DEVELOPMENT OF A METHOD TO ESTIMATE THE MOISTURE CONTENT OF COTTON BALES

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Abstract

Automated and manual methods to quickly and inexpensively estimate the moisture content of universal density cotton bales were developed. As a basis for the methods, new mathematical relationships describing the force required to compress cotton were developed to focus on moisture content. Implementation of these relationships requires values for press volume and pressure at the end of the compression cycle as well as cylinder diameter and bale weight. The automated method is computer-based whereas the manual method is based on retrofitting a traditional hydraulic pressure gauge with a specially configured dial face. Bale moisture is estimated within ± 0.5%. The devices provide inexpensive methods to estimate the moisture content of cotton bales.

Introduction

More than 80 million bales of cotton are produced in the world annually. The official market weight of cotton bales is established at the gin after packaging or at a warehouse shortly after packaging. Cotton is normally ginned at moisture levels of 3 to 6% and packaged. Systems to add moisture to the lint before packaging have become the accepted practice. These systems are usually operated to bring the bale moisture to 7%; however, due to lack of knowledge of the actual moisture content of the bale, gin operators usually attempt to stay below the optimum 7% moisture level. Devices to measure the bulk moisture content of cotton bales after packaging are not commercially available, primarily because gins add moisture to the cotton before packaging and the surface moisture disrupts the measurement. Bales are thus produced at low moistures which cost the farmer about 10 to 20 pounds of marketable material per bale at a current market value of $7 to $14 in the U.S. If excessive moisture is added, biological degradation occurs (Lalor et al., 1994); if the bale is packaged at low moistures, compressive and restraint forces are high, bale weight is low, and money is lost (Antyhony et al., 1994). The purpose of this study was to develop an inexpensive device to estimate bale moisture.

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Discussion

The moisture content of compressible materials such as cotton can be accurately predicted during the compression cycle based on knowledge of the mathematical relationships involved and the compression force as a function of the moisture content of the material and the density of the material of interest. For cotton, those general relationships are given by Anthony et al. (1994),

where:

$$\text{Log}_{10}\,(\text{force}) = 3.0929 - 0.0313 * (\text{lint moisture}) + 2.4469 * \log_{10}\,(\text{density}) \quad (1)$$

This relationship is broad and was established to represent all cotton bale presses in existence and includes cross-sectional areas ranging from 1,020 to 1,458 square inches. While this relationship is sufficient for general press design, it is not accurate enough to provide moisture predictions of real use in the industry.

Separation of the density variable into its basic components of weight (mass) and volume represented by the cross-sectional area of the press box and the distance between the platens at a given time substantially increases the accuracy of the prediction equation for a given press. The compression force can also be divided into the hydraulic pressure times the effective area of the hydraulic cylinder(s) used to compress the material. This concept can be applied to all the different models of presses manufactured today.

Equation 1 then becomes:

$$\text{Moisture} =\{-C1+[(\text{Pressure}* C7) - C3*C4*\text{Weight}/(C5*C6)]/\}C2 \quad (2)$$

Where
C1= intercept constant
C2= constant for moisture variable
C3= constant related to density variable
C4= conversion constant from cubic inches to cubic feet (1728)
C5= platen separation, inches
C6= press box area, square inches
C7= hydraulic cylinder diameter, square inches.

Further, this equation can be solved for given combinations of pressure and weight for a fixed press box area, ram size, and platen separation.

Several studies were conducted in a gin universal density press to ascertain the utility of the concept and to develop more refined relationships between force and moisture. In one study, 27 bales of like cotton were ginned. The first 3 bales were ginned without heat (7.4% moisture) but with the standard cleaning machinery and bale weights were targeted for 450, 500 and 550 pounds; they were compressed to about 21" platen separation. The next 3 bales were ginned like the first three except that a platen separation of 20" was used; the next three were compressed to 19". The above 9 bale test was repeated with 9 bales at 5% moisture (2 tower dryers at 150 °F). The next 9 bales were ginned at 3% moisture (2 dryers at 250 °F). For each bale, 10 moisture samples were taken. Final platen separation, final compression force, and bale weight were precisely measured. Data from the 27-bale study showed moisture ranged from 3.7 to 7.8%, densities from 35.1 to 47.2 lb/ft^3, and forces from 440,856 to 1,020,751 pounds.

A method to estimate the moisture content of a bale as it is compressed was developed based on the data in Table 1 as well as other data (not shown). The method consists of a pressure transducer, a microswitch and/or a potentiometer to accurately measure the final volume of the bale press, a transducer or electronic scale to determine the bale weight, a single-board computer with display and serial output, as well as the new mathematical relationships between compression force, density, and moisture. The system estimates the moisture of the cotton bale at final compression. The entire process can be accomplished electronically with algorithms imbedded in a programmable chip. Electrical signals representing the bale weight, pressure, and platen separation are passed to the chip that already contains the operator selected values for ram area, box area and the required algorithms. The moisture content is displayed digitally and its electrical representation is available to help control drying, moisture restoration and other processing equipment. Many gins already have automated bale-weighing mechanisms and press volume estimation devices (microswitches), thus requiring only the addition of a pressure transducer and a single-board computer equipped with ARS software. Partially automated systems can be used wherein some manual measurements are entered into the computer.

For non-automated systems, a pressure gauge equipped with a specially designed face was developed to provide a direct moisture reading. Different faces are used for different ram diameters, compressed volume, and weight. A standard hydraulic pressure gauge typically equipped with a 6" face dial was retrofitted with a specially configured face dial (Figure 1) that reflects the relationship described in equation 2. In essence, bale weight is plotted on concentric circles of an ever increasing diameter and overlaid with moisture values at given levels of pressure, the pressure levels are indicated by a moving needle indicator. The moisture can be read directly at the intersection of the needle and the bale weight circle. Following each compression cycle a "lazy" hand or a "demand" needle is provided to indicate the maximum pressure achieved for ease of reading. The needle remains in place at the maximum pressure until it is manually reset. This additional needle allows the operator time to weigh the bale, read the moisture from the gauge, and reset the lazy hand on the gauge. Cost of this system will likely be less than $1,000. A different face plate is used for each model press and each final platen separation. For instance, a particular model of press will have the same press box size and ram diameter but the operator may choose to use a final platen separation of 19, 20, or 21 inches. Thus, each model has at least three possible face plates.

The device(s) allows gin operators to better regulate the amount of moisture in the bale thereby 1) reducing compression costs, 2) avoiding press damage due to excessive compression forces, 3) preventing possible fiber degradation due to excess moisture, 4) avoiding possible bale tie failures, and 5) increasing the market weight of the bale by 10 to 20 pounds or $7 to $14 per bale.

Summary

Automated and manual methods to accurately estimate the moisture content of a bale after it is compressed were developed. The automated method consists of a pressure transducer, a microswitch and/or a potentiometer to accurately measure the final volume of the bale press, a transducer or electronic scale to determine the bale weight, a single-board computer with display and serial output, as well as mathematical relationships between compression force, density, and moisture. The system estimates the moisture of the cotton bale at final compression.

For non-automated systems, a pressure gauge equipped with a specially designed face was developed to provide a direct moisture reading. Different faces are used for different ram diameters, compressed volume, and weight. The devices allow gins to regulate the amount of moisture in the bale thereby reducing compression costs, avoiding press damage due to excessive compression forces, preventing possible fiber degradation due to excess moisture, avoiding possible bale tie failures, and increasing the market weight of the bale by 10 to 20 pounds or $7 to $14 per bale.

Disclaimer

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

References

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Table 1. Means for bale packaging parameters.

Bale weight, lb.	Lint moisture, %	Platen separation, in.	Force, pounds	Density, lbs./ft
471	3.7	20.1	725717	39.4
472	3.8	20.1	720630	39.5
471	4.0	20.1	708761	39.4
452	4.2	20.1	627372	37.8
466	4.2	20.4	695196	38.4
516	4.3	20.1	986839	43.1
565	4.3	20.8	1020751	45.6
531	4.5	21.4	779976	41.8
464	4.7	20.1	644328	38.8
528	4.8	20.3	898668	43.8
488	4.8	20.2	695196	40.6
486	4.9	20.4	661284	40.1
534	4.9	19.2	1017360	46.8
504	5.0	19.2	881712	44.2
470	5.2	20.1	640937	39.3
447	5.2	21.4	440856	35.1
474	5.3	19.1	708761	41.7
524	6.1	20.1	810497	43.8
518	6.1	19.0	915624	45.8
454	6.2	20.1	512071	37.9
495	6.2	20.1	668066	41.4
488	6.2	19.1	749455	42.9
554	6.2	21.1	766411	44.1
452	6.5	19.0	573113	40.0
472	6.9	21.1	474768	37.6
500	7.0	20.9	556157	40.1
466	7.1	21.1	434074	37.1
540	7.1	20.9	678240	43.4
534	7.3	19.0	919015	47.2
503	7.4	19.0	732499	44.5
470	7.6	19.0	603634	41.6
558	7.7	20.4	796932	46.0
491	7.8	20.4	505289	40.5

Table 2. Analysis of variance for compression force for a typical bale press.

Source	DF	Mean Square	F Value	Prob>F
Model	2	90865907379	470.612	0.0001
Error	30	830548193		
Total	32			
Root MSE		28819.23	R-square	0.97
Dep Mean		713642.07	Adj R-sq	0.97
C.V.		4.04		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob>|T|
INTERCEP	1	-947128	69378.1	-13.65	0.0001
DENSITY	1	49040	1694.4	28.94	0.0001
LM	1	-65959	4095.5	-16.10	0.0001

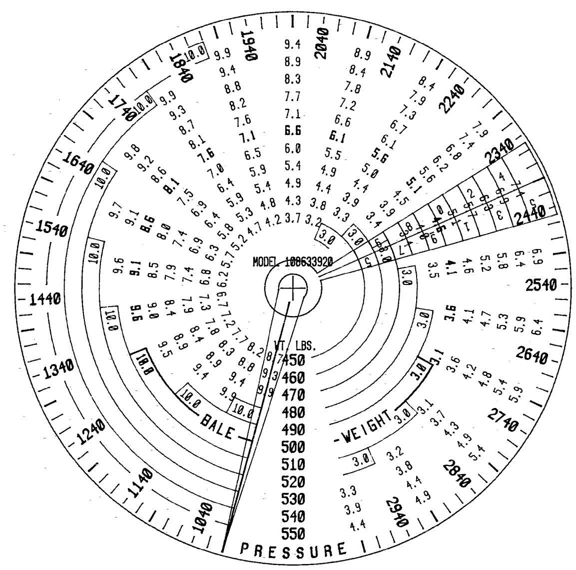

Figure 1. Special dial face for a hydraulic pressure gauge for a typical press.