained from the charge hopper was predicted with the data from the resistance moisture meter on the tramper. The resulting residual mean square was 0.29, but when the software was allowed to use two equations, one for tests with no moisture added at the lint slide and the other for the tests when moisture was added with the Humidaire, the residual mean square dropped to 0.20. This is evidence that there were differences in the measurements made with the tramper related to the application of the moisture at the lint slide. The cotton variety did not contribute significantly to the regression.

The mc data by the oven method for samples taken from the charge hopper were predicted based on a linear model including the tramper mc measurements and the mc measured ahead of the lint cleaners with the resistance meter. Fitting this model to the data resulted in a residual mean square of 0.17.

When the data for the three bales for which a water mist was applied with nozzles much of the resistance mc data indicated mc higher than could be measured with the meter. This was attributed to excessive water being deposited from the lint on the sensor, which shorted out the electrodes used to measure the resistance. These results showed that the sensor could not be used reliably in the tramper when liquid water was applied with nozzles without more development work. Thus, those three bales were not used in further analysis.

Algorithm Testing

The regression model developed with the data collected in Feb. was used to predict the mc based on measurements between the gin stand and the lint cleaner and on the tramper of the bale press for the data collected in May, 2001. These data were compared to mc determined from samples by the oven method. The root mean square difference for this data was 0.33, which is higher than desired, but would generally not be considered to be significantly greater than the expected value in the range 0.2 to 0.3 (Shepherd, 1972). Considering the differences in cotton, weather, and equipment for the test in February where we obtained the calibration for equation 1 and the test in May, the fact that the data sets were completely independent, and the difficulty of measuring mc accurately the root mean square difference of 0.33 was judged to be good.

Because the fit of the first model to this data set was good it was proposed that the two data sets were not, in fact, based on different relationships. Therefore, the data set obtained in February was combined with that obtained in May. With the combined data set the best model was:

$$Pmc = 1.67 + 0.325*mc_l + 0.190*mc_t \qquad (1)$$

where Pmc = predicted mc,

mc_l = mc measured ahead of the lint cleaner by the resistance method,
mc_t = mc measured on the tramper by the resistance method.

This model fit the 41 data points from both February and May with a resulting root mean square error of 0.24, which is a reasonable error for this data set. A root mean square error of this magnitude supports the conclusion that the relationships were not different between the data collected in February and that collected in May.

Figure 6 shows the mc predicted by equation 1 plotted against the mc determined by the oven method. Separate symbols were used for the data collected in February and May. Equation 1 is considered to be the best available model for this application, but the coefficients may need to be adjusted for different specific field applications. The range of oven-based mc data was 4.2 to 7.5 and the range of the predicted mc was 4.2 to 7.3. The authors believe that the approach is applicable beyond this range, but caution the reader that the approach needs to be verified before use outside this range.

Conclusion

Resistance-type moisture sensors installed before and after moisture restoration by humidified air at a gin can be used to accurately predict (±0.24%) bale moisture content.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U. S. Department of Agriculture and does not imply approval of the product to the exclusion of others that may be available.

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Table 1. Means of lint mc ahead of moisture addition at the lint slide for the two drier treatments.

Was moisture added at drier 2	Moisture measured by resistance meter between gin stand and lint cleaners (%)	
	Mean*	**Standard deviation**
No	5.1 b	0.23
Yes	6.5 a	0.16

*Different letters denote means that were significantly different within a column.

Table 2. Means of mc of lint samples taken from the charge hopper and measurements made in the bale press.

Moisture addition		**Moisture by oven method of samples taken from the charge hopper* (%)**	**Moisture by resistance meter of samples taken from the charge hopper* (%)**	**Moisture by resistance located on the tramper* (%)**
To seed cotton	**To lint**			
No	No	4.4 d B	4.5 d B	5.5 d A
Yes	No	5.1 c B	5.4 c B	6.1 c A
No	Yes	5.4 b C	7.6 b B	10.5 b A
Yes	Yes	6.2 a C	8.4 a B	12.9 a A

*Different lower case letters denote means that were significantly different within a column and different upper case letters denote means that were significantly different within a row.

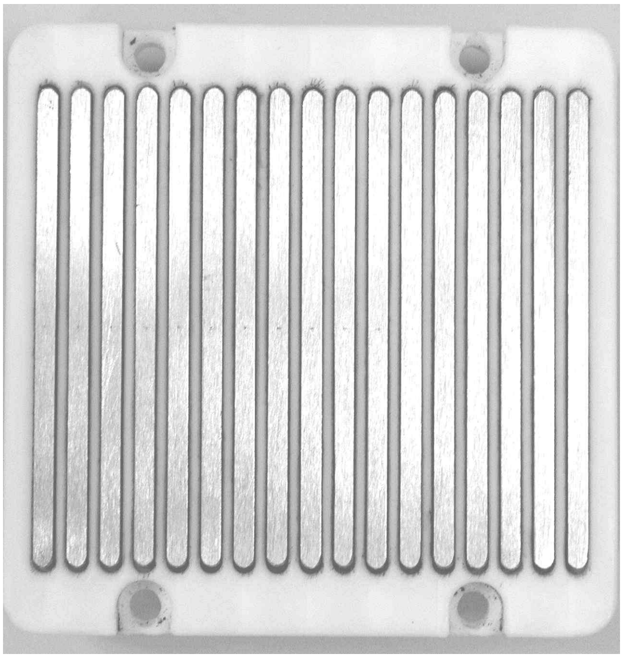

Figure 1. Stainless steel electrode grid set in plastic used in the resistance-based moisture sensors.

Figure 2. Lint slide grid used in moisture restoration system.

Figure 3. Humidaire Unit used in the moisture restoration system.

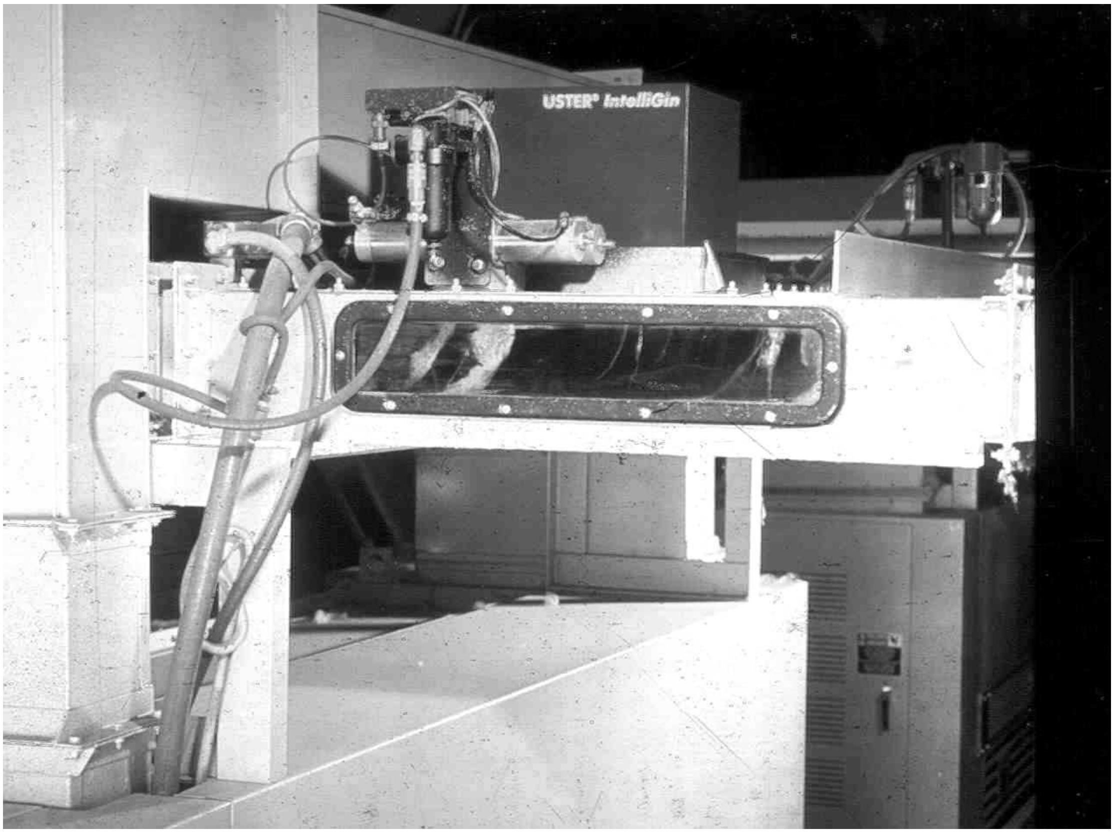

Figure 4. Intelligin station 2 located between the gin stand and the lint cleaners used to measure the mc before moisture restoration.

Figure 5. Photograph of tramper located in the bale press showing the moisture-sensing grid.

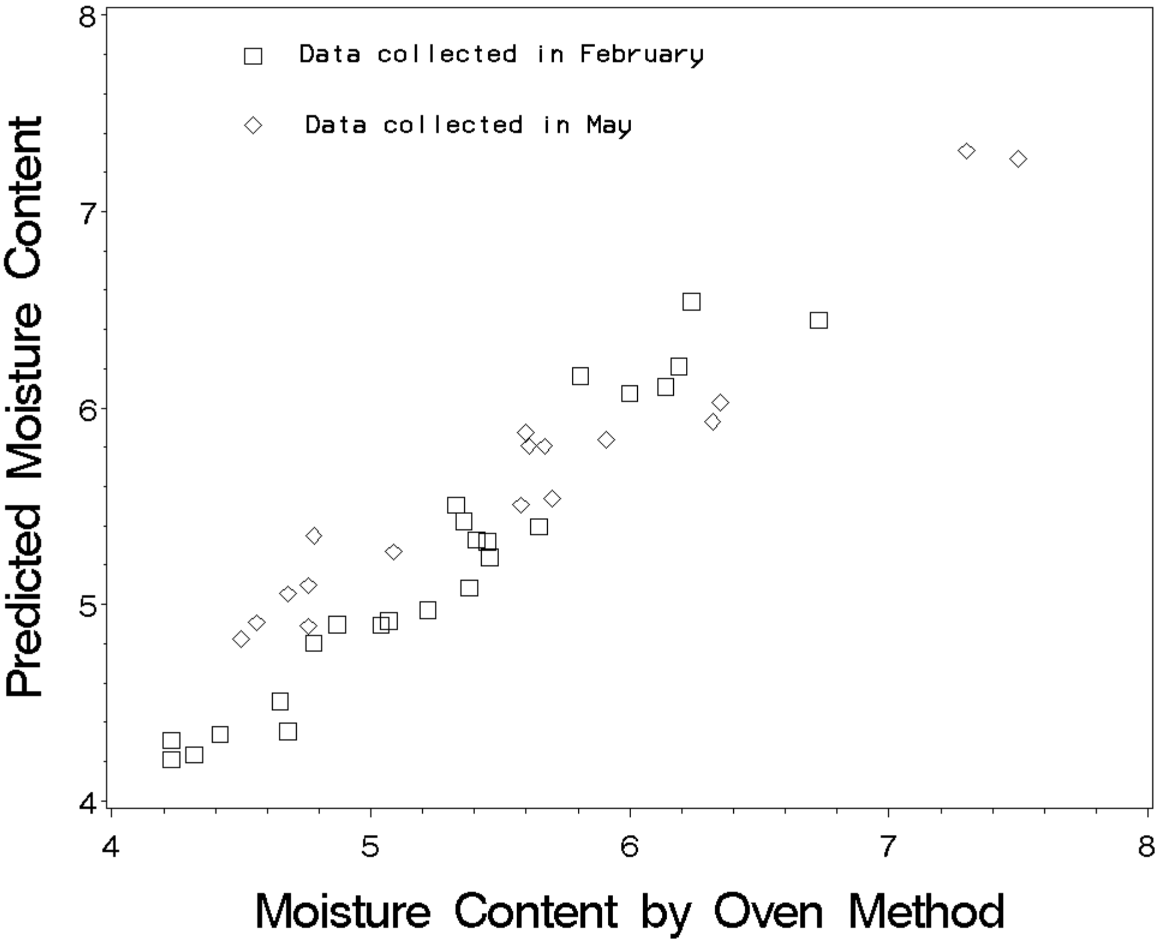

Figure 6. Mc predicted by equation 1 vs. oven mc at charge hopper with data collected in February and May.