ON-THE-GO MOISTURE TESTING IN THE BALE CHAMBER

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Abstract: A very important factor in hay baling is the moisture level of the feed hay entering the baler. Ideally a baler operator should have a moisture meter in front of him which would continuously show him the percentage moisture of the incoming feed. Such a baler-mounted "on-the-go" moisture monitoring system has been designed, proto-typed, tested, patented, and marketed. Tests by Utah State University, two baler manufacturers, and the developer/manufacturer indicated the monitoring system is accurate to within 2.6 percentage points of oven dried samples of the same hay and to duplicate the readings of handheld moisture meters within one percentage point.

Keywords: Hay moisture level, hay quality, shattering, mildew; oven-dried samples, electrical resistance-type moisture meter, handheld probe, "on-the-go" moisture testing baler sensor, flush-mounted, mounting location.

INTRODUCTION

The moisture level at which hay is baled is critical to the quality of the finished bale. Hay which is baled at a moisture level which is low (below approximately 12%) shatters during the baling process, causing the leaves to separate from the stems of the plant and pulverize into fine powder. Hay which is baled at a moisture level which is too high (above approximately 25%) mildews and deteriorates in the bales, resulting in hay which is undesirable as feed. Hay baled at a moisture level above 25% is also susceptible to spontaneous combustion. Hay baled in the 22-25% moisture range tends to turn brown (carmelized or tobacco) and is not suitable as feed in the horse market.

STATE OF THE ART MOISTURE DETECTION TECHNOLOGY

Various methods of detecting the moisture level of hay are available. A skilled operator can break the alfalfa stems in his hands and know the approximate moisture level. One method of determining moisture level involves sampling the hay, weighing the sample, drying the sample, weighing the dry sample, and calculating from the two weights the actual moisture level of the sample. This method suffers the disadvantage of being too cumbersome to be practical during the baling operation. In addition, since hundreds of acres of hay may be baled in a single baling session, many hay samples are needed, and it is very difficult if not impossible to obtain a representative sample of hay which is to be baled.

Techniques for measuring the moisture content of hay based upon the direct relationship of electrical resistance to moisture content are well known. This technology was known as early as 1907 when the U.S. Department of Agriculture published a bulletin outlining the method for use on grain.[2] A thesis by G.W. Isaacs at Michigan State in 1954 entitled "The Design of Simplified Equipment for the Rapid Determination of the Moisture Content of Grain and Forage Crops"[3] summarizes the state of the art at that point in time; however, a number of meters for use in forage crops were already on the market at that time. Today several companies manufacture forage moisture meters. In some such instruments, a sample of hay is placed in the test compartment of the instrument which measures its electrical resistance. In other variations, an elongated probe having two electrodes in its tip is caused to penetrate a bale to provide resistance readings of interior regions of the bale. Figure 1 shows the accepted relationship between electrical resistance and hay moisture content.[4]

EFFECT OF SAMPLE SIZE ON TEST RELIABILITY

Several factors cause the moisture levels of hay in various parts of a field to vary from one another. Terrain which varies and is not flat causes one part of a field to dry faster than another; in particular, the swales tend to dry at a slower pace than the ridges.

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Areas of a field which are infested with weeds or grass are slower drying. Weed and grass infestations generally occur first in areas where the hay receives excess water such as around sprinkler valves, or in areas of heavy clay soils (as opposed to lighter sandy soil)where the moisture level of the soil remains highest, causing hay moisture to vary in a given field in a random and non-uniform manner. Areas of an alfalfa field which have not been watered will dry more slowly than areas which have not been recently watered. These conditions and others result in hay moisture levels which are not uniform throughout a field.

In addition to the non-uniformity of moisture content of hay in a given field, hay is a hygroscopic material and relative humidity of the ambient air will affect the moisture content of hay laying in a windrow. Table 1 shows the equilibrium moisture content of hay as a function of the percent relative humidity of the ambient air.[5] Most baling occurs during the night time to take advantage of this dew effect. As the ambient temperature cools during the night, the relative humidity increases, resulting in the equilibrium moisture content of the hay rising. When the relative humidity reaches approximately 70%, and the hay moisture content about 13%, the leaves do not shatter from the stems resulting in a better quality of hay. When the relative humidity exceeds approximately 90%, the hay moisture content exceeds 20% and baling should be stopped to avoid spoilage due to mildew. Since the relative humidity changes during a given session of baling, the moisture content of the hay changes and the baler operator must monitor the hay moisture content.

G.W. Isaacs reported "Tests of resistance-type moisture meters indicated that a single reading taken on hay or grain is not a good index of the moisture content of the whole lot. When testing hay with a resistance-type meter, at least 25 readings should be taken and the results averaged in order to obtain a reliable indication of the moisture content of the whole field." Isaacs designed and tested an automatic averaging device which gave a single indication of the average moisture content of a large number of samples of hay in a windrow by rolling the device up a windrow of hay to be tested.[3] However, the averaging device did not receive widespread acceptance among hay producers.

Under the non-uniform and constantly changing conditions of field hay moisture described, and in order for the baler operator to be aware of the moisture content of hay entering the baler, a system of continuously monitoring the moisture content of hay during baling is needed. Using such an "on-the-go" monitoring system, the baler operator can be aware of hay moisture content at all parts of the field and can stop baling when he encounters a wet area of the field or when the dew level is either too high or too low so as to produce an inferior quality of hay.

BALER MOUNTED "ON-THE-GO" SYSTEM

The baler mounted "on-the-go" moisture monitoring system consists of three components: (1) an electrical resistance-type moisture meter which reads in percentage of hay moisture and which is mounted in clear view of the baler operator. (2) a two conductor electrical cord which extends from the moisture meter to the hay sampling location in the chamber of the baler. (3) A sensing device mounted in the baler chamber area and which is in contact with the compressed hay.

Since many thousands of meters with a handheld probe are presently in use by hay producers, it was determined that the only required new technology for providing a continuous readout of hay moisture level was a sensor for mounting to the baler and a cord The sensor and cord were constructed compatible and interchangeable with the existing Delmhorst DHM-1 or F-4 meters by unscrewing and removing the bale probe and by replacing it with the cord. In addition, a new DLB-2 meter which features lighted digital readout for night baling, continuous operation with no on-off buttons to hold on, and an auxillary power jack for connection to the baler/tractor power supply to conserve battery life is now available.

Since at the time of forming the bale in the chamber, the moisture is uniform from the outside to the inside of the bale (the baler does not segregate the high moisture hay to the center or some other part of the bale), a prototype "flat" sensor which senses the moisture at the edge or outside of the bale was constructed and tested. The sensor consists of an inner or positive electrode, a concentric ring of insulation around the electrode, and a holding tube for the assembly which is welded to the baler and which also acts as the ground or negative elctrode. The spacing between the electrodes duplicates the handheld probe spacing at 0.5 inches. The entire assembly is mounted to the outside of the baler chamber such that the inner electrode and insulation is flush with the inside of the chamber and contacts the hay as the hay slides through the chamber. Because of the very harsh conditions of wear and corrosion to which the sensor is exposed, the inner electrode was constructed of stainless steel and the insulating ring was constructed of phenolic plastic. The sensor design allows for easy removal of the assembly for cleaning purposes from the outside of the chamber without removing the bale from the chamber should it scale over during baling. Although wear was almost non-existant after 100,000 bales through the test baler, the design also allows for deeper insertion of the assembly to compensate for wear. Figure 2 is a schematic diagram of the baler sensor. Photograph 1 is a photograph of the mounted sensor.

TEST RESULTS

The"on-the-go" moisture monitoring system was tested a number of different ways to determine its accuracy in relation to both the handheld probe and to oven dried samples of the hay, and to determine variance in readings due to various mounting locations of the baler sensor.

Prototype sensors were sent to two baler manufacturers: J.A. Freeman and Son, Portland, Oregon and Sperry New Holland (now Ford New Holland), New Holland, Penn. Both companies indicated that the monitoring system worked well and read accurately, but no actual written test results were provided. New Holland mounted the sensor on the uncut side of the baler approximately 12 inches behind the end of the plunger stroke and approximately one-third of the way up the side of the chamber. Freeman located the sensor on the squeeze rail lip on the uncut side of the baler approximately 6 inches past the squeeze rail hinge.

A prototype sensor was provided to the Agriculture Department of Utah State University, Logan, Utah. Graduate student Jodi Gale did some extensive tests comparing "on-the-go" readings with both oven dried samples and with the Delmhorst handheld probe. The results of the Utah State University tests were published in the January, 1988, issue of Hay and Forage Grower Magazine. Readings averaged 2.6 percentage points of moisture higher than values obtained by oven-drying samples of the same hay. The handheld probe attached to a Delmhorst digital meter averaged 3 percentage points higher than those of the oven dried samples. In the Utah State University test, the prototype sensor was mounted on the uncut side of a New Holland baler approximately one foot behind the end of the plunger stroke and approximately one third of the way up the side of the chamber.[6]

The author conducted a series of tests comparing readings of the "on-the-go" system with readings using the handheld probe. A sample of these tests comparing 4 to 6 readings each on 4 bales of hay using baler mounted sensors in 2 different locations on the uncut side of the baler and a handheld probe mounted to a Delmhorst F-4 meter are shown in Table 2. This test conducted on July 12, 1986, showed the "on-the-go" system to average 16.0% moisture at each location while the handheld probe averaged 15.2%. These tests showed a variation between the two systems of less than 1%.

Tests of multiple sensors on the baler were also made. These tests compared readings with one baler sensor mounted to the uncut side of the baler to readings with two baler sensors both mounted to the uncut side of the baler and connected to one another in a parallel circuit. When multiple sensors are connected in a parallel circuit, the sensor which is in contact with the wettest hay will allow the current to pass most easily and will therefore provide the reading; therefore, the effect of multiple sensors is to increase the average moisture content which is read. Tests 1 and 2 bore out this fact, since the two tests averaged 15.8% and 15.7% using one sensor and 17.4% and 18.8% using two sensors. The data of tests 1 and 2 are shown in Table 3. Since the Utah State University tests have shown that the "on-the-go" system already gives readings which are approximately 2.6% higher than oven dried samples, and since multiple sensors will tend to increase these readings further, it is concluded that only one sensor should be used on a baler and that one sensor is adequate to monitor the moisture content.

In order to determine the optimum mounting location for the baler sensor, tests of baler sensors located on the uncut side versus the cut side of the baler were also made. Mounting to the cut side of the baler caused much greater fluctuation of the readings. This is due to the unevenness of the cut side of the bale resulting in the bale at times not even making contact with the sensor, causing a number of readings below 10% and some readings of zero. Cut side readings also jumped up to 30-50% much more often resulting in readings which were confusing because of the large variation. Table 4 lists the results of this test. As can be seen in Table 4, the readings of this test averaged 28.2% on the cut side while averaging 15.1% on the uncut side. Based upon this test, it is concluded that the baler sensor should be mounted only on the uncut side of the baler. As shown, however, in Table 2, very little variation in readings was found due to different locations of the sensor on the uncut side of the baler. In fact, averages of 20 readings each at two different locations on the uncut side of the baler showed no variation since readings from each location averaged 16.0%. It is therefore concluded that the baler sensor may be located on the uncut side of the baler at any location where the hay is in good contact with the sensor.

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4. As measured on a Model F-4 hay moisture meter manufactured by Delmhorst Instrument Company, 51 Indian Lane East, Towaco, NJ 07082.

5. Operating Instructions for the Triton 30 and 300 Hay Moisture Gauges Manufactured by Valley Products and Design Inc., P.O. Box 396, Rt 418 Milford, PA 18337.

6. Hay & Forage Grower, Volume 3, No. 1, January 1988, Webb Publishing Company, 1999 Shepard Rd., St. Paul, MN 55116.

TABLES

TABLE

Equilibrium Moisture Content of Hay as a Function of Percent Relative Humididty of Ambient Air

Temperature Range 60-90 °F

Percent Relative Humidity	Equilibrium Moisture Content
10%	5.9%
20	7.1
30	8.5
40	9.5
50	10.5
60	11.5
70	13.4
80	15.5
90	19.5

TABLE 2

Comparison of Readings of "On-The-Go" System with Handheld Probe

Date of Test: July 12, 1986
Location of Test: Evans Farm, Parowan, Utah

Baler Location No. 1: Squeeze rail lip of Freeman 330 baler about two thirds of the way up uncut bale side

Baler Location No. 2: Chamber area of Freeman 330 Baler about half way up uncut bale side

Location No. 1	Location No. 2	Handheld Probe
	Bale No. 1	
20 %	17 %	21 %
14	18	20
19	16	16
13	15	16
15	16	13
Avg. 16.2 %	16.4 %	16.7 %
	Bale No. 2	
13 %	14 %	13 %
14	20	15
17	15	15
17	17	15
18	17	14
18	20	15
Avg. 16.2 %	17.2 %	14.5 %
	Bale No. 3	
17 %	15 %	18 %
17	18	15
16	15	14
15	15	13
Avg. 16.3 %	15.8 %	15.0 %
	Bale No. 4	
16 %	16 %	14 %
17	13	14
15	14	15
14	16	15
14	14	15
Avg. 15.2 %	14.6 %	14.6 %
	Average of 4 Bales	
16.0 %	16.0 %	15.2 %

TABLE 3

Effect of Multiple Baler Sensors on Readings

Test No. 1

Date of Test: June 12, 1987
Location of Test: H A Farms Inc, Parowan, Utah

Readings taken using 1 baler sensor located in chamber area of a Freeman 330 baler one third distance up bale on uncut side of baler: 15.1, 16.4, 14.0, 14.6, 14.6, 0, 8.3, 25.0, 17.5, 14.7, 20.4, 16.8, 16.3, 16.2, 15.0, 16.1, 14.4, 13.6, 14.7, 15.0, 17.1, 14.2, 23.2, 17.1, 17.6, 15.7, 16.7, 19.8, 15.4, 16.7, 14.5, 17.7, 15.3, 17.3, 15.6

No. of Readings: 35
Average of Readings: 15.8 %

Readings taken using two baler sensors connected in a parallel circuit, one sensor being the same as above, and the second baler sensor located on the uncut side of the baler on the upper squeeze rail lip, 12 inches behind the squeeze rail hinge of the same baler: 21.0, 15.4, 21.0, 17.0, 17.6, 17.8, 18.0, 23.0, 20.8, 16.2, 20.5, 19.9, 15.7, 1.0, 19.7, 16.2, 14.6, 17.6, 21.6, 21.5, 21.5, 19.3, 4.2, 16.4, 14.0, 14.3, 15.7, 14.8, 20.7, 22.3, 14.5, 14.3, 20.0, 18.9, 25.5, 22.4, 14.6, 16.5, 15.4, 14.9

No. of Readings: 40
Average of Readings: 17.4 %

Test No. 2

Date of Test: June 13, 1987
Location of Test: H A Farms Inc, Parowan, Utah

Readings using 1 baler sensor as described above: 14.1, 14.0, 15.0, 14.5, 15.9, 13.9, 14.9, 15.1, 14.4, 14.4, 14.3, 14.9, 17.5, 27.7, 14.4, 14.5, 15.0, 14.2, 15.2, 14.5, 18.5, 15.4, 17.7

No. of Readings: 23
Average of Readings: 15.7 %

Readings using 2 baler sensors mounted as described above: 17.8, 14.3, 15.1, 14.8, 56, 14.6, 17.3, 24.1, 23.6, 16.2, 14.4, 14.5, 21.6, 16.1, 16.6, 16.4, 18.0, 14.0, 15.6, 14.3

No. of Readings: 20
Average of Readings: 18.8 %

TABLE 4

Mounting of Baler Sensors to Uncut Versus Cut Side of Baler

Date of Test: June 12, 1987
Location of Test: H A Farms Inc, Parowan

Readings using one baler sensor mounted to the uncut side of the baler: 15, 20, 20, 15, 15, 14, 14.5, 15, 15, 14, 16, 17, 14, 15, 14.5, 14, 14, 14, 15, 14.5, 15.5, 15, 14, 14, 14, 14, 15, 14.5, 14, 20

No. of Readings: 30
Average of Readings: 15.1

Readings using one baler sensor mounted to the cut side of the baler: 6.4, 20.1, 37, 44, 29, 2.2, 15.1, 58, 37, 15.9, 18.6, 3.9, 13.1, 17.1, 41, 14, 0, 27.5, 6.0, 31.6, 14, 15

No. of readings: 22
Average of Readings: 28.2

FIGURES

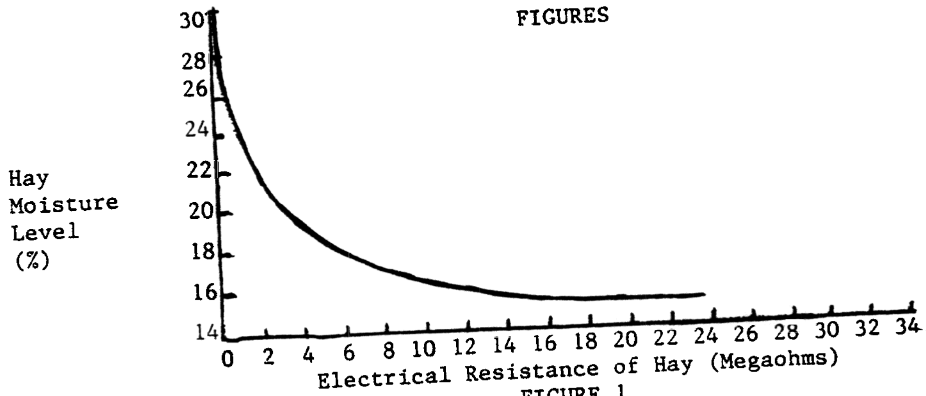
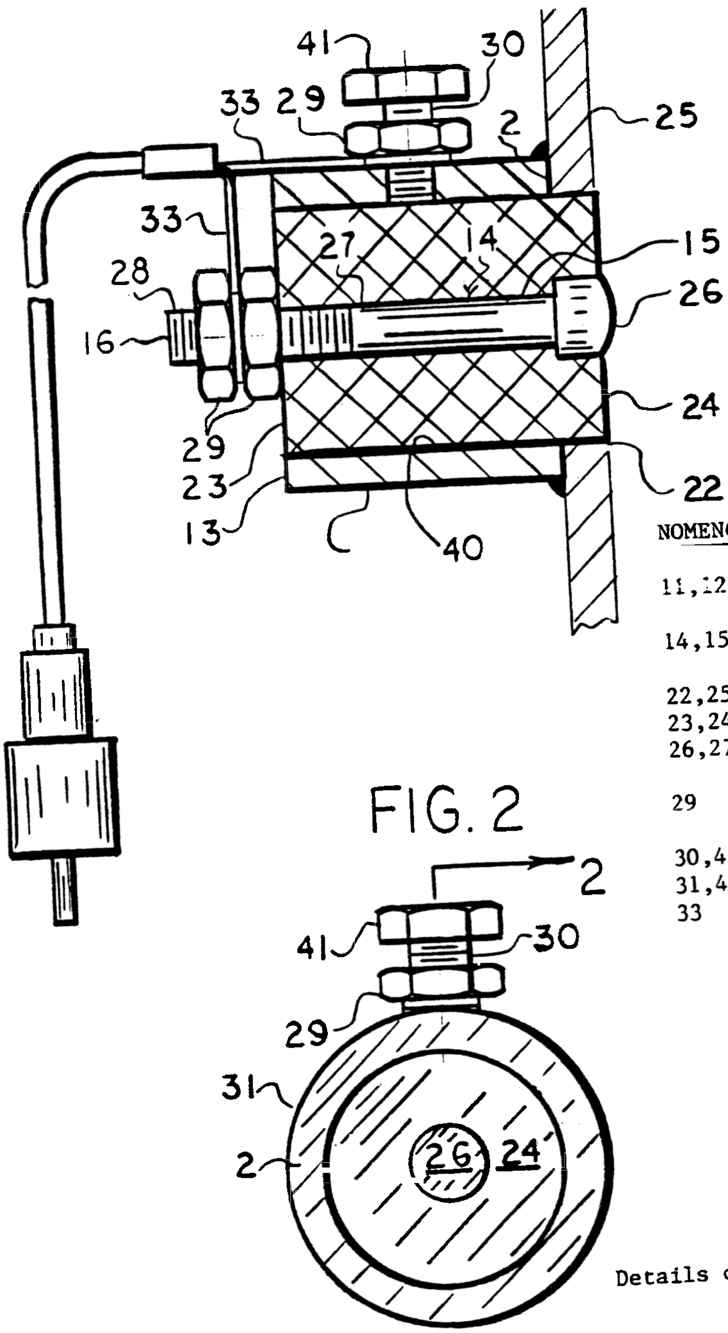


FIGURE 1

Hay Moisture Content as a Function of Electrical Resistance



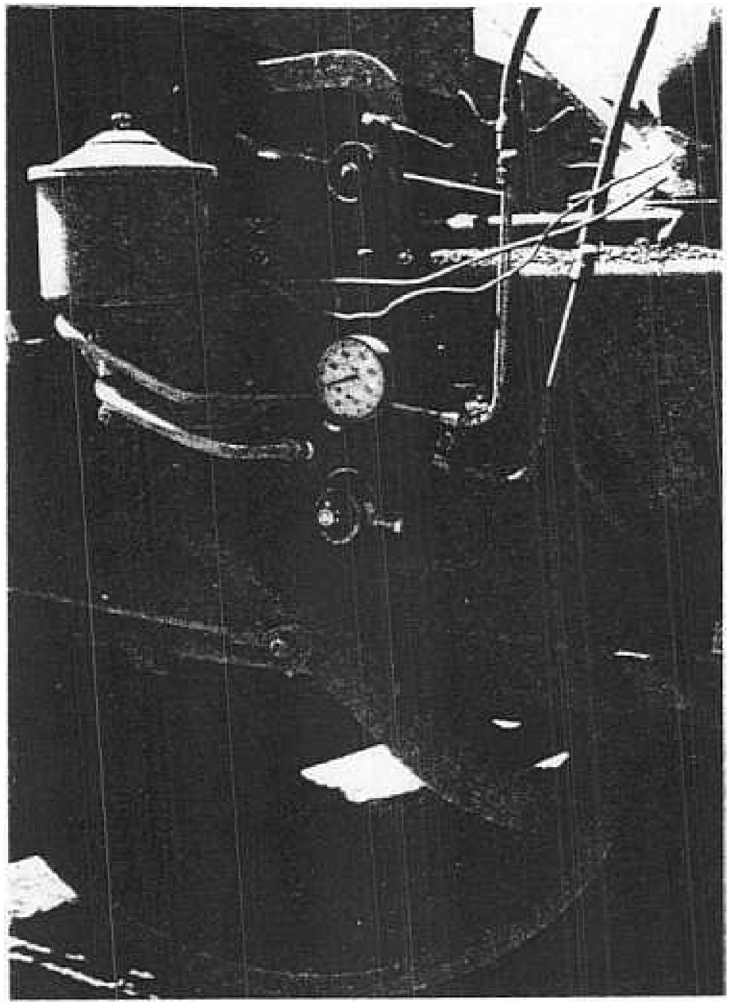
NOMENCLATURE

11,12,13--Holding Tube/Outer Electrode
14,15,16--Stainless Steel Inner Electrode
22,25 --Inside Wall of Baler
23,24 --Phenolic Insulator
26,27,28--Stainless Steel Inner Electrode
29 --Electric Cable Holding Nuts
30,41 --Sensor Assembly Set Screw
31,40 --Holding Tube/Outer Electrode
33 --Electrical Cable

FIGURE 2

Details of the Baler Sensor

PHOTOGRAPHS



PHOTOGRAPH

Mounted Baler Sensor