ESTIMATING LINT CLEANER WASTE FLOW-RATE

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Abstract

Knowledge of the mass flow-rate of cotton and its by-products produced during ginning should improve process control. Tests of a previously developed device were conducted to evaluate its capabilities in measuring mass-flow of lint-cleaner-waste (LCW) in the lint-cleaner-exhaust of both a small research gin and a full-size, commercial gin. Results of regression analysis of data collected in the research gin revealed a good correlation (R^2 = 0.88) between sensor output and actual mass flow-rate of LCW through the device. The sensor was then reconfigured and installed and tested in a commercial gin. Linear regression analysis revealed a high correlation (R^2 = 0.95) between sensor output and the amount of LCW that passed through the device during tests in the commercial gin.

Background

Automated process control in cotton gins involves decisions made to remove or add moisture, bypass different stages of seed cotton cleaning, or bypass stages of lint cleaning (Byler and Anthony, 1997). Process control is important because quality degradation can be minimized while profit is optimized by adjusting parameters during the process itself. In order to control different parameters of a process, one must be able to measure those parameters. Measuring mass flow-rate of cotton and cotton waste in gins should enhance gin process control systems already in use.

Efforts have been made to measure mass flow of agricultural products. A mechanical method, involving a paddle elevator and load cell to measure grain flow in a combine, was reported by Howard et al. (1993) to predict grain yields within 5%. Two systems capable of detecting grain yield variations of 10%, one measuring the grain level over a paddle wheel and the other measuring electromagnetic energy attenuation of the grain, have also been reported (Auernhammer, 1993).

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A device to measure cotton flow in pneumatic conveying systems was developed by Wilkerson et al. (1994). Their device measured the attenuation of light passing from a source on one side to photo-detectors on the other side of a cotton picker chute due to cotton flowing through the chute. They reported a high correlation (R^2 = 0.93) between mass of cotton passing through the device and the device's output.

Two devices to measure mass flow of cotton and its by-products in gins were reported by Thomasson et al. (1997). One device has been approved for patent application. Thus, details of its operation are not available. This device's output exhibited a strong relationship (R^2 = 0.90) to seed cotton mass flow in a gin unloading duct of a small-scale gin, but did not predict LCW well. The second device consisted of a light-sensing bar and light source to measure light attenuation as seed cotton or LCW passed through the device. The device's output correlated well (R^2 = 0.92) with LCW mass flow from the lint-cleaner-exhaust of a small research gin.

Objectives

The objectives of this work were two-fold. First, to confirm earlier work by Thomasson et al. (1997) using the same light-sensing bar equipment to measure LCW flow in a small-research gin to determine if further research in a full-size gin was warranted. Second, to determine whether the light-sensing bar device could be used to measure LCW flow in a full-scale gin.

Materials and Procedures

Sensor

A light-sensing bar (LICOR, LI-191SA), 39.4-in. long × 1-in. wide, was used to measure the amount of light, from a 12VDC source, attenuated by LCW flowing through a duct in the lint-cleaner-exhaust (Thomasson et al., 1997). The light-sensing bar produced an electrical current proportional to the incident energy which was converted to a voltage. In earlier tests, Thomasson et al. (1997) found that the reduction in output voltage was well correlated to the flow of LCW between the light-bar and the light source. These same results were expected for a similar configuration and test procedure.

Study 1: Small Research Gin

Duct Configuration. The light-sensing bar was attached to the underside of a square duct, 7-in. cross-section and 48-in. long, at an angle spanning the entire width of the duct (fig. 1). The light source was mounted on the top of the duct and parallel to the light-sensing bar. In a small research gin, the duct was connected to the lint-cleaner-exhaust so that all LCW passed between the light-sensing bar and light source.

Data Collection. For each test in the small research gin, the ginning rate was approximately 1 bale/hr and air velocity in the lint-cleaner-exhaust duct was 2900 ft/min.

The research gin was equipped with full process control allowing for selection of 0 to 3 lint cleaners at any time. A 35-lb lot of seed cotton was ginned for each test. The sequence of machinery employed before the gin stand was 1st tower dryer, 6-cylinder cleaner, stick machine, 2nd tower dryer, impact cleaner, and extractor feeder. The number of lint cleaners was varied from 0 to 3 and 3+ with 5 replications. A test with 3+ lint cleaners involved three lint cleaners plus the LCW collected during the previous 3-lint cleaner test added back into the lint cleaner discharge. The light source was allowed to stabilize before any data was collected and reference baseline voltages (sensor output with no LCW flowing) were taken after each test. While ginning each lot of seed cotton, LCW passed through the sensing device and the light-sensing bar output was recorded.

The LCW was removed from the air stream by a drum condenser and collected in a container. The contents of the container were weighed and sampling time was noted.

Data Analysis. The mass of material collected for each test was divided by sampling time to get average mass flow-rate over the test. Instantaneous data from the sensor were converted to a measured reduction in sensor output (voltage difference) by subtracting it from the average reference voltage taken at the end of each test. The voltage differences were averaged to obtain a mean voltage drop over the test period (fig. 2). Voltage differences were also integrated over the test period to obtain voltage difference curve area. The mean voltage drop and voltage difference curve area were then compared to sample weight and flow-rate. It was hypothesized that mean voltage difference would correlate well with flow-rate and voltage difference curve area would correlate with sample weight. Regression analyses were performed to determine the best correlation between sensor output and flow-rate or sample weight.

Results and Discussion. Data for this study are shown in table 1. As expected, sample weight and flow-rate were correlated with sensor output. Simple linear regression analysis of mean voltage difference with flow-rate resulted in an R^2 value of 0.88 and probability of non-significance less than 0.0001 (fig. 3). Also, an R^2 value of 0.87 and probability of non-significance less than 0.0001 resulted from the regression analysis of voltage difference curve area with sample weight (fig. 4). The mean voltage difference correlated better with flow-rate than sample weight and the opposite was true for voltage difference curve area. From these results and those found earlier, it was decided to install the device in a full-size gin and determine whether it could be used in that setting.

Study 2: Full-Size Gin

Duct Configuration. A custom duct was built and installed in a local gin in a vertical section of pipe between the mote fan and cyclone for the #1 lint cleaners (fig. 5). The duct was 96-in. long and 7-in. deep × 36-in. wide. A 36 in. square-to-round section was attached to each end of the duct to transition to and from the existing 18-in. diameter pipe. The light-sensing bar was attached to the duct at an angle (approximately 22º) so that it spanned the entire width of the duct. The light source ran parallel to and on the opposite side of the duct from the light-sensing bar.

Data Collection. For the full-size gin, light-sensing bar output was recorded while LCW from the #1 lint cleaners passed through the sensing device and was collected in sacks at the mote cyclone. The contents of each sack were weighed and analyzed for moisture content and sampling time was recorded. Ginning rate for all 24 tests was 30-35 bales/hr.

Data Analysis. Mass of material collected for each test was divided by sampling time to get average flow-rate over the test. Instantaneous data from the sensor were converted to a measured reduction sensor output (voltage difference) by the following two methods (fig. 6):

- Method - 1 The instantaneous sensor data were averaged over one second intervals and subtracted from a reference output taken with no LCW flowing in the duct.
- Method - 2 The average sensor data for each second were subtracted from the maximum output for that 1-second. It was hypothesized that the maximum output would be similar to the reference.

The resulting voltage differences, from both methods, were averaged over the test time to give a mean voltage difference. The voltage differences from methods 1 and 2 were also integrated over the test time resulting in voltage difference curve area. Mean voltage differences were also multiplied by the test time to obtain a similar value to curve area.

The total weight collected and the actual average flow-rate were compared with the mean voltage differences, mean voltage differences × time, and curve area calculated by Methods 1 and 2. Correlation procedures and regression analysis were performed to determine the best correlation between sensor output and actual flow-rate or weight collected.

Results and Discussion. The sensor device produced data (Table 2) that correlated well with the weight of LCW collected that passed between the light-sensing bar and light source. Correlation procedures showed that the area under the voltage difference curve area calculated from the maximum sensor output (method 2) and the mean voltage difference × test time calculated from the maximum sensor output (method 2) correlated well with total sample weight, with correlation coefficient 0.97 for both (Table 3). Pearson correlation coefficients for all other sensor output data with sample weight or flow-rate were low ($|R| < 0.60$). None of the sensor data parameters (mean voltage difference, curve area, or mean difference × time) calculated using method 1 (difference from reference) correlated well with either total weight of sample collected or average flow-rate (|R| < 0.58). One reason for this was the difficulty in obtaining good reference data (sensor output with no LCW flowing), around the same time period when tests were performed, as the gin was a commercial facility and ginned continuously. Also, actual flow-rate (LCW mass per time) did not correlate well with any of the sensor data parameters, as the correlation coefficients, R, ranged from -0.08 to 0.60. The reason for this is at this time unknown, but will be explored further.

Regression analysis showed that the voltage difference curve area, calculated by method 2, predicted sample weight, with $R^2 = 0.94$ and probability of non-significance less than 0.0001 (fig. 7). Similarly, mean voltage difference from the maximum output multiplied by test time was also shown to predict sample weight well by regression analysis, with $R^2 = 0.95$ and probability of non-significant slope less than 0.0001 (fig. 8).

Conclusions

It was confirmed that the light-sensing bar device could be used to measure LCW flow in the small research gin. Correlations between sensor output and LCW flow were good, but not as strong as those encountered in earlier research. The results warranted further tests of the device in a full-size gin. In the full-size gin, the light-sensing bar device worked well for measuring the amount of LCW passing through a duct. As expected there were strong correlations between sensor output and total weight of sample collected and equations to estimate weight of LCW that flowed through the device for a known time period from sensor output were produced ($R^2 = 0.95$). Unexpectedly, sensor output did not correlate well with actual flow-rate of LCW (mass of LCW divided by the known sampling time) in the full-size gin.

Disclaimer

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

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Table 1. Summary data for LCW and sensor output from the small research gin (Study 1).

		LCW		Voltage difference	
Replicate	No. of lint cleaners	Sample weight, lbs	Flow-rate, lbs/hr	Mean	Curve area
1	0	0.28	4.00	0.0003	0.078
	1	0.30	4.39	0.0020	0.487
	2	0.50	6.95	0.0111	2.888
	3	0.72	10.58	0.0188	4.596
	3+	1.24	19.16	0.0321	7.467
2	0	0.12	1.66	0.0007	0.172
	1	0.34	5.37	0.0076	1.745
	2	0.62	7.89	0.0106	3.012
	3	0.62	8.49	0.0143	3.760
	3+	1.20	17.14	0.0284	7.147
3	0	0.10	1.53	0.0015	0.350
	1	0.32	5.54	0.0040	0.830
	2	0.46	5.77	0.0143	4.108
	3	0.72	9.49	0.0148	4.025
	3+	1.32	15.95	0.0184	5.481
4	0	0.14	1.79	-0.0004	-0.118
	1	0.32	4.48	0.0017	0.428
	2	0.52	6.73	0.0095	2.637
	3	0.64	7.81	0.0166	4.886
	3+	1.24	15.72	0.0220	6.249
5	0	0.10	1.60	-0.0006	-0.138
	1	0.40	6.23	0.0091	2.102
	2	0.50	8.65	0.0149	3.108
	3	0.70	8.46	0.0151	4.485
	3+	1.28	17.66	0.0219	5.725

Table 2. Summary data for LCW and sensor output collected from the full-size gin (Study 2).

				Voltage difference for calculation method			
				Method 1 - reference		Method 2 - maximum	
	LCW						
Run no.	Sample weight, lbs	Flow-rate, lbs/hr	Moisture content, %	Mean	Curve area	Mean	Curve area
1	11.04	317.98	10.25	0.0357	4.27	0.0341	4.08
2	23.76	247.25	10.05	0.0356	12.43	0.0234	8.11
3	48.90	286.24	9.13	0.0568	33.23	0.0243	14.19
4	50.30	274.78	8.91	-0.0018	-1.16	0.0330	21.72
5	55.10	322.54	9.13	-0.0013	-0.77	0.0355	21.76
6	62.48	363.96	8.78	-0.0247	-15.26	0.0338	20.83
7	55.84	403.66	10.24	-0.0047	-2.33	0.0293	14.54
8	74.64	447.84	10.08	0.0105	6.31	0.0492	29.68
9	9.73	346.81	10.00	0.1359	13.57	0.0393	3.92
10	11.64	337.94	11.40	0.1262	15.41	0.0378	4.63
11	14.30	440.00	11.35	0.1257	14.54	0.0380	4.40
12	12.90	521.80	10.90	0.1313	11.49	0.0384	3.37
13	9.32	447.36	10.90	0.1291	9.63	0.0370	2.77
14	21.37	341.92	9.33	0.1311	28.98	0.0386	8.55
15	35.67	375.47	9.90	0.1293	43.53	0.0384	12.95
16	48.57	405.69	11.75	0.1298	55.02	0.0384	16.32
17	57.89	411.87	9.75	0.1297	64.65	0.0381	19.09
18	10.94	312.57	10.70	0.1133	14.19	0.0359	4.49
19	19.56	389.04	10.92	0.1280	23.09	0.0385	6.90
20	10.64	379.25	10.91	0.1151	11.51	0.0361	3.62
21	11.85	398.69	10.91	0.1179	12.48	0.0335	3.54
22	30.20	385.53	9.52	0.1216	34.61	0.0373	10.51
23	42.05	389.15	10.08	0.1203	47.09	0.0361	14.05
24	52.99	370.42	10.01	0.1186	61.28	0.0360	18.54

Table 3. Pearson correlation coefficients for voltage difference vs. sample weight or flow-rate by calculation method (Study 2).

Voltage difference calculation method	Voltage difference	Sample weight	Flow-rate
Method 1 - from reference	Mean	-0.58	0.38
	Curve area	0.15	0.12
	Mean × time	0.15	0.12
Method 2 - from maximum	Mean	0.04	0.60
	Curve area	0.97	-0.07
	Mean × time	0.97	-0.08

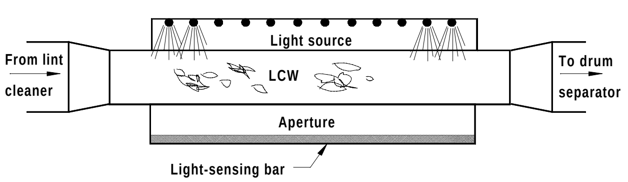

Figure 1. Diagram of light-sensing bar/duct configuration for small research gin (Study 1).

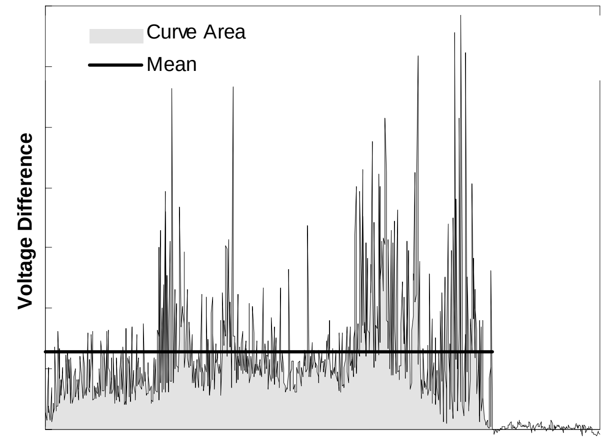

Figure 2. Example of mean voltage difference and voltage difference curve area calculations.

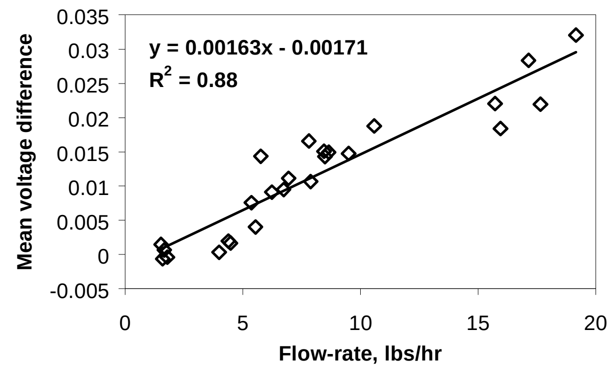

Figure 3. Mean voltage difference vs. Actual flow-rate for data from small research gin (Study 1).

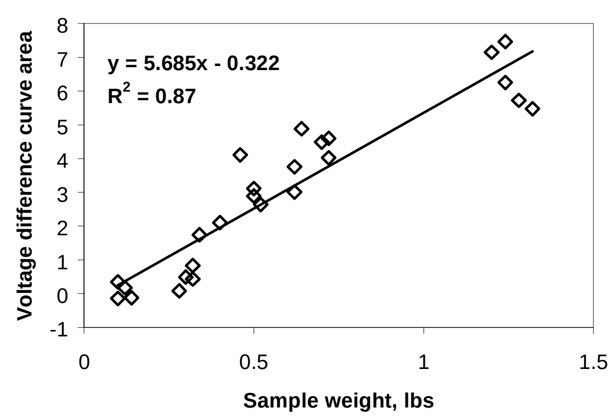

Figure 4. Voltage difference cure area vs. Actual flow-rate for data from small research gin (Study 1).

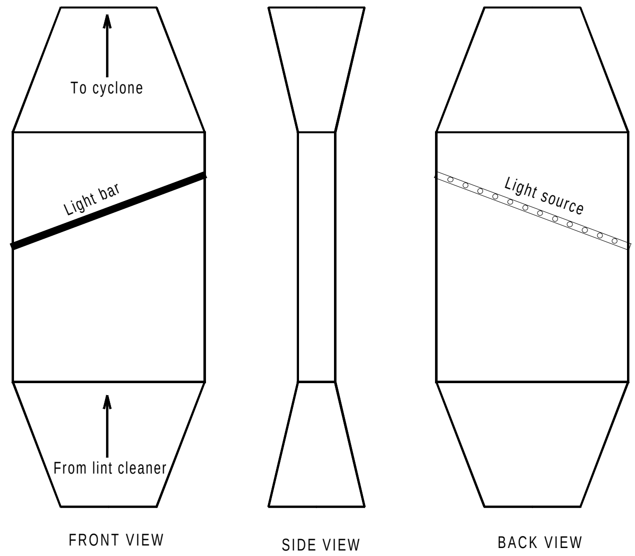

Figure 5. Diagram of light-sensing bar/duct configuration for full-size gin (Study 2).

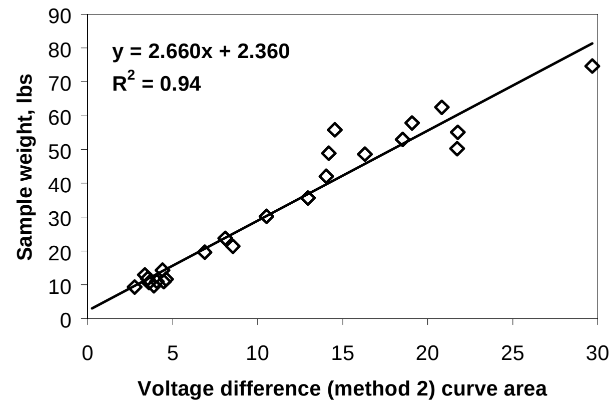

Figure 7. Sample weight vs. Voltage difference (method 2) curve area for data from full-size gin (Study 2).

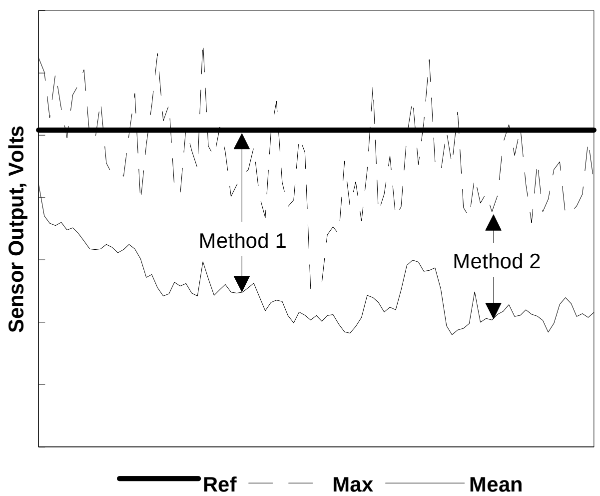

Figure 6. Example voltage difference calculation by method ! (difference from the reference) and method 2 (difference from the maximum).

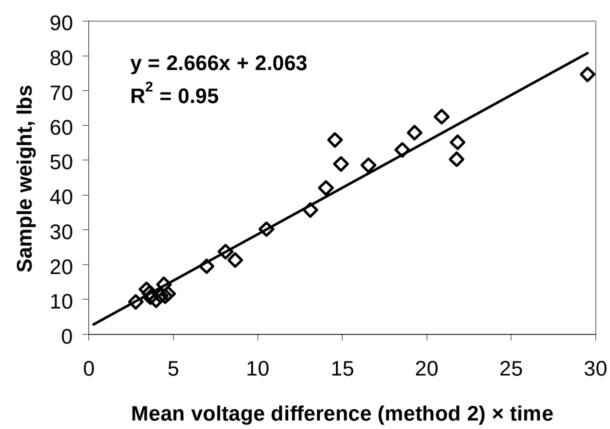

Figure 8. Sample weight vs. Mean voltage difference (method 2) X time for data from full-size gin (Study 2).