Computerized Process Control for Gins

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ABSTRACT

A computerized gin process control system (CGPCS) to "prescription process" cotton was developed and implemented in the United States. Properly controlling the cleaning and drying that cotton receives during processing at the gin with a CGPCS increases monetary returns to the farmer, increases fiber yield and improves fiber quality. The CGPCS can be simple or complex and can range from a single camera that measures the colour and trash of the cotton to a full CGPCS that has several camera systems to measure colour and trash, multiple moisture sensors and automated valves that allow continuous and immediate diversion of the cotton during processing. Positive results from field experiences over a 9-year period from 1989 to 1997 at commercial cotton gins indicated that the equipment and software are very beneficial to the farmer. Sufficient increased profits to the farmer and ginner should recover the entire cost of the CGPCS system during the first year of operation. In general, controlling the level of drying increased bale weights about 4.5 kg (10 lb.) per bale and bypassing one stage of lint cleaning on cotton selected by the computerized system increased the bale weight about 4.5 kg (10 lb.) per bale. Monetary returns can be increased by $7 to $21 per bale for 16-20 million bales produced annually in the U.S. Fiber yield is increased 6% and neps and short fiber content are decreased over 40%.

Introduction

The amount of trash and moisture in seed cotton harvested and brought to the gin varies greatly. The trash may be composed of many different sizes of trash particles with some of these trash particles being very difficult to remove. Trash removal is complicated for some "hairy-leaf" varieties by the presence of plant hairs or trichomes on some of the plant particles that make them more difficult to remove from the cotton fiber. Most cotton in the U.S. is processed through the same amount of cleaning and drying equipment in a gin regardless of initial trash level, hairiness of the variety, desired final grade, and to some extent, moisture level. Individual gin stands process as much as 15 bales per hour and most gins have several gin stands. In order to produce the highest value from the cotton, gins must move to an automated system and gin each bale of cotton based on its trash and moisture content and the desired end product.

How does a CGPCS work? Simply put, the current CGPCS measures the moisture, colour, and trash content of cotton before processing; estimates the influence of gin machines on those factors; considers the improvement in market price versus the reduction in marketable lint; determines the optimum machine sequence; executes the decision for machines; again measures moisture, colour and trash in the system; refines the process; and again measures the colour, moisture and trash. The selection of cleaners is currently an incremental decision; it is either a yes or no only. In contrast, modifying the moisture level of the cotton prior to cleaning allows continuous rather than incremental improvements in the final trash grade and colour grade of the cotton. The objective of the CGPCS is to maximize profits and manage quality. In essence, a system like this "prescription ginning."

To make the system commercially viable, a comprehensive, long-range research program to systematically develop and implement required components of the automated system was initiated. This research encompassed computer simulation models to describe the effects of each gin machine on fiber quality, infrared and resistance moisture sensors to detect moisture content, cameras to measure the colour and trash, automated bypass valves, semi-automated bypass valves, automated sensor calibration devices, automated sample collection apparatus, and software to analyze sensor data to determine the optimum process sequence and route cotton through the proper machinery. As each part of the system was developed, tests were conducted at commercial gins to validate the system in a commercial setting.

Material and Methods

Research primarily at the U.S. Cotton Ginning Laboratory, Stoneville, MS, showed that it is possible to monitor the trash and moisture level of the cotton as well as its colour. In 1982, a computer program was developed to optimize the gin process based on the physical properties of the input cotton, the performance characteristics of gin machinery and the potential market prices of the cotton (Anthony, 1982). This program generated a matrix of optimum decisions for all possible values for incoming colour, moisture, and trash (Anthony, 1985). In 1986, a small-scale cotton ginning system (microgin) equipped with a single gin stand and a full complement of seed cotton cleaners, lint cleaners, and dryers with a capacity of less than one bale per hour was retrofitted with cameras to measure the colour and trash of the cotton, and infrared meters to measure the moisture content of the cotton. A computerized gin process control system was fully implemented in the Microgin at the USDA Cotton Ginning Laboratory at Stoneville, MS, in 1989 (Anthony, 1990).

The system consisted of three sensing stations (one at the feed control, one immediately above the extractor-feeder, and one at the battery condenser) for moisture content, colour and trash with computer software to collect and analyze the data and determine the optimum process sequence, and in-line directional valves to continuously redirect the flow of cotton as indicated by the computer. Each sensing station consisted of an infrared moisture meter manufactured by Infrared Engineering of Waltham, Massachusetts (Anthony, 1991) and a video camera manufactured by Motion Control, Inc., of Dallas, TX (Anthony, 1989) to measure colour and trash. Measurements were made about every three seconds and transmitted to a host computer that controlled the process. In order to improve the accuracy of the sensors, a compression ram was installed at the feed control and at the hopper above the extractor-feeder to compress the cotton against the sensors (Anthony, 1994 and Anthony and McCaskill, 1989). The process control systems were operated extensively and the sensors functioned correctly. This system also included additional valving that allows instantaneous diversion of the cotton from a machine or to a machine throughout the entire gin process.

Concurrent with implementation of the initial hardware to monitor the physical properties of the cotton, control software was developed to integrate the measurement from the sensors into the optimization model and direct the cotton automatically into the desired machinery sequence (Anthony, 1990). Data collected in the microgin indicated good correlation with laboratory measurements of moisture and trash. The data also correlated well with official classing of the cotton by the United States Department of Agriculture, Agricultural Service (USDA-AMS).

Results and Discussion

Stoneville

In 1991 and 1992 the commercial-size gin at the U.S. Cotton Ginning Laboratory, Stoneville, MS, was retrofitted with process control equipment. An infrared moisture meter and a colour/trash meter were incorporated with a paddle-sampler device and inserted between the trailer and the feed control to continuously monitor the moisture, colour, and trash content of the cotton. The moisture sensor was used to help control the drying process. A second moisture sensor was installed after the last stage of seed cotton cleaning and before the extractor-feeder. Colour/trash meters were also installed behind the gin stand and before the battery condenser. Initial studies in the Stoneville gin indicated that at least $7.00 per bale could be saved on average by utilizing decisions recommended by the process control system.

Burdette Gin

Equipment similar to that used in the Microgin was installed in a phased approach over a 6-year period beginning with the infrared moisture meters and increasing each year until most of the system was available. Initially, an infrared moisture meter and a single colour/trash sensing station were used in a commercial gin at Burdette, MS (Anthony *et al.*, 1994). The infrared moisture meter was positioned above the extractor-feeder and the colour/trash meter was positioned in an off-line automatic sampling device that continuously extracted cotton from the lint flue, formed it into a batt on a condenser screen and compressed it against the video camera, and then released it back into the lint duct. These devices worked well but were expensive. The next year, a colour/trash meter was installed above the extractor-feeder and a compression ram was used to press the seed cotton up against the camera in order to improve the accuracy of the readings. Measurements on seed cotton, especially colour, were difficult to make and as a result, a new device called a paddle sampler was developed (Anthony, 1994) to allow cotton to be captured as it was pneumatically transported in the gin. This device allowed cotton to be collected as it was flowing through a seed cotton or lint cotton pipe at velocities of 1829 m (6,000 ft) per minute or so, compressed against the sensor, and then released. This device made it possible to move the colour/trash sensor (camera) that was initially located immediately above the extractor-feeder to a point immediately behind the gin stand. It also allowed replacement of the complicated automated sampling and measurement device near the lint flue with one that was installed in the lint flue. The camera and infrared systems worked well in the commercial gin. The lint-cleaner valves at Burdette Gin were automated by equipping the directional leafs with pneumatic cylinders, position sensors and programmable controllers (Anthony *et al.*, 1994).

At Burdette Gin in 1994, a new sampling station that included an automated calibration device as well as new solid-state cameras was installed before the battery condenser. The station was primarily for operational evaluations and only minimal data was collected. The system survived several fires and exposures to extreme water use. The only damage was to the calibration tiles. The system at Burdette performed satisfactorily during the ginning season.

After 1995, emphasis was placed on enhanced moisture measurement and dryer control as well as other research.

Westlake

In 1992, the on-line colour/trash monitoring system was also installed in a commercial gin in California. One colour/trash meter was installed behind the gin stand while another was installed immediately before the battery condenser. These meters allowed continuous assessment of the colour/trash content of cotton before and after lint cleaning. Following recommendations of the process control system increased farmer profits about $250,000 on the 40,000 bales ginned.

In 1993, a colour/trash camera and a moisture sensor were also installed in the hot-air line between the module feeder and the first tower dryer. The primary purpose of this measurement system was to aid in dryer control by identifying the trash content of the cotton and to provide guidance as to the level of seed cotton cleaning required. Following recommendations of the process control system again increased farmer profits about $240,000 (Anthony *et al.*, 1995a).

In 1994, two of the three sensing stations were replaced with ones that incorporated an automated calibration device (Anthony *et al.*, 1995b). The system was evaluated while ginning over 40,000 bales. In terms of process control, only one lint cleaner was used as recommended by the system for the first 25% of the season, whereas two lint cleaners were usually required in the middle of the season due to adverse weather conditions in the field prior to harvest, and only one was required late in the season. As a result of the information available from the online monitoring and control system, about $7/bale was made by bypassing the second lint cleaner on 50% of the bales for an average of about $3.50/bale for the season. Reduced drying on nearly all of the cotton increased profits about $7/bale. Generally, the lint cleaning decision avoided the sharp price break between leaf 5 and 6 for colour 31 on the market price schedule.

In 1995, abut 50% of the bales were ginned with one-lint cleaner rather than the conventional two-lint cleaners, and the cotton was dried about 2 percentage points less. Thus bale weight was increased about 9 kg (20 lb) each and dollar values increased by $15 each for total of $600,000.

The limited process control system was continued for 1996 and 1997 seasons, however, reportable monetary data is not available.

Servico

In 1994, the most nearly complete computerized process control system was installed at Servico Gin in Courtland, AL (Anthony *et al.*, 1995b). The system included three sensing stations similar to ones previously used in other commercial gins. Additional new components such as resistance moisture sensors, temperature sensors, automated calibration devices, automated directional valves, and new cameras were also installed and evaluated. Installation of the new equipment in a conventional commercial gin before field testing a prototype deviated from the normal research approach. However, it offered a needed opportunity to reduce the technology transfer time. Three measurement stations were installed--before the feed control, after the gin stand, and before the battery condenser. Moisture sensors (Anthony *et al.*, 1995a) were installed in the paddle of the paddle sampler and automated calibrators were installed in conjunction with the camera system. The directional valves were installed between lint cleaners to allow continuous and on-line redirection of the cotton without stopping the machines or the flow of cotton. Much of the computer equipment and the cotton and computer monitors were installed in the control console for the gin. Valves were installed during the season to bypass three stages of seed cotton cleaning and the second stage of drying. Over 45,000 bales were processed after the experimental equipment was installed.

Measurement of the temperature, moisture, colour, and leaf grade of the seed cotton and lint as it was processed through the ginning machinery was successful. Temperature sensors provided good estimates of the temperature to which the cotton was exposed throughout the gin process that should be very beneficial to the textile mill. The first sampling station did not capture an adequate sample of seed cotton sufficiently often to allow good representation of the moisture, colour and trash at that point because the cotton was travelling too fast for the paddle to collect a sample. The second and third sampling stations collected lint samples satisfactorily. The experimental moisture sensors measured the moisture above 5%, wet basis. Moisture levels were controlled about 1-2% higher than normal as long as satisfactory leaf grades were obtained. Colour and trash measurements followed the onsite classer as well as the official AMS class.

The automated calibration devices worked well without cotton in the system but had a tendency to collect cotton when operated during ginning. They were operated at a number of different time intervals from 30 minutes to 4 hours over the course of the season.

Measurements taken at the last sensing station at Servico correlated with the official classification of the cotton samples; colour was exactly the same 42% of the time, differed by one grade 27% of the time, and differed by one integer 13% of the time (Anthony *et al.*, 1995b). Leaf was exactly the same 60% of the time and differed by one 37% of the time. More importantly, the correct optimum decision on how to clean the cotton was recommended 81% of the time regardless of the correlation between AMS and the gin. This was true because the same decision is made for a number of colour-leaf combinations, especially when the market value is the same for different combinations of colour and leaf grades.

In 1995, bypass valves were added to four seed cotton cleaners to further expand the ability to precisely process the cotton. Two of the seed cotton cleaners were consistently bypassed throughout the season. The second stage of lint cleaning was bypassed about 80% of the time. Based on estimates by the gin manager, the value of each bale was increased $10.50.

The field systems were equipped with video indicators to identify the amount of lint cleaning recommended for a particular cotton. Seed cotton cleaners were not considered for bypassing until the 1995 season at Servico. The ginner could, at his discretion, decide whether to shift from one to two lint cleaners or vice versa. Rotary actuators or pneumatic cylinders were added to the valves between the lint cleaners to enable the ginner to simply press a button to disengage the gin stand, allow the lint cotton to clear the lint cleaner, change the valves, and engage the gin stand. For convenience, rotary actuators were installed on the shaft of each valve leaf for the conventional 16-D lint cleaners whereas linear-move air cylinders were used on the Lummus lint cleaners. Each set of valves was controlled by a programmable controller that was integrated with the central microcomputer. This valving option differed from the ones used at the small-scale and commercial-size facilities at the Stoneville Lab in that the valves at Burdette and Westlake gins required the gin stand to be disengaged prior to changing the valves which necessitates a 15-20 second downtime each time the valves are changed. The valves at the Stoneville Lab are switched automatically and on-line without disengaging the gin stand, but the Stoneville valves require replacement of the existing valving system at a significantly higher cost. Directional valves similar to the Stoneville ones were installed between lint cleaners at Servico to allow continuous and on-line redirection of the cotton without stopping the machines or the flow of cotton.

Commercialization

Based on the successes in 1994 and 1995, Zellweger Uster licensed several USDA patents to enable them to make the CGPCS available to the cotton industry. In 1996, the CGPCS at Servico was upgraded with Zellweger Uster cameras. Again, the upgraded CGPCS was very successful. Prior to the 1997 season, new Zellweger Uster manufactured sampling stations, flash cameras, FM data transmission equipment, and other improvements were installed at Servico. The new system essentially operated on “automatic pilot” during the 1997 season. Frye (1998a) reported 40% fewer short fiber and less mill waste from processing cotton from Servico when using the CGPCS. He also reported that cotton quality exceeded that from both the Birmingham, AL and Visalia, CA cotton classing offices. Experiences with the cotton from Servico at one textile mill have been exceptionally favourable (Frye, 1998b). The same mill (Parkdale) has purchased the entire gin production for 1998 (Greene, 1998).

New beta sites were also installed prior to the 1997 season at Marianna and Dumas, AR, and were Zellweger Uster’s first installations. Four additional CGPCSs are being installed for the 1998 season (Ghorashi, 1998). Thus, this new technology is now available to the cotton industry on a limited basis.

Conclusion

Rapid expansion of automated and intelligent process control systems for cotton gins will vastly improve the quality of cotton. The capability to rapidly determine the essential fiber quality features of cotton and to consider the ability of individual cotton machines to modify those fiber quality characteristics every few seconds, and to make those measurements at multiple locations in the ginning process and refine the machinery selection is the basis for a new frontier in cotton ginning. Armed with a full spectrum of knowledge concerning the fiber qualities of cotton online during processing and the capabilities of gin machines to influence those fiber qualities, this new frontier will represent many future opportunities for improved ginning processes. It will also serve as a platform for major advancements in gin machinery, in fact, some are already in the patent process. New, less aggressive and less damaging machines can be developed and integrated into existing gin systems that can now monitor the performance of those machines. Ginners will now be able to achieve the desired fiber qualities based upon guidance from the farmer or textile mill within constraints of initial fiber quality characteristics. Farmers, ginners, gin managers, and the textile industry now have access to instantaneous online measurements of cotton quality. Interactive, responsive processing at the gin can now be controlled remotely by the buyer of the cotton. Enormous opportunities exist for re-engineering the post harvest processing of cotton to deliver textile mills precise products that meet their specifications. With control of the cotton fiber quality characteristics comes the opportunity for improvements in the textile industry. The stage is now set for ginning to be the next new frontier in cotton processing.

The amount of trash and moisture in seed cotton harvested and brought to commercial ginning facilities varies significantly. However, most cotton in the United States is processed in the gin using the same amount of cleaning and drying equipment regardless of its initial trash level, colour and moisture content. Many commercial gins process cotton at a rate between 30 and 100 bales per hour so they cannot process each bale of cotton differently.

The CGPCS was developed for "prescription ginning" of raw seed cotton to ultimately improve the quality of the end product and increase the monetary value and quantity of the cotton to the farmer. The CGPCS represents a major milestone in the cotton industry. The CGPCS uses commercially available or ARS-developed sensors to measure cotton quality at various stages of the ginning process. Dynamic optimization computer models integrate the performance characteristics of gin machinery with the initial quality of the cotton and its potential market value to determine the optimal gin sequence. The computer directs valving to automatically route cotton through the optimal machine sequence, so cotton with variable contents of trash, moisture and colour are not treated at the same level, thus the gin processing is optimized.

The CGPCS technology will revolutionize the cotton ginning industry by ensuring that cotton can be dried to the proper moisture content for optimum cleaning and ginning, while avoiding fiber damage. Savings in fiber weight alone will increase cotton production by 6% or 1 million bales annually. Experiences thus far suggest an increase in profits of $7 to $21 per bale for the 15 to 21 million bales produced in the United States, representing as much as $441 million to cotton farmers in the United States alone. The same technology can be applied to the international cotton industry, which produces over 80 million bales annually.

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