INITIAL EXPERIENCES IN COMPUTER CONTROL OF COTTON GIN DRYING

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ABSTRACT
A computer-based dryer control system was developed and tested in two cotton gins during the 1990 ginning season. The drying temperature setpoint was adjusted based on the seed cotton moisture content before and after drying as measured by infrared moisture meters. The control system adjusted the air temperature by opening and closing the modulator valve on the gas line feeding the burner. Over 500 h of testing of the measurement system and about 60 h of testing of the control system in a commercial gin indicated good reliability of the system. The seed cotton moisture content was rarely as much as 0.5% wet basis from the setpoint, indicating that the system controlled moisture content adequately.

KEYWORDS. Cotton, Drying, Control, Computer.

INTRODUCTION
The 1990 U.S. cotton crop yielded approximately 3.8 million tons (15 million bales, U.S. Dept. of Commerce, 1991) of ginned lint valued at over $5 billion. The gins charged over $500 million for ginning. Cotton ginning includes drying, trash removal from seed cotton, lint-seed separation, trash removal from lint, and bale packaging. The quality of cotton after ginning is dependent on its initial quality as well as the type and degree of cleaning and drying that it receives during the ginning process. The efficiency of the gin process is strongly influenced by the quantity of moisture and trash that the cotton contains. Four stages of seed cotton cleaning are normally used to remove trash from spindle-harvested cotton (fig. 1). Both the efficiency of the cleaning machines and damage done to the cotton fibers are strongly influenced by the fiber moisture content (Griffin and Mangialardi, 1961).

Griffin (1977) reported that the moisture content of cotton should be within a range of 6.5 to 8% to maintain optimum fiber quality. He also suggested that some of the cotton required minimal or no drying, and that in some instances moisture should be added to the cotton to preserve fiber qualities.

There are usually two stages of drying in a gin, each consisting of a gas burner and tower dryer. The tower is typically 2 m x 2 m x 6 m (6 ft x 6 ft x 20 ft) and consists of a series of shelves between which the cotton is moved by air at rates of approximately 12 m/s (2,400 ft/min). The dryers are controlled by the gin operator setting the drying temperature. Commercially available proportional, integral, differential (PID) controllers are used to control the drying temperature based on a temperature probe located in the drying tower. Temperatures in the range of 120° C to 180° C (250° F to 300° F) are generally used.

All cotton in a particular gin usually receives the same degree of cleaning and drying without regard to the amount of trash and moisture in the cotton initially, primarily because no automatic method exists for measuring the trash in cotton continuously during gin processing. Processing cotton at the gin is complex and proceeds at rates as high as 24 tons of lint per hour.

Anthony (1990a) used a dynamic programming model that optimized farmer profits and minimized gin processing and energy consumption as a basis for computer selection of gin machinery sequences. The model utilized the cotton market price and performance characteristics of the gin machinery to determine the optimum machinery sequence. The gin process control system operated successfully and demonstrated the potential to minimize fiber damage and machinery usage while optimizing profits. This system operated in a small-scale gin and appeared to have potential for use in a full-scale gin. The dryer-control system was designed to control special multi-path dryers rather than the tower dryers that are usually used in commercial gins. Thus, different software and hardware were needed for a commercial gin.

Gin plants are not ideal environments for computer-based control. The numerous, large electrical motors used to power the machinery also produce considerable electrical noise. The operating temperatures inside the gins vary from 0° C to 35° C (32° F to 95° F) and there is a considerable amount of dust and vibration.

A computer-based drying system controller capable of monitoring and adjusting the drying system to maintain a constant lint moisture content at the gin stand could substantially reduce the drying energy costs. Such a system would reduce overdrying of the cotton thereby saving energy and improving the quality of the product. The system should: 1) operate reliably under commercial gin conditions; 2) be expandable to control other aspects of ginning because longer range plans call for computer-based control of gin machinery in addition to the dryers;
and 3) should maintain a constant lint moisture at the gin stand despite variation of the input lint moisture content.

**OBJECTIVE**

The objective of this research was to establish the hardware and software necessary for a computer-based cotton dryer control system and to test such a system in a commercial gin.

**MATERIALS AND METHODS**

The basic control problem was to monitor the moisture content of the lint at the gin stand and control it by adjusting the dryer temperature. A cascade-control approach was used where the basic control loop maintained a specified drying air temperature by opening or closing the modulator valve on the gas line feeding the burner (fig. 2). The higher level of control compared the seed cotton moisture content just before it entered the drying air and just before it entered the gin stand with the moisture content setpoint. It then adjusted to the desired burner temperature based on the differences. Temperatures were sensed with thermistors and the moisture content was sensed with commercial infrared moisture meters. The system was based on a personal computer with a program written in C.
HARDWARE

The system had to sense the important analog inputs: 1) lint moisture content before drying; 2) lint moisture content after drying; 3) ambient relative humidity; 4) ambient air temperature; 5) air temperature before the air/cotton mixpoint; 6) air temperature immediately after the mixpoint; and 7) air temperature later in the dryer. Each burner was controlled by two 120 VAC on/off switches—one to open the modulator valve and one to close it. For a three-burner control system this required an interface to a minimum of 13 analog inputs and 6 on/off switches. The compiled C code used 59 Kbytes of memory plus a small amount of temporary data storage.

A 80386SX-based personal computer with a 42 Mbyte hard drive was used as the basic data logger/controller. This "office" quality machine was housed in a protective enclosure to isolate it from the dust and dirt. An uninterruptable power supply was used to power the system because of the power problems often encountered in rural areas where large electrical loads are being switched on and off, such as is the case in most gins.

Seriplex network units were selected (APC, 1990) which use one four-conductor cable and allow up to 256 on/off inputs/outputs, or 240 analog inputs/outputs to be controlled and/or monitored by the computer. These units are designed for an industrial environment and are optically isolated, relatively immune to electrical noise, rated to 85°C (185°F), and operate on 12 VDC. The network can span distances of over 1 km (0.6 mile). Modules are available for A/D conversion, D/A conversion, controlling/monitoring AC loads, and controlling/monitoring DC loads.

For this design, two modules each capable of 16 channels of 12-bit A/D conversion, three modules each capable of monitoring and controlling two 120 VAC loads, and a personal computer interface card were purchased. A microprocessor on the interface card handles the network communication protocol by receiving and transmitting information on the communication cable. The cable has four wires used for ground, 12 VDC power supply, data, and clock. Communication can be considered to be synchronous serial with this system using a 25 KHz clock. The system obtained an updated digital I/O value once every 2.2 ms and a new input for all channels of the A/D converter once in each 36 ms. These times resulted in no restrictions in this application because other parts of the system were slower by orders of magnitude.

Fenwal Electronics (1985) 135-103FAG-J01 thermistors were used to sense the temperatures. The system was designed to measure temperatures from 0°C to 200°C (32°F to 400°F) with the upper limit to temperature being the insulation on the wires, even though high temperature Teflon-coated wire was used. The circuit had a nonlinear temperature sensitivity but had a resolution of 0.1°C (0.18°F) or better over the most important temperature range, 25°C to 150°C (77°F to 300°F), with the 12-bit A/D converter. The Steinhart-Hart equation (Fenwal Electronics, 1985) was used to linearize the thermistor temperature-resistance relationship using manufacturer's data.

At most of the points where temperatures were measured, air and cotton were both present and traveling at speeds of over 10 m/s (2400 ft/min). The thermists were held in the stream of air and cotton, and protected from damage with probes. The probes were constructed from 0.6 cm (% in.) diameter stainless steel tubing by drilling six holes near the end of the tube and gluing a thermistor in the end of the tube with high temperature, thermally conductive epoxy (fig. 3).

Calibration was achieved by placing the thermistor probes in an oven in the laboratory. Calibration data were collected with the computer system at six different temperatures as measured by a laboratory-grade liquid in a glass thermometer. A linear regression was performed between the temperature measured with each thermistor and that measured by the thermometer and the residuals examined. A linear correction was used to convert the temperature calculated with theoretical coefficients in the equation to the calibrated temperature. This approach gave statistically significant improvement in prediction of the measured temperature compared to using the theoretical coefficients for the equations. The calibration resulted in a standard error of 0.8°C (1.4°F), which was considered to be acceptable for this application.

Moisture Systems' Quadra-Beam Analyzers were used to measure the seed cotton moisture content. These instruments use near infrared light to determine the moisture content of materials. Anthony (1990b) used these meters previously with cotton and found them to agree with oven-based moisture measurements to 1% wet basis over the range 2.5% to 10%. These meters have an analog output which was connected to the A/D converter.

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**Figure 3—Thermistor probe construction.**
SOFTWARE

A program was written to collect data from the sensors, record the raw data on the hard disk, convert the raw data to engineering units, and control the moisture content of the cotton at the gin stand by controlling the drying air temperature. For proper operation of the control algorithms and for safety, it was important that temperature measurements be made on a regular and frequent basis. Interrupt-driven software can be used for this type of problem. In this case, however, the internal computer clock was used to coordinate the data-collection interval. The code was written so that the computer would check if hardware (such as the keyboard) was ready before accessing it. Therefore, the computer never waited for hardware which may be slow to, or may never, respond. The program was interactive, displaying data on the screen and allowing the user to change final moisture goals and other settings while the program ran.

The temperature control used an integral velocity algorithm. The measured air temperature, just before the air mixed with the cotton, was compared with the desired temperature to determine a temperature error. The modulator valve was opened or closed for a period of time, in 0.2 s increments from 0 to 1.8 s, proportional to the error. The change of modulator position usually resulted in a change of air temperature. Because the change of setting, rather than the setting, was proportional to the error, the system used an integral (only) velocity control algorithm with the advantages and disadvantages of integral control. The velocity control algorithms do not suddenly change settings but also cannot immediately determine the proper setting. The algorithm was relatively slow but easy to adjust. If given a steady state load and enough time, it always found the best setting.

The seed cotton moisture control was based on both the cotton moisture content before drying and the moisture content after drying (fig. 2). The dryer set temperature was chosen every 2 s with the moisture control algorithm (eq. 1).

\[ T_m = K_{fp}E_i + K_{bp}E_f + K_{bi} \sum E_f + 40 \]  \hspace{1cm} (1)

where

- \( T_m \) = the set temperature at the mixpoint (°C)
- \( K_{fp} \) = the controller feedforward proportional gain
- \( K_{bp} \) = the controller feedback proportional gain
- \( K_{bi} \) = the controller feedback integral gain
- \( E_i \) = initial moisture content-setpoint difference
- \( E_f \) = final moisture content-setpoint difference

Equation 1 is an algorithm with proportional feedforward control and proportional-integral feedback control. \( E_f \) tends to 0, but \( \sum E_f \) tends to a value necessary to adjust for changes in the system response, such as changes in ambient relative humidity. \( E_i \) was positive and \( K_{fp}E_i + 40 \) gave a reasonable operating temperature so that \( \sum E_f \) could be near 0. In order to handle anticipated noisy moisture data due to electrical noise, as well as variations in the actual moisture content of the lint, a first-order lag smoothing function was added to the change in temperature setpoint (eq. 2).

\[ T = T_p + 0.005 \left( T_m - T_p \right) \]  \hspace{1cm} (2)

where \( T \) is the temperature set point (°C) and \( T_p \) is the previous set point (°C).

The lower allowable temperature limit at the mixpoint was determined by the ginner as 103° C (217° F). The upper limit of 150° C (300° F) was used because studies have shown that cotton fibers can be severely damaged by drying air hotter than 176° C (350° F) (Griffin, 1977). A set of data including all analog input values and the current settings chosen by the control algorithm were stored on the hard disk at 2-s intervals. This resulted in about 6 Mbytes of data per day and the 40 Mbyte hard disk held about six days of data. Operation in a commercial setting would not require nearly as much stored data, 200 Kbytes per day would probably be adequate if a record of drying data were needed at all. This system was designed for research but a similar system could be used commercially.

The system was designed to be reliable, and the uninterruptable power supply kept the computer running through short power outages. However, if such a system is to be allowed to control gas burners in a commercial application, further safety design is needed. Over-temperature limit switches on the burners completely independent of the computer system are an obvious beginning. C language was used because the program could be ported to other systems more easily than other languages and because it is a good language for control.

PROCEDURES

The system was installed in the commercial-size gin at the U.S. Cotton Ginning Laboratory, Stoneville, Mississippi, the first week of September 1990. Testing was done to check the software, calibrate the control parameters with two 3 GJ (3 million BTU) burners, and test the stability of the system.

It was observed during testing that at low drying temperatures, 100° C (212° F), the controller gain needed to be much lower than at high temperatures, 150° C (300° F). It was theorized that this was caused by the nonlinear response properties of the modulator valve. Slight movement in the nearly closed position changed the gas flow considerably more than the same movement in the nearly open position. This caused the overall system gain to be higher at low temperatures than at high temperatures when a constant controller gain was used. The temperature controller gain, \( K_t \), was varied linearly from 100° C to 150° C (212° F to 300° F) such that the gain at 150° C (300° F) was twice as large as that at 100° C (212° F). This approach gave a reasonable response at all operating temperatures.

After initial trial and error adjustment of the gain in the algorithm, it was determined that a measurable steady state error was often observed when the gain was low enough to ensure stable, well-damped response to step changes in setting. The problem resulted from the fact that the control system was digital, therefore, discrete changes by the control system were mandatory and the gas modulator had to be changed in 0.2-s intervals. This problem was reduced
by summing the errors until a total error large enough to demand a 0.2-s change of the modulator valve occurred. This approach improved the system response with a fairly rapid and well-controlled response to large step changes in the setpoint, and small changes over a long period while the system searched for the best setting. Part of the problem was the inherent lag in the measurement system. It was assumed that the air temperature changed almost immediately when the modulator position was changed. The air was traveling at approximately 20 m/s (4 000 ft/min) and had less than 20 m (65 ft) to travel from the burner to the measurement point. The thermistor itself had a 4-s time constant, but when the time constants for the surface film with air, epoxy, and stainless steel tube were added the overall time constant was measured to be 43 s. Careful placement of the thermistor and drilling holes in the tube (fig. 3) reduced the time constant to 18 s in air moving at about 7 m/s (1 400 ft/min). Analysis of experimental data showed a time constant for the gin installation of 12 s. This time constant of the measurement system resulted in the control system, working on a 2 s interval, using measured data which lagged the real values by a considerable amount when the actual temperature was changing rapidly, as was the case when the system responded to large step changes. Because the measured temperature lagged the actual temperature, the controller tended to over compensate for errors, thereby reducing stability. The gain had to be reduced to keep the system stable and to get it to settle quickly at the new setpoint. When the measurement system was measuring a stable temperature, the lag did not cause any error and small adjustments could be made based on the measurements.

A similar system was then installed in a commercial gin near Burdette, Mississippi, in early October 1990 with a moisture meter installed at the feed control and another located above one gin stand. The commercial gin had a 6 GJ (6 million BTU) burner for the first stage of drying, and two 3 GJ (3 million BTU) burners for the second stage, and processed about 4 Mg (16 bales) of cotton per hour with four gin stands. The system was designed to operate all three burners but the ginner chose not to use the burners with four gin stands. The system was to maintain a constant temperature at the gin stand at a constant moisture content. It was beyond the scope of the testing of this portion of the system to have a moisture meter installed at the gin stand to determine the actual moisture content of the unmoving cotton even though that cotton was not flowing—the meter could be exposed to cotton or could be treated by the most recent setting of the system, then the computer system was not used to control the air temperature much more smoothly than the traditional temperature controllers. No problems were encountered in moving the control system to the commercial gin. Minor adjustment was made to the controller gain but no other change was necessary. The computer-based moisture content controller maintained a more constant drying air temperature than the commercial temperature controller at the commercial gin.

RESULTS

The hardware and software operated for the test period with no malfunctions. In the gin at the U.S. Cotton Ginning Laboratory, the computer-based controller adjusted and controlled the air temperature much more smoothly than the traditional temperature controllers. No problems were encountered in moving the control system to the commercial gin. Minor adjustment was made to the controller gain but no other change was necessary. The computer-based moisture content controller maintained a more constant drying air temperature than the commercial temperature controller at the commercial gin.

One problem occurred repeatedly during the long-term testing in the commercial gin when the flow of cotton from the first meter to the second meter was disrupted, either because the flow of cotton was stopped altogether, or because the gin stand at which the second meter was located was stopped. The feedback portion of the control algorithm worked because cotton was treated by the current setting of the drying air and the effects were measured by the second meter. If the second meter did not read cotton treated by the most recent setting of the system, then feedback was not occurring but the computer could continue to change the modulator valve setting. Two situations could occur when cotton was no longer flowing—the meter could be exposed to cotton or could be exposed to air only. If the meter was exposed to cotton, it would continue to indicate the moisture content of the unmoving cotton even though that cotton was not indicative of the current dryer setting. If the meter was exposed to air, the initial moisture content meter indicated a high reading, near 15%, and the final moisture content meter indicated a low reading, near 2%. Because of the integral term in the control algorithm and the first order lag function in the temperature setting, it took several minutes for the control system to recover from any incorrect readings.

An examination of the available data revealed that there was a temperature drop in the air from just ahead of to just after the point where the cotton mixed with the drying air between 5° C and 20° C (9° F and 36° F) when cotton was entering the stream and virtually none when no cotton was entering the stream. This temperature drop was used in the software to detect when cotton was not flowing in the system and changes were not made in the setting during such periods. This temperature drop input reduced problems due to lack of feedback but could not entirely solve the problem. Additional sensors will be needed to further reduce the adverse affects of temporary lack of feedback on the controller.

Figure 4 shows the operation of the system with traditional control where the air temperature at the mixpoint was set by the operator and maintained by a commercial analog (PID) controller. The plot shows conditions after the controller had been running for some time. It can be observed that the drying temperature was fairly low in this example and that an increase in initial moisture content of the seed cotton was reflected by an increase in final moisture content.

Figure 5 shows the system response when using the computer-based control system. This data set was collected immediately after the computer control was begun. Data
during the first 0.1 h shows the control system responding to an initial error in the setting. The control system response can be seen to be smooth and to have produced seed cotton with a reasonable final moisture content. The more rapid rise in setpoint compared to the decrease in setpoint can be observed at about 0.3 h. The temperature is more stable over the short term with the computer controller than with the traditional controller. At about 0.5 h, ginning began on wetter cotton. The system response can again be seen to have been smooth and within acceptable limits.

The system response to a step change of input is one test which is commonly used for control systems. Generally, the moisture content of the lint entering the gin was constant. However, three examples where there was a sudden change in input lint moisture content were identified for periods when the temperature was being controlled by a commercial analog controller and three others where the computer was controlling the final moisture content. Table 1 lists the mean moisture content before the sudden change and after the change for the lint before and after drying as measured by the infrared meters. The first and fourth lines in this table are for the data represented in figures 4 and 5, respectively.

These data were analyzed using the General Linear Models procedure (SAS, 1985). The 0.95 level was considered significant for all tests. Based on the results, the null hypothesis that there was no difference in the initial moisture content before and after the change was rejected for the tests using the PID controller and for the tests using the computer controller. The null hypothesis that the final moisture content was the same before and after the step change of input was rejected for the PID-controlled cases but was not rejected for the computer-controlled cases. That is, when there was a significant change in initial lint moisture, the final moisture content changed with the traditional controller but did not change significantly when the computer-based controller was used.

Data collected during the last 10 days, when the computer was controlling the final moisture content, were examined. Data during periods when there had been gin machinery malfunctions were removed from the analyses.

<table>
<thead>
<tr>
<th>Controlled Parameter (controller)</th>
<th>Moisture Content Before Drying</th>
<th>Moisture Content After Drying</th>
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<tbody>
<tr>
<td></td>
<td>Wet Module</td>
<td>Dry Module</td>
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<tr>
<td>Temperature (traditional)</td>
<td></td>
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<tr>
<td>8.0a</td>
<td>6.2 b</td>
<td>6.0 c</td>
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<tr>
<td>Temperature (traditional)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.2 a</td>
<td>7.1 b</td>
<td>6.2 c</td>
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<tr>
<td>Temperature (traditional)</td>
<td></td>
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</tr>
<tr>
<td>8.0 a</td>
<td>7.1 b</td>
<td>5.9 c</td>
</tr>
<tr>
<td>Moisture content (experimental)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.5 a</td>
<td>6.8 b</td>
<td>5.4 c</td>
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<tr>
<td>Moisture content (experimental)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.6 a</td>
<td>8.9 b</td>
<td>6.0 c</td>
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<tr>
<td>Moisture content (experimental)</td>
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<td></td>
</tr>
<tr>
<td>9.1 a</td>
<td>8.2 b</td>
<td>4.9 c</td>
</tr>
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</table>

* Test periods averaged about seven bales per module.
† Means in the same row are not significantly different at the 0.95 level if followed by the same letter.
This left just over 14 h of data during which the computer was controlling the final moisture content. The measured final moisture content was compared with the final moisture setpoint, including some periods when the final setpoint was changed. The percentage of time that the measured and desired moisture content were within 0.5% wet basis of each other was calculated. This analysis showed that in a commercial operating gin, the system could keep the measured final moisture content to within ±0.5% wet basis of the setpoint 90% of the time. During some periods of these tests the two moisture contents were within 0.5% over 99% of the time, and the few points outside the ±0.5% band were considered to be due to electrical noise in the measurement system. During one period, however, there were as few as 50% of the observations within the ±0.5% band while the system was attempting to adjust the final moisture content to a value near the physical limit of the dryer. In all cases, the controller adjusted the burner appropriately and was never observed to behave erratically.

SUMMARY

A personal computer-based dryer control system was designed, installed, and tested in two gins during the 1990 ginning season. Infrared moisture meters were used to measure the moisture content of the seed cotton before and after drying. The control system controlled the air temperature by adjusting the modulator valve on the gas line feeding the burner. The air temperature setpoint was adjusted based on the measured initial and final seed cotton moisture contents. Over 500 h of testing the measurement system and about 60 h of testing the control system revealed no problems in the hardware and indicated good reliability of the system.

When the dryer temperature was held constant with traditional control, the lint moisture content at the gin stand changed when the lint moisture content entering the dryer changed. However, when the final moisture content was controlled with the experimental equipment, the final moisture content did not change significantly. Based on 14 h of data, the final moisture content was within ±0.5% wet basis of the setpoint 90% of the time, including periods when the initial moisture content or setpoint was changing.

REFERENCES