Corn Moisture Measurement using a Capacitive Sensor

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***Abstract*—Corn moisture content is the main factor of effecting corn safe transportation and storage, and is also an indispensable measurement part when it is used to feed, food and industry. Due to large particle size, corn will produce large gap during measuring moisture content. Because air has much influence on dielectric constant of the device, moisture content is not precision. In all kinds of corn moisture measurement methods, capacitance method becomes the main method with simple structure, low cost and online measurement. This paper designs a sensor for measuring the corn moisture that uses a capacitance detection circuit based on the relationship between the capacitance and the dielectric constant of the corn. In addition, different operating modes of the detection circuit are analyzed. The relationship between the moisture content of corn and the sensor capacitance is obtained through experiment and a binary cubic equation is obtained by the least squares fitting method.**

***Index Terms*—corn moisture measurement, capacitive sensor, detection circuit**

I. Introduction

The moisture component of a corn cell is essential for maintaining its life activities. Furthermore, the moisture content must not be too high or too low. Higher moisture contents will cause corn mildew and other biochemical reactions. Lower moisture contents may destroy organic material and damage the dry matter. Hence, the measurement of moisture levels is important for the safe storage of corn[1,2].

The traditional method for measuring moisture content uses an oven which leads to high accuracy but because it is time-consuming and involves a complicated procedure, it is not suitable for field use. Various techniques for indirect testing methods have been studied for replacing the traditional oven method at home and abroad, e.g. the use of conductance, capacitance, X-rays, neutrons, and microwaves. These methods allow quick measurements and are easily applied under field conditions[3]. The most common method is the capacitive method which has advantages of low cost, small volume and fast detection, although it lacks high precision.

Since the 1960s, many countries' researchers attached great importance to the development of grain moisture measurement technology. Along with the measurement methods of grain moisture emerged, advanced grain moisture measurement methods and the instruments are being promotion at home and abroad. TABLE I and TABLE II show the company produced the measuring corn grain moisture instruments.

TABLE I
MOISTURE METER PRODUCED BY FOREIGN COMPANY

Capacitance method	Finland Humicoy company produced the WILE100 moisture meter [4]
	Japan KETT institute developed high frequency capacitive moisture meter
Conductance method	European control company produced the CM - 4 type moisture meter
Decompression	A Japanese enterprise produced VME type moisture meter
Infrared method	British infrared engineering company produced the SM4 infrared moisture meter
	Japan QianYe institute produced the IR-AM300 infrared moisture meter
	A Japan company produced the FD - 230, FD - 310 and FD - 600 infrared moisture meter
Microwave method	The battery motor manufacturing produced online microwave moisture meter
Carlfee Hugh method	A Germany company produced continuous moisture meter
	Japan Kyoto electronic company produced the MKA - 3 type moisture meter

TABLE II
MOISTURE METER PRODUCED BY DOMESTIC COMPANY

Capacitance method	East food inspection produced the SC – 5F corn moisture meter
	Jinan detecting instrument company produced ly - 8 capacitive moisture meter and LDS – 1G grain moisture meter
	Shanghai Qingpu testing instrument company produced LDS-IF , LDS-2,LDS – IA and LDS - ID
	Tianjin science and technology company produced SFY-60 corn rapid moisture meter
	Beijing technology company produced high frequency capacitive grain moisture meter 81W1PM-8188 and grain moisture meter BHC1 - PM818
	Beijing huatai instrument technology company produced JCY13 / SFY -60d moisture meter
Conductance method	Wuhan electronic instrument produced LSKC - 4 type grain moisture meter
	Hunan instrument factory balance instrument factory produced inserted link type moisture meter
Infrared method	Hunan instrument factory balance instrument factory developed SCT - 3 moisture meter
	Xi'an light ministry of light industry developed 3 YBSIA four beam infrared moisture meter
	Guangdong test analysis and wuhan combine automation instrument developed WSHT - 102 type infrared moisture meter
	Tsinghua university developed near infrared moisture measurement instrument has completed the principle prototype

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Microwave method	Jilin province developed WSY - 100 microwave corn moisture meter
Neutron method	Nanjing university developed SHD - 1 type of neutron moisture gauge

II. Theory

The absolute permittivity divided by the permittivity of free space is small for samples because of the air gaps between particles in the container. Therefore, we adopt a coaxial cylinder arrangement in the design of the capacitive sensor to ensure the plates' effective area is large enough. The electrodes of the sensor are asymmetrical in that the inner electrode is enveloped by the external one. This geometry is very effective in preventing human body induction. The design of the capacitive sensor is shown in Figure 1.

The corn sample is placed in the media cavity between the two plate sensors. Changes in relative permittivity corresponding to different corn moisture contents cause variations in capacitance allowing the moisture content to be estimated.

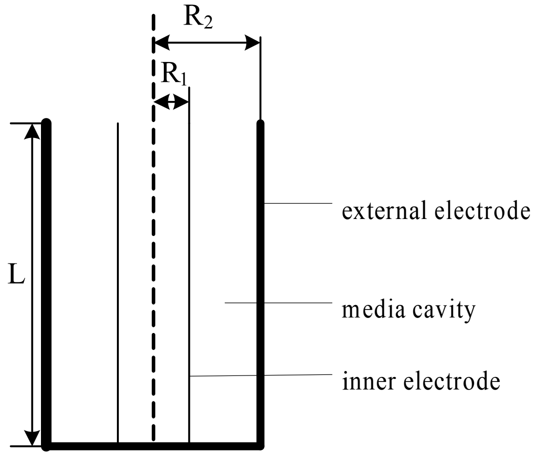

Figure 1. capacitive sensor schematic

The cylinder height is L; the external surface radius of inner cylinder is R_1; the inner surface radius of external cylinder is R_2. If $L >> R_2 - R_1$, the edge effect of cylindrical ends can be ignored.

The capacitance of the sensor can be calculated from the formula [5]:

$$C = \frac{2\pi\varepsilon L}{\ln R_2 / R_1} \tag{1}$$

Permittivity is understood to represent the relative complex permittivity. The permittivity relative to free space, or the absolute permittivity divided by the permittivity of free space [6].

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \tag{2}$$

After the sample is placed into the sensor the capacitance [7] is:

$$C = \frac{2\pi\varepsilon_r\varepsilon_0 L}{\ln\frac{R_2}{R_1}} \tag{3}$$

It can be seen from the above formula that the changes of capacitance and relative dielectric constant of corn are linearly related. Since relative dielectric constant will change with corn moisture content, the latter can be obtained from the measured capacitance.

When the corn relative dielectric constant changes $\Delta\varepsilon_r$ capacitance changes

$$\Delta C = \frac{(\varepsilon_r + \Delta\varepsilon_r)L}{1.8\ln\frac{R_2}{R_1}} \times 10^{-10} - \frac{\varepsilon_r L}{1.8\ln\frac{R_2}{R_1}} \times 10^{-10} \tag{4}$$

Sensitivity for constant

$$K = \frac{\Delta C}{\Delta\varepsilon_r} = \frac{\frac{\Delta\varepsilon_r L}{1.8\ln\frac{R_2}{R_1}} \times 10^{-10}}{\Delta\varepsilon_r} = \frac{L}{1.8\ln\frac{R_2}{R_1}} \times 10^{-10} \tag{5}$$

So ΔC and $\Delta\varepsilon_r$ is linear relationship. For moisture content corn M, when the corn moisture content changes ΔM, relative dielectric constant changes $\Delta\varepsilon_r$, causes the capacitance change is ΔC ,therefore ΔC also ΔM is linear relationship.

III. Measurement circuit

Hardware structure diagram of corn moisture measurement system is shown in figure 2. The main parts are the main control circuit, capacitance detection circuit, temperature detection circuit and RS232 communication circuit.

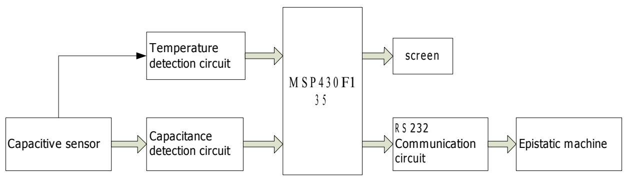

Figure2 Measuring system structure diagram

The working principle of moisture measurement system is: capacitance detection circuit and temperature detection circuit will set detected signal to the single-chip microcomputer. The single-chip microcomputer will received signal processing as shown on the screen.

The capacitance and changes of capacitance are very small in the capacitive sensor. Hence, detection circuits are needed to measure the tiny capacitance increments. Usually we translate the tiny capacitance increments into a single value function of voltage, current or frequency. There are many transformed capacitance circuits, such as capacitance charging and discharging circuit, FM circuit, operational amplifiers circuit, common communication bridge method, diode double T ac electric bridge, pulse width modulation circuit and so on.

In the present work we use charging and discharging of capacitance sensor and transforming capacitance into voltage. The capacitance of the sensor can be obtained according to the voltage

The process of capacitance charge is

$$V_C = V_i\left(1 - e^{-\frac{t}{RC}}\right) \tag{6}$$

Where t denotes charging time, and RC denotes the time constant. The process of capacitance discharged: When C was charged until t_1, C begin to discharging. The process of capacitance discharge is

$$V_C' = V_{C(t=t_1)} e^{-\frac{t}{RC}} \tag{7}$$

The measurement circuit uses the theory of capacitor charging and discharging which make the output signal change with the capacitance of the sensor. We can get the DC voltage signal corresponding to the changed sensor capacitor through difference amplifier, the same phase ratio amplifier and low-pass filter. Capacitive sensor detection circuit, equivalent detection circuit of the capacitance charging and equivalent detection circuit of the capacitance discharging can be seen from Figure 3 to Figure 5.

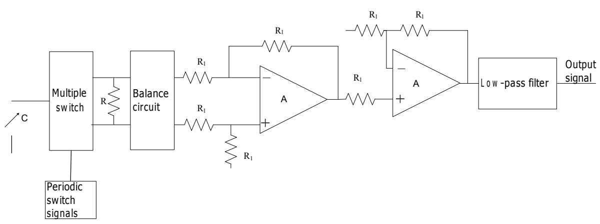

Figure 3. Capacitive sensor detection circuit

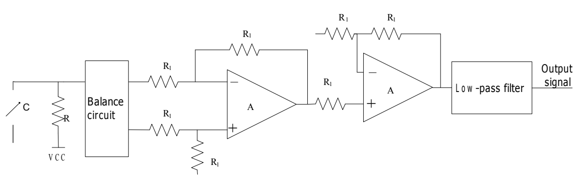

Figure 4. Equivalent detection circuit of the capacitance charging

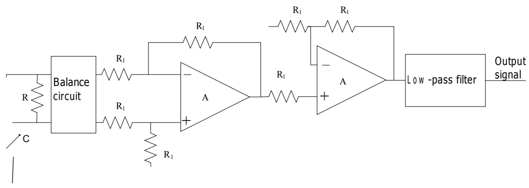

Figure 5. Equivalent detection circuit of the capacitance discharging

VI. Experiment and Data Analysis

Configuration principle is important. If the default moisture content is lower than the original sample corn moisture content , we can dry corn gradually through the oven to reduce the corn moisture content. If the default moisture is higher than the original sample moisture, we can add water to improve corn grain moisture content.

Calculation formula for about adding water weight [8]

$$M = M_1 \frac{H_2 - H_1}{1 - H_2} \tag{8}$$

Among formula, the M is added water weight. $M1$ is corn original sample weight. $H1$ is original sample moisture content. $H2$ is the default moisture content.

During the process of corn sample preparation, if the default moisture value minus corn original sample moisture value is less than 10% [9], the water can be one-time joined. TABLE III shows operation method of shaking jar of time and preparation. If greater than 10%, add water twice.Time about shaking jar and operation method such as shown in TABLE IV

TABLE III

SHAKING TIME IF LESS Than 10%

The first n day	Wetting time(t/hour)	Shaking time(s)
n=1	one-time joined water	60
	t=1	15
	t=2	15
	t=3	15
	t=3~24	15
n=2		15
n=3		15
n=4		15

TABLE IV

SHAKING TIME IF GREATER THAN 10%

The first n day	Wetting time(t/hour)	Shaking time(s)
n=1	Half of total	60
	t=1	15
	t=2	15
	t=3	15
	t=3~24	15
n=2	Another half of total	60
	t=1	15
	t=2	15
	t=3	15
	t=3~24	15

n=3		15
n=4		15
n=5		15

Twelve corn samples were placed in jars of 1L. According to the above two kinds of operation methods prepared containing different moisture values of the corn samples. The sealed jars were stored in the laboratory of shady place. If the sample went bad, we must allocate the same corn samples to do the experiment.

Place corn samples in the lab (laboratory temperature can be adjusted) and choose a temperature (through the temperature measurement circuit). Using dry method measure a group of corn sample moisture content value, at the same time using the capacitive corn moisture measurement system collect capacitance value and voltage value related temperature. The data collection procedure as follows:

1) Use dry method measure moisture content of a group of corn sample and record moisture value.
2) At the same time a sample group will be placed in the cylinder of capacitive sensor. Press the reset button and start measuring. After a period of time, the results of voltage value about sensor capacitance and temperature will be recorded.
3) Weigh the sample and then put into measurement, repeat steps 2 and record the results.
4) Each group samples need to repeat measurement 5 times.
5) Another group of corn samples, repeat steps (1) - (4).

Then configurate the same twelve groups of corn samples in lab (temperature changed) and repeat the above steps. Due to the limitation of the laboratory conditions, choose the five different temperatures. The measured data are saw in the appendix.

In the process of data collection, the measurement of the personnel subjective reason, or the external condition of the objective causes, the results of each measurement can have individual measurement results and the real value a lot of deviation. For each group of corn samples more measured value, need to use some methods to remove or modify the deviation of measured value, the experiment using statistics discriminant method of Dixon (Dixon) criterion [10] get rid of deviation of measured value.

Assuming there are normal measuring population distribution of a sample x_1, $x_2, \ldots, x_n$, arrangement for the sample x_1', $x_2', \ldots, x_n'$ by from big to small, according to the value of n can structure as shown below statistics,

If n=3~7,

$$r_{10} = \frac{x_n' - x_{n-1}'}{x_n' - x_1'} \tag{9}$$

$$r_{10}' = \frac{x_2' - x_1'}{x_n' - x_1'} \tag{10}$$

If n=8~10,

$$r_{11} = \frac{x_n' - x_{n-1}'}{x_n' - x_2'} \tag{11}$$

$$r_{11}' = \frac{x_2' - x_1'}{x_{n-1}' - x_1'} \tag{12}$$

If n=11~13,

$$r_{21} = \frac{x_n' - x_{n-2}'}{x_n' - x_2'} \tag{13}$$

$$r_{21}' = \frac{x_3' - x_1'}{x_{n-1}' - x_1'} \tag{14}$$

If n=14~30,

$$r_{22} = \frac{x_n' - x_{n-2}'}{x_n' - x_3'} \tag{15}$$

$$r_{22}' = \frac{x_3' - x_1'}{x_{n-2}' - x_1'} \tag{16}$$

If $r_{ij} > r_{ij}'$ and $r_{ij} > D(a,n)$ (Dixon coefficient), x_n' can be judged as abnormal value.

If $r_{ij} < r_{ij}'$ and $r_{ij}' > D(a,n)$, x_1' can be judged as abnormal value. Otherwise, there is no abnormal value judgment.

Experimental data obtained is discrete data, each set of data can not always avoid measurement error, need to use data fitting method to get data reflect the change trend of the whole of the approximate function. This paper collected the corn sample data based on the principle of least square fitting method, i.e., looking for a fitting curve y = s (x) to approximate show discrete data that coordinate relationship of function.

All the experiments were carried out at room temperature and take no account of effects of temperature changes. Using the detection circuit to measure the capacitance of samples and the drying method to measure moisture content, we obtained the curve of moisture content versus capacitance as shown in Figure 6 .

Using the least squares method we obtained the binary cubic equation linking the capacitance x(nF) and moisture content y(%) on the basis of the experimental data. The equation is shown as follow

$$y = -0.000054149x^3 - 0.0089798x^2 + 0.63413x + 11.4539 \quad (17)$$

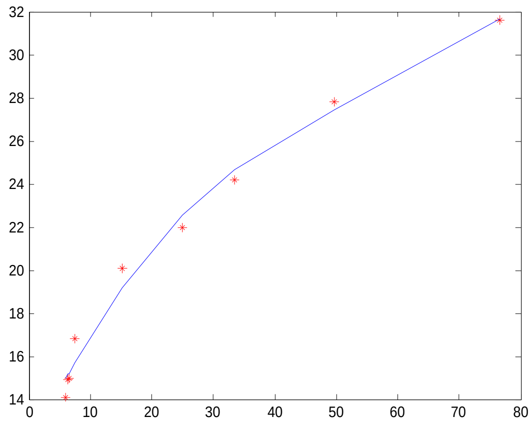

Figure 6. Plot of corn moisture content versus capacitance (the continuous line is the fitting curve)

From Figure 6, we conclude that capacitance increases with increasing corn moisture content.

V. Conclusions

The relationship between moisture content and capacitance was obtained in 8 groups of experiments. The moisture content of the samples can be determined on the basis of capacitance measured by the detection circuit. The error is smaller than in the drying method. We conclude that the accuracy in measuring moisture content by the capacitive sensor circuit is high and that the method is appropriate for accurate assessment of the moisture content in corn.

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