WET-BOTTOMED MODULES - MOISTURE CONTENT MEASUREMENT AND DRYER CONTROL

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Abstract

Recent innovations have enabled samples of cotton to be automatically captured, evaluated, and released in gins. Sensors which measured the moisture content of seed cotton from throughout the module at the module feeder and the lint after the gin stand have been used to control drying. The system worked well except for a few modules which had very wet cotton on the bottom which was not indicated by the sensors. In 1998 a system to measure the moisture content of the bottom of the module was designed, installed, and tested. This new sensor was used to raise the drying temperature if the bottom was extremely wet. The sensor functioned as expected to artificially wetted seed cotton. However, no modules were encountered during the 1998 ginning season which had extremely wet bottoms so the control portion of the system could not be tested. In all respects the system worked as designed and is believed to be ready to respond properly when needed.

Introduction

A project was begun in 1990 to examine improved methods of drying control in the gin (Byler and Anthony, 1991; Anthony and Byler 1994; Byler and Anthony 1997). Traditionally, drying control systems for most applications have been analog based, which means that the system uses a voltage to represent the desired temperature setting. The trend in electronics has been to use more digital signal communication which uses voltage pulses to represent the data which must be transferred from one device to another. A prototype drying control system has been in operation at Burdette Gin since 1990. This system currently uses mostly digital communication and decision making processes for drying control. In the 1997 harvest season two moisture sensors were installed in the module feeder which measured the moisture content (m.c.) of the incoming seed cotton. A near infrared-type (NIR) moisture meter was installed between the air-type and the saw-type lint cleaners behind the second gin stand to measure the fiber m.c. which was to be controlled. This gin has two stages of drying, the first stage begins with a hi-slip drier, then the cotton is split into two streams for cleaning. There are two pickup points for the two streams of cotton for the second stage of drying. Thus there are three burners to control in this drying system. Temperature sensors were installed in the air stream before the mix point for all three burners. A Honeywell UDC 3000 controller was used for temperature control for each burner. The stage one temperature control sensor used by the UDC 3000 was ahead of the mix point but the two stage two controllers sensed the temperature in the top of the tower drier. A personal computer (PC) was used to collect data and to set the desired burner temperature based on the incoming seed cotton m.c., the final m.c. and the final m.c. set point chosen by the ginner. The PC communicated digitally with the UDC 3000's to set the target temperature for them to achieve. The PC requested the current temperature readings from the UDC 3000's.

This system was able to properly control the drying for most of the modules for which it was used in 1997. The major unresolved problem encountered for relatively few modules, was for modules with extremely wet cotton on the bottom. The yield was relatively good in 1997 and there were several rainstorms during the ginning season. Some of the modules had been built where rainwater collected and the bottom inch or two became very wet while the remainder of the module was fairly dry. If the water had been evenly distributed throughout the module the burners would have been set to an appropriate temperature and the system would have operated fine. The sensors in the module feeder sensed the m.c. of the majority of the cotton, which was dry, with a few wet samples and averaged the m.c. Actually, most of the very wet cotton fell directly from the bottom of the module into the hi-slip drier without ever being touched by the beaters in the feeder head, and could not have been sensed by the m.c. sensors. The drying system was properly adjusted for the majority of the cotton in the module, generally the temperatures were set to the minimum allowable. When the small amount of extremely wet seed cotton reached the feeder apron, water could be squeezed out of the locks they were so wet. This cotton did not gin well because it stuck to metal surfaces and greatly increased the load on the gin stand. The ginner's solution was to override the drier control and set the drying temperature to a much higher level. Over drying is not what would normally be recommended, but in this case it is the best option. For improved operation of the automated dryer control system, a sensor was needed which could detect this problem.

The goal of this part of the development of the drying system was to build and test a system which would electronically sense the extremely wet seed cotton on the bottom of modules which had been standing in water and to add software to the control system to properly raise the drying temperature for these modules.

Procedures

The process was divided into 7 steps:

1) Design a system which could detect the wet-bottomed modules based on resistance research done in the past,

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2) Conduct tests in the laboratory which would allow detailed electronics design and verify the design of part 1),
3) Build the system and install it at Burdette Gin,
4) Perform a calibration before the ginning season,
5) Operate the system throughout the ginning season,
6) Examine data from wet bottomed modules on an constant basis soon after they are ginned to adjust the response of the control to detected wet seed cotton, and
7) Perform a calibration check after the close of the season.

Step 1. The design which was chosen was to electrically isolate one of the rollers on the module feeder which are used to transport the modules and measure the resistance from it to the adjacent two rollers, Figure 1. This approach emphasized the wettest portion of the strip of cotton being measured, but that may produce the most beneficial measurement. The geometry of the rollers was a key portion of the calibration of the instrument. It was considered to be simplest to measure resistances on a model of the system and use the results to determine if the approach appears to be feasible, and if so, to obtain basic design criteria for the electronics in the system.

Step 2. Two small metal cylinders 2.67 and 2.75 inches in diameter were used to model the 6.5 inch diameter rolls of the module feeder. The rolls on the module feeder at Burdette gin were spaced 7.0 inches on center. A spacing of the measurement rolls of 3.5 and 4.0 inches was used for the data collection. The modules were about 85 inches wide, the measurement roll was 3.675 inches wide. One set of rolls was used for the data collection, but in the actual gin there would be two symmetric paths from the measurement roll to each of the two adjacent rolls. The resistance in the gin would be expected to be about 46 times lower than what was measured in this test. The contact pressure based on the weight of the module above the measurement zone would be expected to be greater than in the test, producing lower resistances than predicted for the module feeder.

Cotton fiber was preconditioned to relatively high m.c. values because the calibration was only needed for fiber m.c. above 8.0%. Samples were taken from the conditioning chamber and placed in sealed metal cans. A sub-sample was taken from the can and placed on a Teflon mat. Then the two cylinders were placed on the sample at the specified separation distance. A reading of the resistance was made with a megohm meter and recorded. The cylinders were then moved to the other separation distance and the second reading was made. This procedure was repeated three times for each sample. Then the sample was used for an oven moisture determination (Shepherd, 1972) for the reference m.c. A total of 34 samples were taken from several chambers on seven days over a 16 day period. This resulted in 102 observations of resistance for each spacing and 34 observations of the oven m.c. for the samples.

Step 3. Because the data from step 2 was encouraging, the system was installed at Burdette Gin. A roller was chosen and the paint removed from it and the two adjacent rollers. The drive chain was rerouted to not drive the roller which was to be electrically isolated, which meant that one chain had to be lengthened to bypass this roller and all chains from that point to the front of the feeder had to be rerouted. The roller was electrically isolated by replacing the metal bearings at each end with ultra high molecular weight pillow blocks with stainless steel housings. A slip ring was mounted in one end of the shaft for the electrical connection.

Step 4. Seed cotton was conditioned to two moisture levels, one low and the other higher by exposing it to high relative humidity air for over a week. A loading jig was constructed from wood to create a layer of test seed cotton 3 feet wide by 7 feet long. The initial calibration testing was done on Sept. 1, 1998. Approximately 20 pounds of seed cotton were spread on a metal sheet under the frame then a sheet of plywood was placed on the cotton. The metal sheet was removed, then approximately 2000 pounds of weight were placed on the plywood to simulate the pressure from the module on the cotton. The test cotton was moved forward over the measurement rollers and readings were taken. Next, samples of the cotton were taken and the m.c. measured by the oven method. First, a drier sample was measured, then a wetter sample, next a repeat sample of the drier cotton was measured, finally a repeat test with the wetter cotton was measured. In addition to the calibration with cotton, fixed resistors were placed in contact with the sensing roll and one of the outside rolls for a check of the resistance-voltage calibration of the sensing system.

Step 5. The system was operated during the ginning season from Sept. 15 to Oct. 29, when ginning was finished. Data on the measured m.c. at the three locations; the module bottom, the two separate sensors in the module feeder, and the NIR sensor behind the gin stand; the burner temperatures and the color and trash content of the cotton were recorded for later analysis.

Step 6. The data were monitored throughout the ginning season. During this ginning season there was very little rain, only one sizable rainstorm which occurred near the beginning of the season and the gin had moved nearly all of the modules which had been built to the gin yard. During the entire season no modules were encountered which could be called wet based on the experience from 1997. One module had a somewhat raised m.c. as detected by the sensor and the ginner's opinion was that the burner had not been set hot enough, so the m.c. at which increases in burner temperature would be made was decreased.

Step 7. The calibration was rechecked on Nov. 16, 1998, using the same procedures which had been used for the initial in-gin calibration.

Results

Step 1. A constant, regulated 2.5V was used to excite the isolated roller through a 2.2K ohm resistor, Figure 2. The voltage output of the circuit, Vo, was from between the fixed, Rref, and variable, Rm, resistances. Thus if the resistance between the excitation roller and the two reference rollers was very high, the voltage would be 2.5V and if the resistance was very low the voltage would be near 0.0. This circuit was simple and allowed usable readings over a wide range of resistances for the measurement rollers. The 2.2K ohm reference resistor was chosen based on the expected range of interest in resistance of Rm. An A/D converter module was used to read the voltage divider output and transmit the result to the control computer using RS-485 transmission standards.

Step 2. The observed resistances and mathematical transformations of them were used to predict the oven moisture values for each spacing. For the data with the 3.5 inch spacing, the model:

1) $CTL = 11.04 - 1.067*\ln(res) + 0.0116*res$

where: CTL = the moisture content as determined by the oven method, % w.b.
res = the resistance determined by the megohmeter, in megohms.

was found to fit the data with a residual mean square of 0.27. For the data with the 4.0-inch spacing the model:

2) $CTL = 11.22 - 1.012*\ln(res) + 0.0075*res$

was found to fit the data with a residual mean square of 0.33. Both of these models appeared to be good and no problems were seen when the residuals were plotted. The two residual mean square values are probably not different but are more likely estimates of the same standard deviation. The fit of the model to the data was quite good and indicates that the sensor is likely to be useful. The data appeared to be similar to data seen in the past with other resistance moisture measurements. The range of m.c. which was used was from 6.9% to 14.7%.

Step 3. The gin had several spare rollers so one was selected and fitted with the slip ring at one end, and the paint removed. A roller in the module feeder was removed and the converted one installed. The electrical circuit was connected to the hardware.

Step 4. The data from measurements of the fixed resistors from 100 to 3M ohm was examined. The data fit the expected curve quite well with some decrease in accuracy at the highest resistances, as expected. This showed that the electronics were operating as designed. Next the data using cotton to calibrate the sensor was examined. The equation:

$Mbmc = 11.63 - 0.5272*\ln(Vo/(2.5-Vo))$

where: Mbmc = the module bottom moisture content
Vo= the output voltage from the divider circuit.

was chosen as the best model from those which were examined. The model fit the data well, but there were relatively few data points with which to calibrate. The measurement range was from about 7.5 to 15.5 percent fiber moisture content with indication of whether the m.c. was higher or lower than the range if it was outside the range. The actual accuracy of the moisture measurement was not too important, it was important to accurately measure changes in m.c. and allow the control system to respond to those changes. The change of temperature setting which was appropriate for a given change in the m.c. of the module bottom was not known and would have to be determined by trial and error. Therefore, if there was some inaccuracy in the m.c. measurement it would be corrected in the trial and error adjustment of the burner temperatures. However, it was important that the system respond as expected and give significantly different output for different input m.c. The system responded as expected to changes in input m.c.

Step 5. Data were collected and examined from all sensors. The system included a switch on the ginner's control panel to decide if computerized moisture based control was to be used or if temperature control was used. Data are presented showing periods of both types of control. The moisture target when using computerized, moisture-based control is adjustable but most of the time the m.c. target was 4.8%. Much of the time when computerized moisture based control was used the burners were set at or near the minimum allowable, 150°F for stage one. Generally when temperature-based control was used, the ginner selected temperatures between 170 and 200°F. Figures 3, 4, and 5 show the module bottom m.c., the module feeder m.c, and the m.c. after the gin stand, respectively, during a period when the drying temperature was being held at a constant 185°F while ginning on Sept. 23. The pressure of the seed cotton on the module bottom m.c. sensor affected the reading, and in Figure 3 the separation between modules can be seen. For the first full module starting at time 1.2 hours, the module bottom m.c. was about 9.8% while the interior of the module had a m.c. about 9.5%. For the next module the module bottom m.c. was about 10.4% while the interior of the module was about 8.9%. With a constant drying temperature the final m.c. would be expected to follow the module interior m.c. to a certain extent, and comparing Figures 4 and 5 similarities can be seen.

Figures 6, 7, 8, and 9 show data from ginning on Sept. 28. The m.c. in the interior of the module was fairly constant but there was a sudden increase at 16.6 hours in the module bottom m.c. followed by a spike in the interior m.c. at 16.75 hours. The drying temperature changed quite a bit during this period with the minimum temperature being held for only about 0.4 hours of the 2.0 hours represented. The changes in drying temperature were brought about mostly by changes in the final m.c., because the module bottom m.c. was not high enough to raise the drying temperature except at the 16.7 hour interval. But at that time the final m.c. was too low and the controller continued to decrease the temperature setting after a few minutes pause.

Step 6. Because of good weather throughout the 1998 ginning season, there were no modules with the bottom layer of high m.c. as had been experienced during the 1997 ginning season. The highest m.c. which was measured was 12.4 and occurred for about 4 minutes at about 2:45 AM on Oct. 12. During that time the automated temperature selection had been turned off by the ginner and the burners were set at 195°F. The final m.c. was below 3.0% during the period and no ginning problems were apparent. The m.c. measured in the module feeder varied from 7.9% to 8.6% which was more variation than at most other times. Perhaps some of the higher m.c. seed cotton was picked up by the sampler in the feeder head which caused the m.c. to change rapidly.

At two times during the season a portable sprayer was used to apply water in a band across the bottom of the module while it was on the module feeder ahead of the sensor. In both cases the sensor indicated an increased m.c. as expected.

Step 7. There were no significant differences in the readings of the fixed resistors with the system when readings were taken on Nov. 20 compared to those taken on Sept 1. This showed that the measurement system had not shifted in calibration for measurement of resistance. The data from measurement of cotton samples from before the season and after the season were compared and there was not a statistically significant difference in them. This showed that the calibration of the measurement of m.c. of the module bottom had not changed significantly during the season.

Summary

An inexpensive sensor to identify wet spots on the bottom of cotton modules was developed and tested. The sensor functioned well during tests and offers great potential for enhanced control of the gin drying system to prevent operational problems.

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 which may be available.

References

Anthony, W.S. and R.K. Byler. 1994. Status of Gin Process Control Systems. Proc. Beltwide Cotton Prod. Res. Conf., National Cotton Council, Memphis, TN. pp. 170-171.

Byler, R.K. and W.S. Anthony. 1991. Experience with Dryer Control Based on Infrared Moisture Meters. Proc. Beltwide Cotton Prod. Res. Conf., National Cotton Council, Memphis, TN. pp. 1000-1002.

Byler, R.K. and W.S. Anthony. 1997. Measurement concepts in a gin process control system, Proc. Beltwide Cotton Prod. Res. Conf., National Cotton Council, Memphis, TN. pp. 1572-1573.

Shepherd, J.V. 1972. Standard Procedures for Foreign Matter and Moisture Analytical Tests Used in Cotton Ginning Research. USDA agricultural Handbook No. 422.

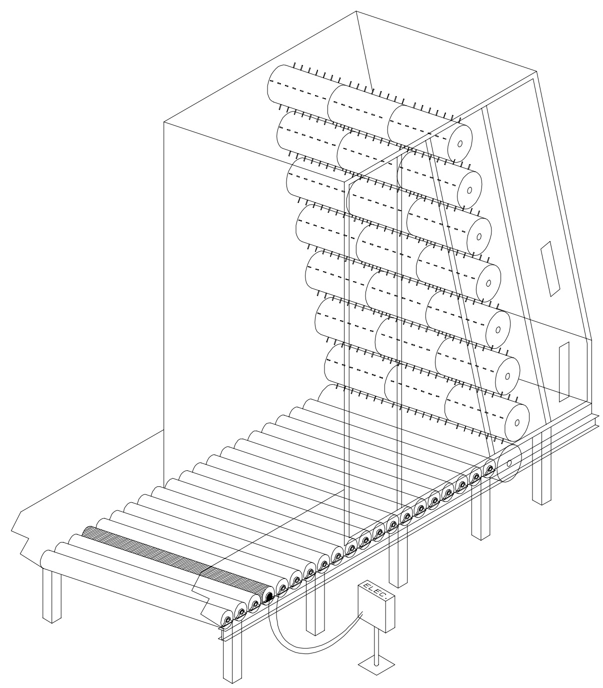

Figure 1. The sensing roller on the module feeder.

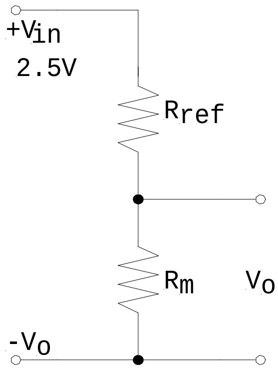

Figure 2. Schematic of the voltage divider circuit used to measure the electrical resistance of the bottom of the module.

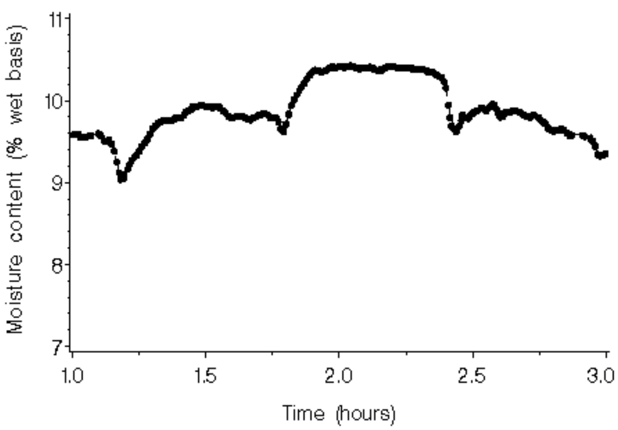

Figure 3. The measured moisture content of the bottom of the module while ginning between 1:00 and 3:00 AM on Sept. 23.

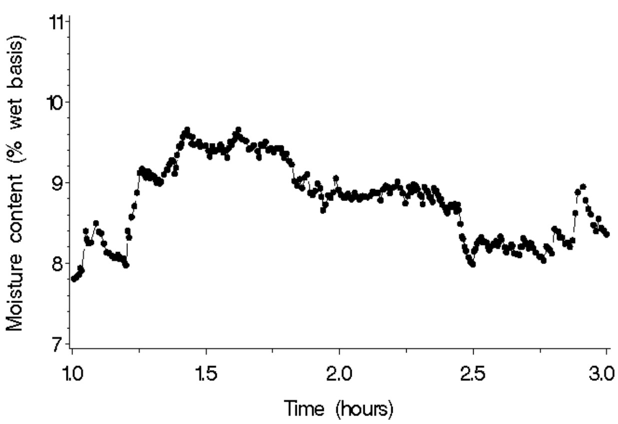

Figure 4. The measured moisture content of the interior of the module measured at the module feeder of the interior of the module while ginning between 1:00 and 3:00 AM on Sept. 23.

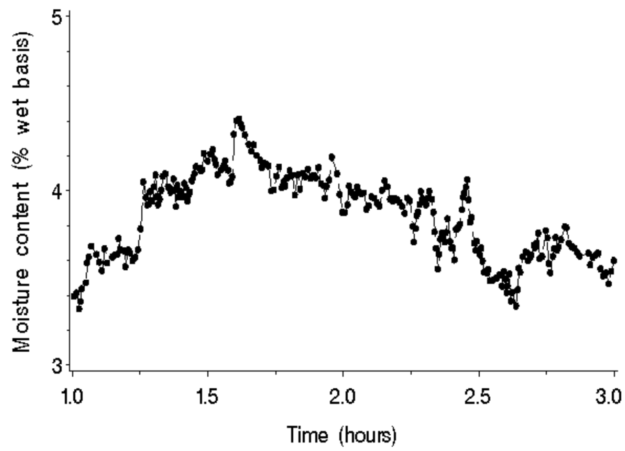

Figure 5. The lint moisture content measured behind gin stand 2 while ginning between 1:00 and 3:00 AM on Sept. 23.

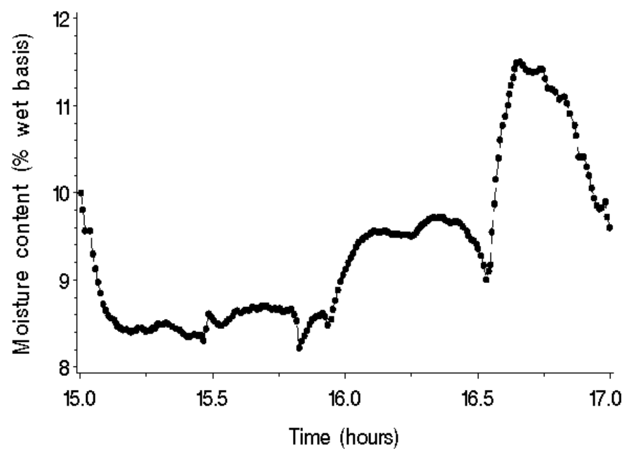

Figure 6. The measured moisture content of the bottom of the module while ginning between 3:00 and 5:00 PM on Sept. 23.

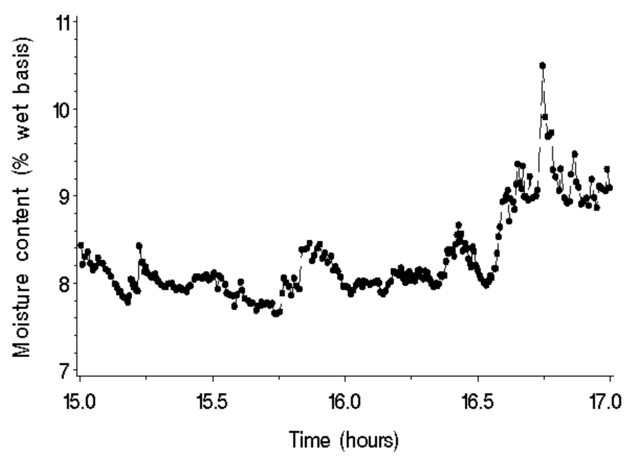

Figure 7. The measured moisture content measured in the module feeder of the interior of the module while ginning between 3:00 and 5:00 PM on Sept. 23.

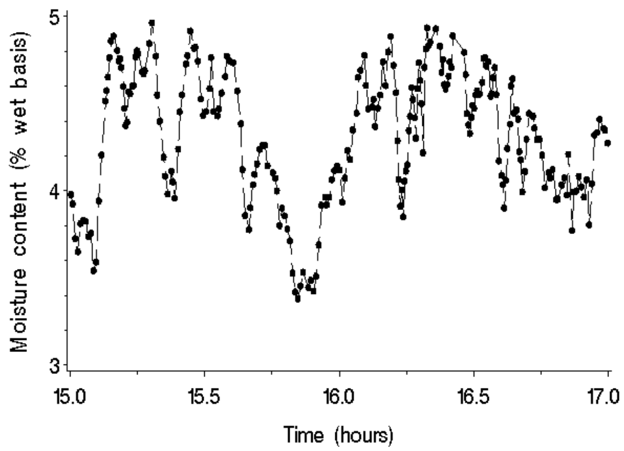

Figure 8. The lint moisture content measured behind gin stand 2 while ginning between 3:00 and 5:00 PM on Sept. 23.

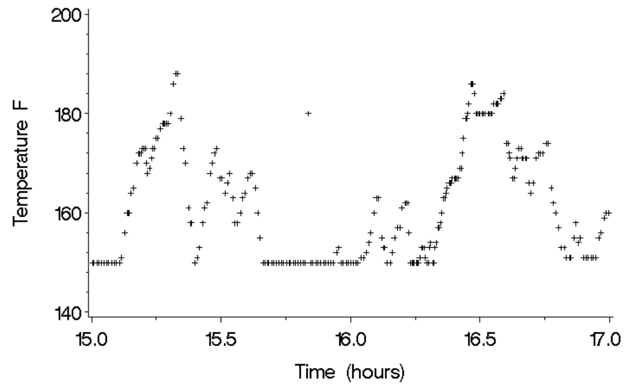

Figure 9. The first stage burner set point chosen by the moisture based control system while ginning between 3:00 and 5:00 PM on Sept. 23.