SEED COTTON MASS FLOW MEASUREMENT

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Abstract

Five experimental mass flow measurement systems were tested against a weighing conveyor belt at the SW Cotton Ginning Research Lab. A certified truck scale verified accuracy integrated over time. Test systems measured the mass flow rate of pneumatically conveyed seed cotton with ultrasonic and optical signal attenuation, elbow inertial force, pressure difference in a vertical pipe and conveying air velocity pressure. Conveying air velocity pressure most accurately reflected mass flow in real time.

Introduction

Cotton gins are experiencing increasing automation to better human productivity and fiber quality. One automation goal includes delivering the correct amount of energy to the drying system. Another goal is delivering the correct amount of seed cotton to gin machinery, or adjusting the gin machinery to optimally treat the amount of material available. Real-time measurement of the mass flow rate of seed cotton is needed to support these automation goals. At the present time there are no mass flow measurement systems commercially available for cotton gins.

Sassenrath-Cole et al. (1999) tested two commercially available yield monitor optical systems (Vision System and Zycom) on cotton harvesters in Mississippi. Yield monitor accuracy was reduced by dust build-up on the sensor face. Sensor drift, tags (small “ropes” of cotton waving in front of the aperture), and trash confounding also limited the systems’ utility. However, Thomasson et al. (1999) and Whitelock et al. (1998) reported a strong relationship ($R^2 = 0.90$) between seed cotton mass flow and light attenuation with an experimental optical system in a small gin. The same correlation was reported by Thomasson et al. (1997). Optical systems are a non-intrusive technique that have the advantage of not restricting the flow of cotton and its conveying air (Wilkerson et al., 1994). In all optical systems, volumetric flow attenuates a signal. This signal is correlated to mass flow.

Other indirect systems attenuate microwave radiation and ultrasonic energy. A microwave system tested by Barker et al. (1999) could not be correlated to mass flow. No literature was found discussing ultrasonic measurement of mass flow of seed cotton, but there may be a correlation since it works with other materials and cotton absorbs sound.

Weighing systems promise to measure the flow of mass more directly. They are limited on harvesters because of dynamic loads (Wilkerson and Hart, 1996) but might work well in stationary applications. Belt scales accurately measured the mass flow in stripper harvested cotton (Barker et al, 1999). No literature was found discussing cotton mass flow sensing by other means.

Objectives

The objective of this investigation was to find a reliable device that can quantify the mass flow rate of pneumatically conveyed seed cotton in real time. Five experimental systems were compared to a belt scale standard to determine which system most consistently and most accurately estimated mass flow during a ten second averaging interval.

Approach

Two indirect systems were tested that attenuated infrared and ultrasonic signals. The ultrasonic system was made of inexpensive, off-the-shelf components. A timer circuit produced a pulse that was counted when cotton blocked the ultrasonic signal. The optical system is a descendant of one developed by Wilkerson et al. (1994). It has been improved and adopted for gin applications (Moody et al., 2000).

The first direct system examined exploited the static force caused when there is a change in the direction of a mass flow. This inertial force may be isolated and quantified to measure the mass flow directly.

A vertical mass flow causes a change in potential energy. This results in a difference in static pressure between two elevations. This method was the second direct method examined. The third direct method monitored changes in the velocity (and hence volume) of the conveying air. Potential energy storage results in a reduction in velocity of the conveying air. As more cotton mass flows upward, more power is required to move cotton and less is available for moving air. A constant speed fan is expected to pull less air volume because it is working against a greater pressure drop.

Materials and Methods

Test material consisted of two machine picked varieties (Upland DP-90-RR and Pima S-6) at two moisture levels (6.3 and 12.6 % dry basis with a standard deviation of 1.00). Five

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Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1571-1574 (2000)
National Cotton Council, Memphis TN

dry lots of one variety were run at five different mass flow rates. Moisture was then added to that cotton by spraying a fine mist on a thin web of seed cotton and storing it in an airtight trailer for 48 hours. Five more lots at five mass flow rates were run with the now wet cotton and then it was dried and ginned in a roller or saw gin stand, depending on variety. This pattern was repeated for the next variety. The experiment was replicated three times. Mass and run time were adjusted for each of the 60 lots to achieve the lot target mass flow rate of from 1 to 5 bales/hour (10 to 50 kg/min) with not less than 400 pounds of seed cotton in not less than 4 minutes.

Three samples were taken from each lot to find moisture content per standard procedures (Shepherd, 1972). One sample per lot was taken to find the trash content by pneumatic fractionator method (Shepherd, 1972). Air temperature, relative humidity, and barometric pressure were recorded for each lot. Conveyor belt speed was recorded by counting pulses from Hall effect transducers triggered by magnets glued to the conveyor belt. Belt speed was constant throughout the test. Date, time and replicate were also screened to determine their significance as parameters in a SAS model predicting mass flow. No confounding was observed.

Seed cotton mass flow rate was controlled by varying the speed of feed rollers at the outlet of a steady-flow hopper (Figure 1). All five experimental systems were connected in series in a duct containing pneumatically conveyed seed cotton (Figure 2). Real-time mass flow rate was quantified by running the seed cotton over a weighing conveyor belt before it entered the instrument duct. Integrated mass flow rate was measured with a stop watch and a certified commercial truck scale.

The two indirect systems consisted of receivers sensing the attenuation of ultrasonic and infrared signals in a 12 inch square duct. The University of Tennessee supplied the optical system. It came with its own PC data logger, ready to run. It used seven infrared lamps spaced evenly across the duct, with sensors on the opposite side. The emitter array projects discrete light beams across the duct to limited field-of-view detectors. Each detector is an integrated circuit that outputs a frequency proportional to the light intensity striking it. The computer sums the pulse count from each sensor to find mass flow, as the pulse sums are inversely proportional mass flow. Algorithms account for baseline offset (no flow), non-linearity and depth variation (Moody et al., 2000).

The ultrasonic system consisted of a rugged industrial through-beam transmitter and receiver pair. It produced a sinking output (with a 4 ms response time) when cotton in the duct blocked the sound. That enabled a Hewlett Packard 34907A data logger multifunction module totalizer to count pulses from a timer circuit. The number of pulses counted per unit time correlated to mass flow.

There were three direct systems in series with the indirect ones. The first was a load cell sensing the inertial force caused by a right angle change in flow direction. It was inside a 1½ x 4 x 8 foot vacuum box, allowing for a break in the duct upstream of the free-swinging elbow without entraining more air. Two differential pressure transducers (half inch water gage) followed. They sensed differential static pressure three and six feet apart in a vertical pipe. Pressure taps (1/4 inch) were plumbed to compressed air tanks of approximately one-gallon volume to dampen fluctuations in the pressure. Finally, an s-type pitot tube was installed in the conveying air flow after the seed cotton separator. It was connected to a third differential pressure transducer.

Four of the five systems were hooked up to a Hewlett Packard 34970A data acquisition/switch unit. Signal values were recorded from 2 to 5 Hz, depending on the length of the run. Fast Fourier transforms of each signal ruled out harmonics at these scan rates. To keep lot weights high (minimizing scale uncertainty) a longer run time was used with lower mass flow. Lot run times were from 5 to 18 minutes. Lots typically consisted of about 1500 observations with cotton and roughly 500 observations without. The difference between the average instrument reading with and without cotton flow was used to find the integrated mass flow for that lot.

Integrated Mass Flow

Integrated mass flow signals (lot average values) were plotted over the primary standard (truck scale total weight divided by lot run time). Linear regression was used to quantify fidelity and to derive an equation relating mass flow to system output signal voltage. This same strategy is envisioned for actual sensor applications where gin production records would be used to update system calibrations on a daily basis. These integrated value equations provided the calibration coefficients used to calculate real-time estimates of mass flow.

The weighing conveyor belt and the five tested systems were calibrated with and compared to a 50,000 lb. commercial truck scale. The truck scale and a stopwatch served as the lab standard for analyzing integrated mass flow. The truck scale was recently calibrated and certified. With an accuracy of ± 5 lbs. and lot weights of from 420 to 625 lbs., uncertainty was approximately one percent. Linear regression comparing the conveyor belt and truck scale standards indicated a close linear agreement based on an R^2 of 0.989 over all combinations of variety and moisture content (Figure 3).

Real-Time Mass Flow

Real time accuracy was measured against a rubber conveyor belt 10 foot in length running at 46.8 feet/minute. The belt was on a frame pivoted at the end where seed cotton dropped on to it, suspended through a load cell at the other end. Counterweights balanced the apparatus so that the load cell primarily measured cotton. The conveyor belt signal was approximately a ten-second moving average.

For each experimental system, the average signal with no cotton flow was subtracted from each observation during cotton flow to get a "cotton only" data set. These cotton only observations were multiplied by the calibration coefficients determined from integrated mass flow (above). Ten second (20 to 50 observations) moving averages of the resulting values were compared to the belt scale estimates of real-time mass flow. The values were plotted over the real-time standard (belt scale estimate) mass flow values. The slope and fit of each measurement system's real time mass flow was found by linear regression.

Results

Figure 4 shows the integrated mass flow signal (lot average values) for a typical system, the differential pressure transducer that was connected to the pressure taps 3 feet apart in a vertical duct. This plot is typical of each of four experimental systems (optical system performance is reported elsewhere in this publication (Moody et al., 2000)). The instrument signal to mass flow correlation was derived by linear regression. Table 1 presents system R^2 values.

The elbow system had no apparent correlation with mass flow even when accounting for air density and flow. The air volume recommended for conveying seed cotton is 20 cubic feet per pound (Anthony and Mayfield, 1994). The conveying air required for one pound of seed cotton has a mass of 1.5 lbs. (thus noise exceeds signal). In light of other systems looking much more promising, the elbow was not analyzed further.

The remaining three experimental systems were compared to the weighing conveyor belt. A typical real time plot of estimated mass flow is presented in Figure 5. The belt scale mass flow and the ten second moving average from two of the experimental systems are plotted together over time. For clarity, only a few data points are shown (there were 2,000 in the typical lot). Table 2 lists regression coefficients for each of the four combinations of cotton variety and moisture content. Each of these values is the average of fifteen lots (three replicates times five feeding rates).

The system that best tracked the weighing conveyor belt was the conveying air velocity pressure system. A lot-by-lot analysis found the velocity pressure system was precise ($R^2 >$ 0.900) for all but 8 of 60 lots.

Conclusions

This initial survey indicates that the velocity pressure concept has merit. It can be calibrated periodically to the integrated gin mass flow. At the end of each shift or each day the gin accountant or scale manager can provide total mass, and the ginner can enter that along with the total minutes running time in a programmable logic controller or gin management software package.

The system still needs to be tested in a commercial gin. A suggestion for the next experiment is placing the Pitot tube in the conveying air after the cyclones where it will see less dust. Frequent maintenance (blowing out) at the end of each shift may still be required to assure accuracy. The low cost and ease of retrofit installation in an existing gin make this an attractive technology in support of gin automation.

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Table 1. Conveyor belt standard and each experimental system correlated to truck scale (60 lots, integrated over entire run).

Instrument	**R^2**
Conveyor Belt	0.9886
Ultrasonic Transducer	0.9193
1 m (3 ft.) Pressure Tap	0.9880
2 m (6 ft.) Pressure Tap	0.9822
Air Velocity Pressure	0.9877

Table 2. Summary of linear regression statistics from lot-by-lot plots of real time experimental system performance on belt scale standard.

Cotton		**Ultrasonic**	**dP 3 ft**	**dP 6 ft**	**Pv**
Variety	**M.C.**	**R^2**	**R^2**	**R^2**	**R^2**
Upland	Dry	.555	.877	.878	.925
	Wet	.680	.898	.902	.937
Pima	Dry	.591	.876	.877	.930
	Wet	.669	.895	.897	.940
Overall Average		**.624**	**.886**	**.889**	**.933**

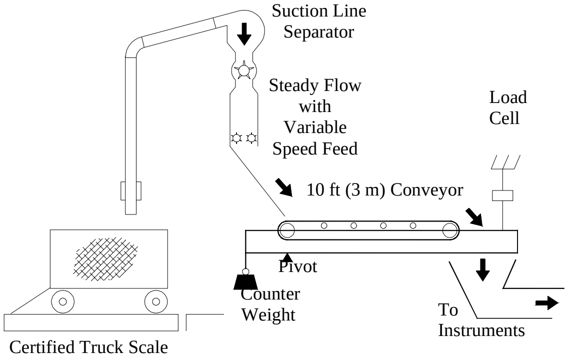

Figure 1. Seed cotton flow path showing variable speed feed and weighing conveyor belt.

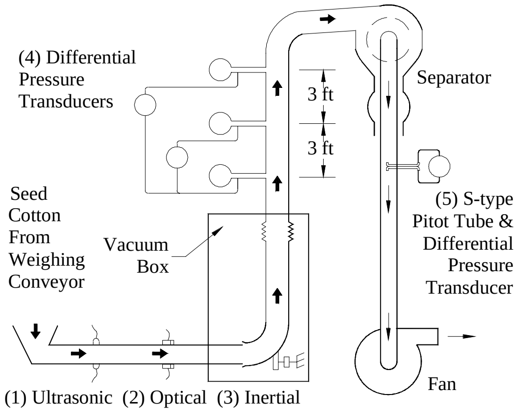

Figure 2. Five experimental real-time mass flow measurement systems.

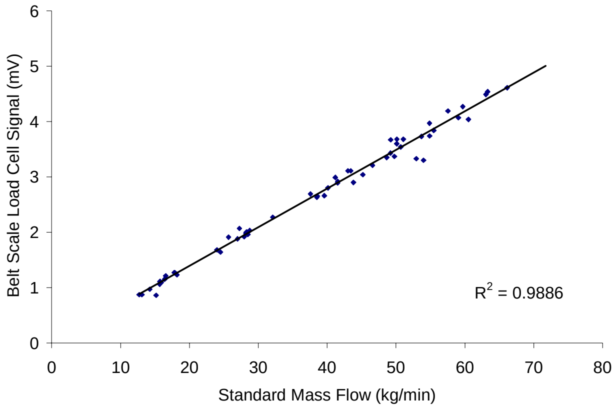

Figure 3. Conveyor belt lot average signals and regression fit to truck scale standard.

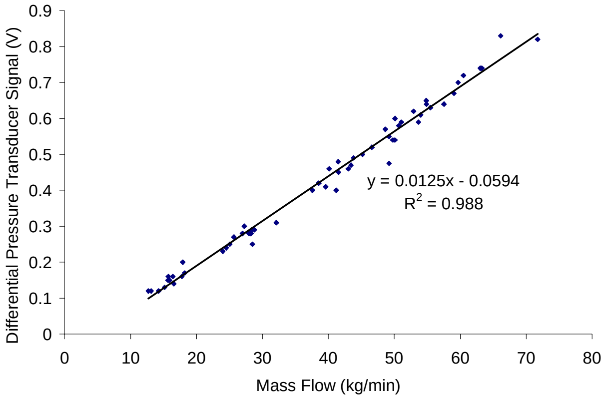

Figure 4. Typical integrated mass flow signal and linear regression used to obtain system calibration coefficients.

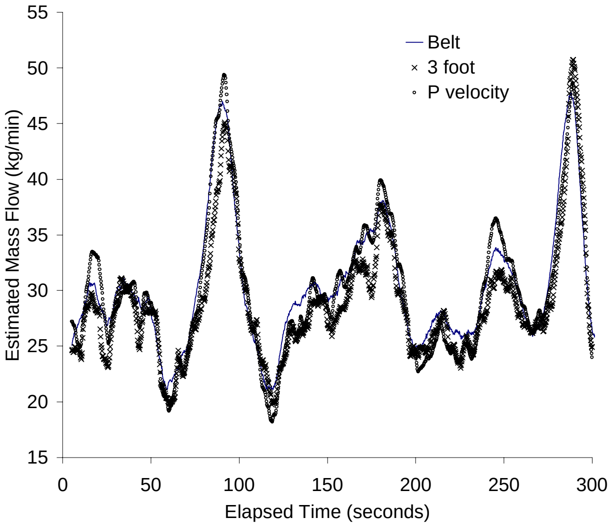

Figure 5. Real-time plot of estimated mass flow for both pressure transducer and velocity pressure systems and belt scale standard.