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ENGINEERING AND GINNING

Evaluation of a Mass Flow Sensor at a Gin

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ABSTRACT

As part of a system to optimize the cotton ginning process, a custom-built mass flow sensor was evaluated at USDA ARS Cotton Ginning Research Unit at Stoneville, Mississippi. The mass flow sensor was fabricated based on the principle of the sensor patented by Thomasson and Sui. The optical and electronic components of the sensor were housed in a single aluminum unit with mounting magnet, which made it easy to install and maintain. To obtain a calibration of the sensor, the total mass flow past the sensor was measured over known periods of time. To evaluate the effect of cotton cultivar on the sensor, a test of the sensor with two cotton cultivars was conducted using a micro-gin to compare lint mass flow with sensor output. Results showed that the sensor output was closely correlated with the lint mass, which passed through the sensor (r^2 = 0.87), and the effect of cotton cultivar on the output of sensor was not significant. This demonstrated that the mass flow sensor can measure the total lint flow over a period of time in the gin and provide valuable information to the ginner.

An automatic control system for cotton ginning process control has great potential in reducing labor costs, preserving fiber quality, and increasing operation efficiency at cotton gins. Real-time measurement of cotton flow at various stages of ginning will be one of the most critical components in the control system. Several optical cotton flow measurement systems have been developed and tested in recent years on cotton harvesters. Wilkerson et al. (1994) developed an optical attenuation-based sensor to measure cotton flow. This system was significantly modified and improved (Moody et al. 2000; Wilkerson et al., 2002) and marketed beginning in 2000 as the AgLeader (Ames, IA) Cotton Yield Monitor. Thomasson et al. (1999) designed and fabricated two light sensing-bar devices for measuring the flow of pneumatically conveyed cotton. FarmScan (Perth, Western Australia), Micro-Trak (Eagle Lake, MN), and Zycom/AGRIplan (Stow, MA) have manufactured commercial optical cotton yield monitors using optical cotton-flow sensors since 1997. These cotton mass flow sensors were evaluated with cotton harvesters under field conditions (Durrence et al., 1998; Roades et al., 2000; Sassenrath-Cole et al., 1999; Wolak et al., 1999; Vellidis et al., 2003).

In addition to being used to measure cotton flow on cotton harvesters, the optical mass flow sensors have also been tested at gins. The light-sensing bar devices reported by Thomasson et al. (1999) were tested in collecting data in the seed cotton unloading duct of a gin and a lint-cleaner-exhaust duct. Results indicated a strong correlation between the output of the devices and the material flow (Thomasson et al., 1999; Whitelock and Thomson, 1998). Moody et al. (2000) tested the mass flow sensor developed by Wilkerson et al. (1994) at a gin. The sensor was installed in a pneumatic seed cotton conveying duct to measure the cotton flow with 59 loads. Data from the first 10 loads were used to calibrate a flow prediction model. Results showed that 48 of 49 total load weights were measured by the sensor to within 10 percent of true values. Moisture content (MC) of the cotton and cultivar had a detectable effect on measurement accuracy. Barker et al. (2000) evaluated several mass flow sensors, including a light bar array to detect the mass flow rate of stripper-harvested cotton. They obtained a very strong correlation (r^2=0.98) between the output signal of the light bar array and mass flow rate of the cotton through the pipes. Gvili (2001) tested a cotton flow sensor at a gin. Measurement accuracies in the range of 5% were achieved.

All of the cotton flow sensors mentioned above used optical detectors. The sensors were based on the same principle and are similar in configuration and operation. Each sensor unit has two parts, a light emitter array and a light detector array mounted opposite each other on a pneumatic duct. The sensors

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measure light attenuation caused by cotton particles passing through the duct. Thus, their installation requires two ports to be cut in the duct and proper alignment of the light-emitter array and a light-detector array. This creates difficulties in installation and possible misalignment over time due to vibration of the sensor.

Thomasson and Sui (2000) and Sui and Thomasson (2002) reported an optical reflectance-based mass flow sensor. Their sensor included light source and detectors mounted in one housing unit on the same wall of a pneumatic duct, thus requiring only one port to be cut in the duct. Such a configuration minimizes the difficulty of installation and maintenance, and removes any requirement for alignment of sensor parts. This mass flow sensor has been used as a cotton yield monitor and has been field tested since 1999 (Ge et al., 2008; Sui et al., 2004; Thomasson and Sui, 2003; Vellidis et al., 2003). Test results indicated the sensor was reliable and easy to install, operate, and maintain on a harvester. However, this sensor has not been used to measure cotton flow at a gin.

Mass flow sensors used on cotton harvesters would need to be adapted for use in cotton gins because of the different operating environment and different demands. When the seed cotton enters the gin it is similar to what was harvested in the field, but after processing, the composition of the material has changed, and after ginning the flow pattern of the fiber in the air stream is considerably different from that of the seed cotton.

The objectives of the study in this phase were to 1) evaluate the functionality and accuracy of the sensor by measuring different total masses of cotton lint produced by the gin stand, and 2) test the effect measurement using two cultivars with different lint properties.

MATERIALS AND METHODS

Mass flow Sensor Description. A mass flow sensor was fabricated based on the principle of the sensor patented by Thomasson and Sui (2004). All components were housed in a single aluminum unit with mounting magnets, which made it easy to install and maintain (Fig. 1). The sensor was 120 mm long and 115 mm in diameter with a 4.5 m long cable. The sensor was designed to detect a mass by sensing the reflectance properties of the measured material as the material passes the sensor. The sensor had an anti-stray-light feature. Therefore, ambient light fluctuations did not affect its performance (Thomasson and Sui, 2004). Furthermore, the mass flow sensor included a built-in temperature control so that the sensor's internal temperature was controlled which improved accuracy and stability of the sensor when used under varying temperatures.

Figure 1. Mass flow sensor for gins.

Sensor Installation and Data Acquisition. The sensor was installed at the Micro-Gin of USDA ARS Cotton Ginning Research Unit (CGRU) at Stoneville, Mississippi (Fig 2). A bracket was built for installation of the mass flow sensor (Fig. 3). The bracket was made of sheet metal with a 76 mm diameter hole and a 30 mm high x 115 mm diameter circular holder at center. One 76 mm diameter hole was cut in the conveying duct (380 Wx150 D mm) after the gin stand and before the lint cleaner for installing the sensor (Fig 2). The bracket was mounted on the duct aligning the central hole with the hole cut in the duct. The mass flow sensor was placed into the circular holder with its window toward duct. The sensor was firmly attached to the bracket by the three magnets on the sensor and two screws on the holder (Fig. 4).

The mass flow sensor was connected to a data acquisition unit reported by Sui and Thomasson (2006). The unit included a 206-MHz, 32-bit CPU and an 8-channel 12-bit analog–to-digital converter (ADC). The analog signal from the mass flow sensor was input to the ADC and then collected by a single board computer in the unit. Sensor data were displayed on a screen and stored in a memory card. Embedded Visual Basic was used as the programming language for the data acquisition unit.

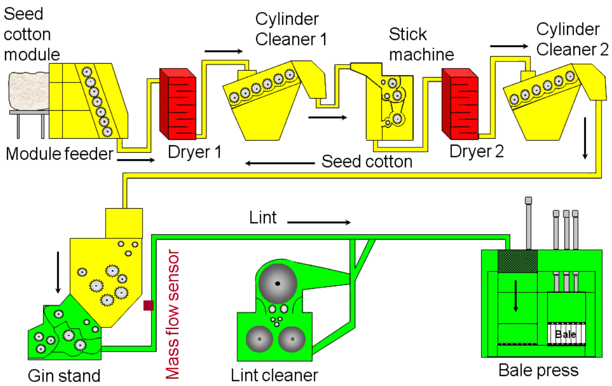

Figure 2. Show the location of mass flow sensor and the ginning sequence in test.

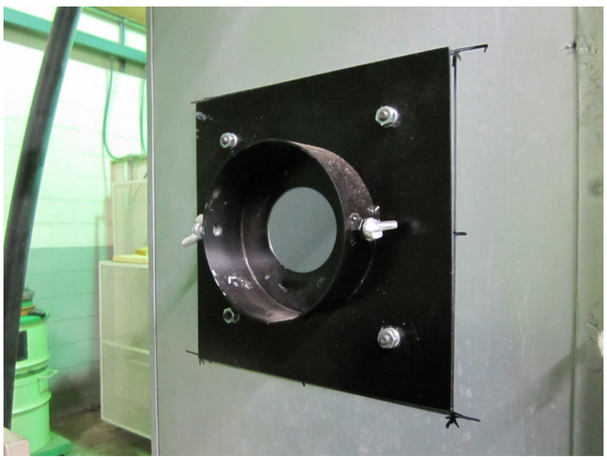

Figure 3. Bracket on gin duct.

Figure 4. The mass flow sensor installed on a duct behind gin stand.

Test Procedures. To evaluate performance of the sensor in measuring lint-flow at the gin and test the effect of cotton cultivar on the performance of the sensor, a test was conducted on July 19 and 20, 2010. The sensor and data acquisition unit was turned on 30 minutes before the test to allow the sensor to warm up. Two cultivars of cotton, FiberMax 960B2 (Bayer CropScience, Research Triangle Park, NC) and PhytoGen 485WRF (Dow AgroSciences, Indianapolis, IN) were used in the test. The cotton was harvested using a cotton picker. Thirty-nine seed cotton samples with a weight range from around 4.5 kg to 58.5 kg of each cultivar ginned in random order with the measurement system collecting data. The seed cotton samples were divided into 13 levels based on their weight, with around 4.5 kg increments. As the cotton was ginned and the lint conveyed past the sensor, the data output from the sensor was recorded with the data acquisition unit that reads the sensor output at a frequency of about 50 Hz and stores the average of the readings in each second. Seed cotton samples were weighed before being ginned and the lint weights were determined after the flow data were collected. The ginning sequence included dryer 1, cylinder cleaner, stick machine, dryer 2, cylinder cleaner, extractor feeder gin stand, and saw-type lint cleaner (Figure 2). There was no heat added in the dryers in the ginning process. Three sub-samples of lint were collected after the lint cleaner from each sample for MC determination and testing with Advanced Fiber Information System (AFIS) and High Volume Instrument (HVI). All lint samples were analyzed at the USDA ARS CGRU at Stoneville, MS and the USDA ARS SRRC (Southern Regional Research Center) to determine the effect of fiber quality on performance of the sensor. Fiber quality parameters, including trash content, reflectance, yellowness, and short fiber content (SFC), were measured with AFIS and HVI tests. MC was determined by the conventional oven method (Shepherd, 1972).

Data Analysis. Average of ten minimum output values of the mass flow sensor with each sample was calculated and used as a baseline of sensor output for the sample. Sensor output was corrected by subtracting the baseline from the original output value. After baseline correction, sensor output values were accumulated over the ginning time with each sample. Linear regression was then used to determine the relationship between the lint weight and the summation of sensor output. Lint weights were computed using the regression functions and compared with the actual lint weights of the samples. Lint weight residuals were also calculated by subtracting the predicted weights from the actual weights. The residuals were graphically analyzed to determine the suitability of the regression model. Signal-to-weight ratio (STWR) was calculated by dividing the summation of sensor output by the lint weight. One-way ANOVA and a Tukey post-hoc test were conducted with SAS to compare the effect of the cotton cultivar on the STWR.

Cultivar differences in fiber moisture content and fiber quality; including micronaire, reflectance, yellowness, SFC, and trash content were also analyzed using an ANOVA test. Additionally PROC MEANS procedure was used to calculate the mean, standard deviation, standard error, maximum, and minimum of the fiber quality data, turnout, and the STWR.

RESULTS AND DISCUSSION

Sensor Performance. The mass flow sensor performed well during the test. As the cotton passed the sensor, the output of the sensor varied with the change of cotton mass flow (Fig. 5a and 5b). Though the mass flow rate was not intentionally controlled in this phase of study, the mass flow rate did change due to the variation of operational condition of the gin such as the fan speed and seed cotton feeding rates. The lint flow rate for data shown in fig. 5a was 2.92kg/min while it was 2.55kg/min for the data shown in fig. 5b. The higher mass flow rate generated greater sensor output values. Fluctuation of the sensor output was about 0.5 V across the range of mass flow rates in the test. The maximum output range of the sensor is 3.8 V. Fig. 6a shows the correlation between lint-flow weight and the sensor output with cultivars FiberMax 960B2 and PhytoGen 485WRF. Fig. 6b is a plot of the lint-flow weight versus the sensor output using combined data of the two cultivars. Both figure 6a and 6b indicated that the lint weight measured by the sensor was closely correlated with summation of the sensor output (r^2=0.87). Lint weights calculated using the regression function shown in Fig 6b were plotted against the actual weights (Fig. 7). Fig. 8 showed a plot of lint weight residuals versus the actual lint weights of samples. The residuals appeared to behave randomly, suggesting that the models fit the data well.

Sensor output data indicated that the baseline varied about ±6% over the tests. This change had significant effect on sensor accuracy. Baseline drift could be mainly caused by the instability of the light emitting diode (LED) that was the light source of the sensor without going through an aging process in this case. The baseline could be expected to become more consistent as the LEDs pass their aging period. However, baseline drift could also be attributed to other issues like noise in electronic circuitry, sensor window contamination, and operational temperature and humidity variation. An effective method to solve this baseline problem could be to detect the baseline and make baseline correction of the sensor output in real time during the data acquisition.

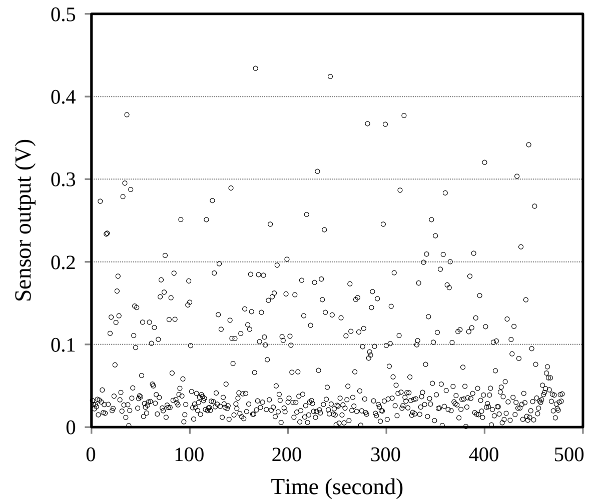

Figure 5a. Mass flow sensor output as cotton passed by the sensor at a higher flow rate (2.92kg/min).

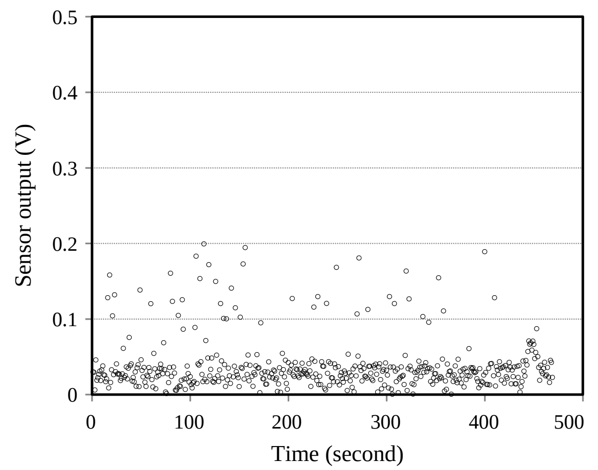

Figure 5b. Mass flow sensor output as cotton passed by the sensor at a lower flow rate (2.55kg/min).

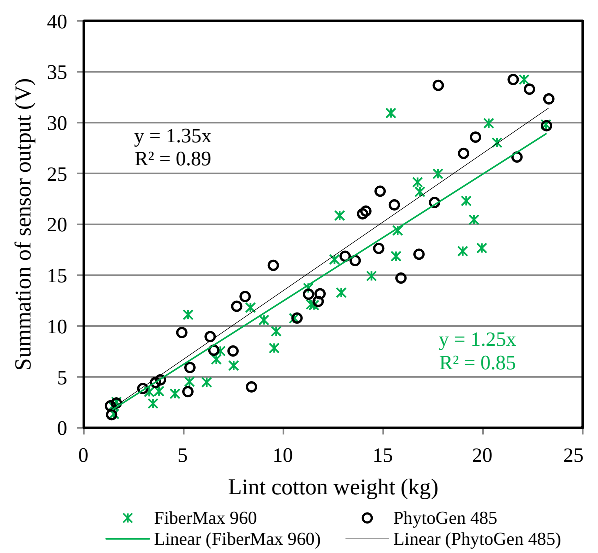

Figure 6a. Correlation of sensor output versus total lint weight with the cultivar FiberMax 960B2 and PhytoGen 485WRF.

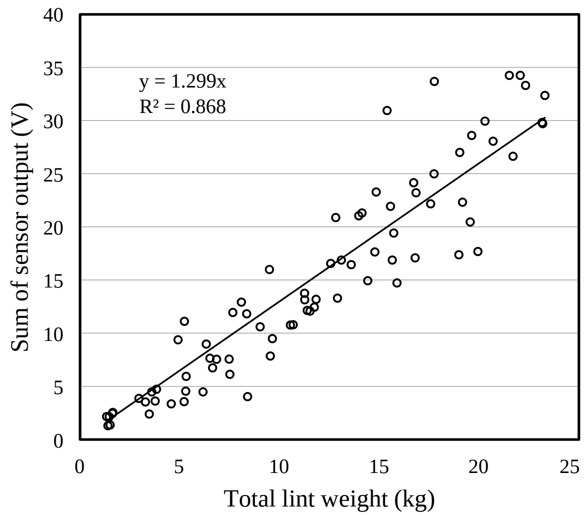

Figure 6b. Correlation of sensor output versus lint weight using the combined data of the two cultivars.

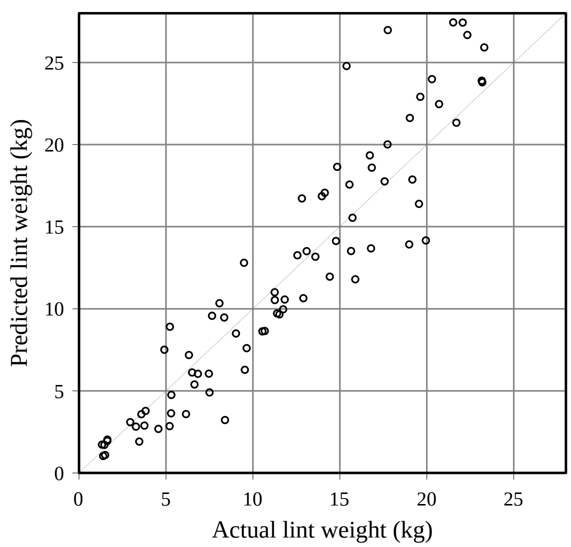

Figure. 7 Actual total lint weight versus predicted lint weight.

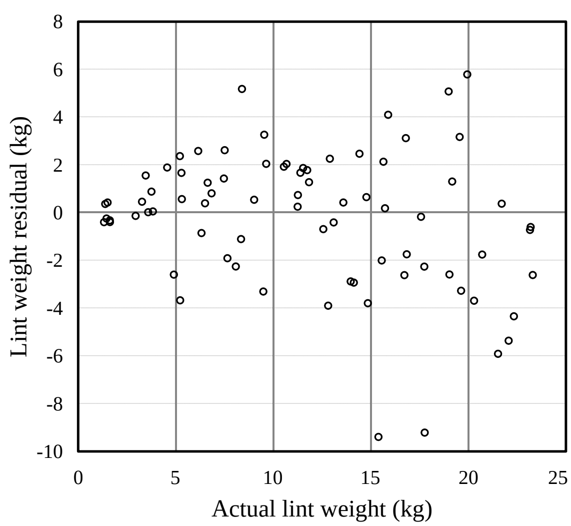

Figure 8. Plot of lint weight residuals.

The sensor's optical window remained fairly clean throughout the test. The method used in sensor installation worked effectively. No maintenance for the sensor was required during the test. However, cotton tags were occasionally created inside the duct on the bolt heads that were used in mounting the bracket. It was possible that the tag could be viewed by the sensor causing a "false" output signal, and generate the measurement error. This issue can be solved by welding the bracket onto the duct instead of mounting it by using screws.

Fiber Quality and Turnout. Table 1 shows major fiber quality factors of the cotton used in the test. A one-way ANOVA test revealed that SFC in the samples differed significantly as a function of the cultivar (F (1, 76) = 81.63, $p < 0.0001$). FiberMax samples had higher SFC (M = 9.28%, SD = 0.58%) than PhytoGen samples (M = 8.03%, SD = 0.64%). The one-way ANOVA tests also indicated that the effect of cultivar on trash content (F (1, 76) = 71.54, $p < 0.0001$) was significant. There was more trash (M = 166.33 cnt/g, SD = 36.02 cnt/g) in PhytoGen samples than the trash (M = 102.31 cnt/g, SD = 30.61 cnt/g) in the FiberMax. MC of the PhytoGen samples was a little higher (M = 6.19%, SD = 0.34%) than that of the FiberMax (M = 6.02%, SD = 0.32%), but the ANOVA test showed the difference was statistically significant (F (1, 76) = 5.25, $p = 0.0214$). The ANOVA test revealed fiber reflectance (Rd) of the FiberMax and PhytoGen cultivar was significantly different (F (1, 76) = 7.32, $p = 0.0084$). And their fiber yellowness was also significantly different (F (1, 76) = 182.61, $p < 0.0001$). Means of the micronaire value were 4.24 (SD = 0.24) with the FiberMax samples and 4.18 (SD = 0.11) with the PhytoGen. They were not significantly different (F (1, 76) = 1.89, $p = 0.1737$). Turnout of FiberMax cultivar (M = 37%, SD = 1%) was one percent higher than the PhytoGen (M = 36%, SD = 2%). However, the difference was statistically significant (F (1, 76) = 5.54, $p = 0.0212$).

Effect on Sensor Output. A one-way ANOVA test revealed that STWR did not differ significantly as a function of cotton cultivar (F (1, 75) = 2.92, $p = 0.0917$). Tukey post-hoc comparison of the two cultivars indicated that STWR of the sensor with FiberMax samples (M = 1.18 v/kg, SD = 0.33 v/kg) was not significantly different from that with PhytoGen samples (M = 1.30 v/kg, SD = 0.30 v/kg) (Table 1). Results showed that effect of the cotton cultivar on the sensor's performance was not significant although fiber quality of the cotton differed significantly between the cultivars.

Table 1. Summary of fiber quality parameters of cotton cultivars used in the test and the effect of the cultivar on STWR.

	FiberMax 960B2				PhytoGen 485WRF			
	Mean[x]	SD	Max	Min	Mean[x]	SD	Max	Min
Micronaire	4.24[a]	0.24	4.99	3.80	4.18[a]	0.11	4.41	3.94
SFC(w) %	9.28[a]	0.58	10.70	8.40	8.03[b]	0.64	9.90	7.10
Trash cnt/g	102.30[a]	30.61	145	31	166.33[b]	36.02	233	39
MC %	6.02[a]	0.32	6.95	5.30	6.19[b]	0.34	7.00	5.35
Rd	74.04[a]	1.61	75.23	64.74	73.32[b]	0.48	73.97	72.03
+b	8.02[a]	0.17	7.82	7.10	7.45[b]	0.21	8.50	7.57
Turnout %	37.00 [a]	1.00	39.70	34.86	36.00[b]	2.00	40.95	30.53
STWR v/kg	1.18[a]	0.33	36.49	17.43	1.30[a]	0.30	35.00	15.34

[x] **Means with the same letter are not significantly different at the 0.05 level.**

Moisture and trash content of the cotton could be two key factors which may negatively affect the sensor performance because either can change spectral characteristics of the cotton. However, this study indicated that the variation of moisture and trash content in the samples did not significantly affect the sensor output. The mass flow sensor functioned well in measuring lint flow at gin. However, the cotton processed at gins has a greater range of variability than the cotton used in this study. Maximum tolerance of the sensor to the variation of cotton properties, including MC and trash content, needs to be further evaluated.

CONCLUSIONS

A mass flow sensor was built and evaluated with two different cultivars of cotton to predict lint mass flow at a gin. The mass flow sensor was installed on a conveying duct between the gin stand and the first lint cleaner. Lint weight showed a close correlation with the accumulated sensor output ($r^2 = 0.87$). It was qualitatively observed that higher lint flow rate generated greater sensor output though the lint flow rate was not directly controlled in this phase of the study. Fiber quality of two cotton cultivars used in the test was analyzed using AFIS and HVI tests. The results indicated that the SFC, trash content, reflectance, yellowness, and MC differed significantly. Sensor output was not significantly affected by cultivar. Baseline drift of sensor output and its affect on sensor accuracy was observed. Sensor baseline needs to be detected and corrected in real time for improving sensor's accuracy. The flow rate sensitivity and moisture sensitivity of the sensor will be tested in next phase of the study. The mass flow sensor was easy to install and maintain. It has the potential to be used for the control of cotton ginning processes.

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DISCLAIMER

Mention of a commercial product is solely for the purpose of providing specific information and should not be construed as a product endorsement by the authors or the institutions with which the authors are affiliated.

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