

Development of multi-grain capacitive sensor for determination of moisture content in grains

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RESEARCH ARTICLE

Abstract

The dielectric properties of a variety of Indian whole cereal grains viz. mustard, moong, masoor, chick pea, urad and wheat, with moisture content (MC) ranging from 7 to 35% (wet basis), were characterised to develop a prototype multi-grain moisture meter based on the capacitive sensing technique. The operating frequency of the multi-grain moisture meter was fixed at 230 kHz. It consisted of a calibrated oscillator circuitry, capacitive sensing cell as a sample holder, temperature sensor and microcontroller circuitry. It senses the MC of cereal grains due to variation of dielectric medium resulting in capacitance variation by using an oscillator tank circuit connected across a fixed reference capacitance value. This generates proportionate frequency modulations at the output of the oscillator circuitry. The empirical calibration equations for the prediction of moisture in a variety of grains were developed, validated and embedded in the microcontroller unit. A unique empty cylinder referencing system based on the relative frequency sensing technique associated with grain sample moisture variations was developed to compensate for empty cylinder referencing variations. This enabled the accurate measurement of frequencies. A thermistor was introduced in the oscillator circuitry to compensate for thermal drifts of the output signal. This enhanced the precision and stability of the oscillator unit. The coefficient of correlation between grain MC and capacitance variation was high and measurement accuracy was found to be 1%.

Keywords: moisture content, multi-grain moisture meter, frequency modulation, capacitive sensor, complex permittivity

1. Introduction

The moisture content (MC) of cereal grain is an essential factor affecting the physical and chemical properties related to storage, processing and quality control. It was recognised nearly 50 years ago that the electrical measurement methods could provide a rapid test to indicate the MC of grains (Briggs, 1908; Burton and Pitt, 1929; Chug *et al.*, 1973; Nelson, 1977). Several methods have been proposed to measure MC in grains. Resistance type and radio frequency capacitance type moisture meters (MM) are most commonly used. MM using the resistance method has an advantage of low cost, but grain samples are crushed and wasted. Also design of the associated circuitry is complex. An interesting method of estimation of grain MC is based on the capacitive properties of grains. It is a simple, rapid and low cost method and because of these advantages, researchers have utilised the capacitive sensors and dielectric properties of agro-products for different

purposes such as volume estimation and quality assessment for fruits and vegetables, etc. An MM measuring d-c conductance of grain was described by Brockelsby (1951). A non-destructive method was developed for estimating the MC of the kernels of corn from measurements of capacitance, dissipation factor, and phase angle on a small parallel-plate capacitor by Kandala *et al.* (1989). The influence of various factors on the accuracy of capacitance-type MM was carefully considered by Matthews (1963) and the design requirements were developed for such an instrument on the basis of these studies. Campbell *et al.* (2005) designed and developed a capacitive sensor based system for monitoring bees passing through a tunnel. The system was able to distinguish between entering and exiting bees and provided information on the size and velocity of each bee. Jarimopas *et al.* (2005) designed and developed an electronic device with a cylindrical capacitive sensor to measure the volume of selected fruits and vegetables. Ragni *et al.* (2006) used a sine wave radio frequency oscillator

with a parallel plate capacitor sample probe to predict the quality of egg during storage. Thakur *et al.* (2011) carried out studies on electrical properties of wheat as a function of MC (14.3% to 29.38%, wet basis) for the frequency range of 100 kHz-10 MHz. An evaluation of the calibration performance of a laboratory developed moisture meter for Indian wheat by two different techniques has also been reported by Babankumar *et al.* (2012). The performance evaluation of a digital grain moisture meter for Indian wheat using capacitance variation has also been reported recently by Bansod and Thakur (2011).

Although a lot of work has been reported on the development of capacitance based moisture meters, much less work has been done on moisture meters for multiple grains and especially for Indian grains. This paper deals with an improved multi-grain instrument based on the capacitance principle used for moisture determination in grains. The dielectric properties of various Indian cereal grains viz. mustard, moong, masoor, chick pea, urad and wheat with a MC range of 7-35% on wet basis were characterised to develop a prototype multi-grain moisture meter (MGMM) based on the capacitance variation technique with a sensor based grain moisture meter whose operating frequency is fixed at 230 kHz. Moisture measurement using the dielectric variation technique is affected by bulk packing density, temperature, uniformity in the dielectric cell, grain size, type of grain, and range of moisture measurement. The developed capacitive sensor achieves 0.5-1% accuracy.

2. Materials and methods

Theoretical background

The moisture measurement device is based on the use of the parallel plate capacitor technique with plane surface electrodes. This configuration provides a uniform electric field between the plates of empty capacitor. If the space is completely filled with a homogenous dielectric, the capacitance is given by:

$$C = \frac{\epsilon\epsilon_0 A}{d}$$

Where ϵ is the relative complex permittivity of the dielectric, ϵ_0 is the permittivity of free space, A is the area of each of the plates, and d is the separation between the parallel plates. In general, $\epsilon = \epsilon' - j\epsilon''$, is a complex quantity. The real part, ϵ' is the dielectric constant and the imaginary part, ϵ'' is the dielectric loss factor. Also, $\epsilon = |\epsilon| \exp(-j\delta)$, where δ is the loss angle of the dielectric. The permittivity of water is very high, about 80 at low frequencies, compared to about 3 for grain dry matter. For sensing moisture in grains, it is important to understand the dependence of dielectric properties of grain on MC and other factors. The dielectric constant always increases with increasing MC, and

generally, the dielectric loss factor also shows such changes. Dielectric properties also vary with the temperature and the bulk density of grains. Both the dielectric constant and the loss factor of grains generally increase with increasing temperature. As the bulk density of a grain sample increases (close packing) additional mass is present to react with the electric fields. Consequently, the permittivity (dielectric constant and loss factor) will increase. Thus, all of these factors must be taken into consideration when designing and calibrating instruments for measuring GMM.

Design considerations and construction of the dielectric cell

The dielectric cell designed for the instrument is in the form of concentric cylindrical capacitor whose capacitance is given by:

$$C = \frac{2\pi\epsilon_0 L}{\log(b/a)}$$

Where ϵ = dielectric of medium filled in concentric space; L = length of cylinder; b = inner radius of outer cylinder; and a = outer radius of inner cylinder.

In the above relation all the parameters are constant, except ϵ , which is dependent on the MC of the material. The behaviour of the sensor/dielectric cell designed for the system has been studied for different grains at various moisture levels. The concentric cylindrical design of the dielectric cell which houses a fixed volume of grain sample is shown in Figure 1.

The selected length, inner radius of outer cylinder, outer radius of inner cylinder are 5.7, 4.7 and 2.2 cm, respectively. The length of the wire connecting the cylinder and the circuit is 52.5 cm. The dielectric cell is made up of hollow aluminium cylindrical rods applied with material treatment such as anodizing process and special coating of polyethylene.

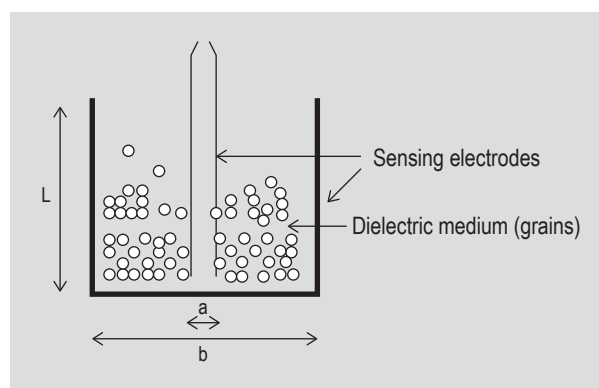


Figure 1. Cylindrical sensor design of dielectric cell. L = length of cylinder; b = inner radius of outer cylinder; and a = outer radius of inner cylinder.

Sensing electronics and instrumentation

For detecting change in capacitance, a square wave generator was used (Figure 2).

The circuit is comprised of two integrated circuits (ICs): LM339 (Texas Instrument, Helsinki, Finland), an operational amplifier (op-amp), and 74ACTQ14, a Schmitt trigger IC (Fairchild Semiconductor, San Jose, CA, USA). The op-amp is comprised of a timing circuit and a biasing circuit. The parameters of the timing circuit were selected according to the desired frequency output, i.e. 230 kHz, while the resistor values of the biasing circuit were selected to get the desired square wave output (digital pulse). The output of the op-amp was then given to a Schmitt trigger which acts as a buffer between the op-amp and the microcontroller chip (C8051F120; Silicon Laboratories, Austin, TX, USA). Another important functionality of the Schmitt trigger was to sharpen the edges of the square wave output of the op-amp. The frequency output of this square wave generator is dependent on the capacitance value of the capacitor (cylindrical capacitor cell + wire connecting the cylinder with generator circuit). Keeping the values of all components except the variable cylindrical capacitor (C_2) constant in the RC timing circuit, any change in output frequency of the oscillator depends solely on the variation in C_2 due to the varying moisture in the sample. Hence, by measuring the frequency output of this circuit the MC for a variety of grains was calibrated. The values of resistance and capacitances are as follows:

$C_1 = 10 \text{ pF}$; $R_2 = 180 \text{ K}\Omega$; $R_3 = 68 \text{ K}\Omega$; $R_4 = 68 \text{ K}\Omega$; $R_5 = 33 \text{ K}\Omega$; $R_6 = 15 \text{ K}\Omega$; $R_7 = 20 \text{ K}\Omega$; $R_8 = 1 \text{ K}\Omega$.

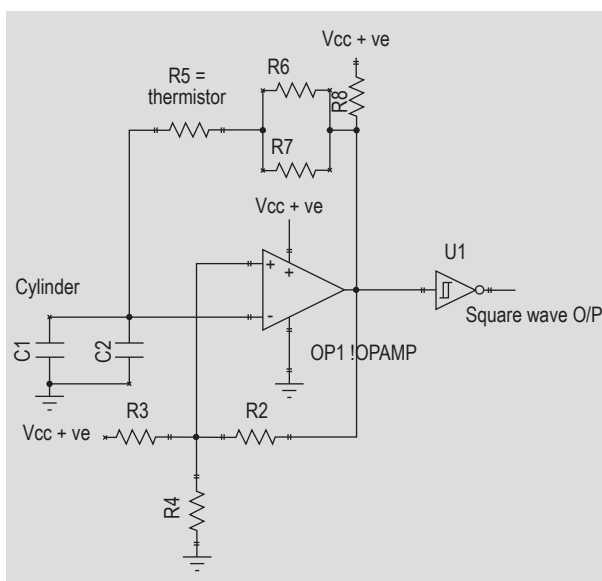


Figure 2. Circuit diagram of square wave generator (R2-R8 = resistance; C1-C2 = capacitances; U1 = Schmitt Trigger IC; Vcc = positive power supply).

In earlier studies researchers found that the variation of dielectric properties with moisture was found to be most linear at 230 kHz. This was the reason for choosing this value of frequency in the present work

Temperature compensation for oscillator stability

On studying the behaviour of the circuit it was observed that there was some drift in the frequency with temperature change of the surroundings. To compensate for these variations due to temperature changes various studies were conducted with different component values. Ultimately, a negative temperature coefficient (NTC) thermistor was selected. The resistance of the NTC thermistor increases with decrease in temperature. The increase in resistance increases the value of the RC time constant which in turn decreases the frequency and compensates for the increases in frequency and vice versa. The parallel combination of the thermistor-resistor value was chosen to compensate for variations in frequency based on the variations in oscillator frequency over a temperature range of 15-40 °C.

Design considerations for the cylinder cable

The effective capacitance of the cylinder was affected by the stray capacitance of the cable used to connect the cylinder. Even a small change in the gap between the wires connected to the cylinder resulted in changing the cable's capacitance value which in turn changed the frequency of the circuit. Also, the cable was more prone to external electromagnetic interferences which could change the final frequency. To avoid these possibilities the cable was shielded, grounded, and tightly fixed in a constant position thereby defining a fixed electrical path. Two parallel conductors, comprising the connector, also formed some constant capacitance value which was added to the capacitance value of the cylinder. This value was taken into account while adjusting the oscillator frequency. This value of capacitance and wire length was fixed in order to maintain the accuracy and frequency output of the circuit as desired.

Frequency measurement and calibration

The output of the square wave generator, proportional to sample moisture variation, was given to the mixed signal microcontroller unit (MCU) which calculated its frequency by counting the number of pulses. The MCU was used to measure the frequency output of square wave generator circuit using pulse counting technique. The steps of the algorithm for this technique are:

1. Decide the time slot for capturing the number of pulses (it should be decided based on the criteria that pulses with minimum frequency are captured properly and all the captured pulses show their different frequency).
2. Record the number of pulses captured and the actual frequency applied.

3. Find the relationship between the two values which should be a linear relation. Also, find the equation representing the relationship.
4. Apply this relation to the calculated count in order to get the actual frequency.

Block diagram of a multi-grain moisture meter

The complete block diagram for the MGMM (Figure 3) consists of the cylindrical capacitor, square wave generator, embedded microcontroller, LCD display, printer, PC, keyboard and temperature sensor in addition to a real time clock (RTC).

A temperature sensor was used to measure the room temperature at which the MC of grains was calculated. RTC was included in the circuit to measure time and date of operation. The keypad was used to instruct the MCU to perform various operations. The output of the MCU program was displayed on the LCD and interfaced to a printer.

3. Results and discussion

Calibration of calculated frequency

The MCU counts the number of input pulses in order to calculate final frequency variations occurring as a result of varying moisture conditions in different samples. This counting of the digital pulse width modulated frequency waveform was confirmed through a number of trials conducted using a waveform generator which can generate any desired wave shape and frequency. A unique software algorithm was written in the firmware of the MCU to accurately calculate the frequency for the applied digital pulse width modulation available at the input. This algorithm in the MCU was compared and tested for accuracy with the frequency supplied from the standard arbitrary waveform generator.

The results obtained using the algorithm to measure pulse width modulated frequency showed a high degree of correlation between the values predicted by the MCU and those supplied from the arbitrary waveform generator (standard frequency) (Figure 4).

To compensate for the deviations in frequency predicted by the microcontroller based algorithm an empirical equation was derived to precisely display the measured/predicted frequency using actual variable (frequency) and measured variable (frequency).

Calibration of a multi-grain moisture meter and its evaluation

Calibration of the MM involved matching its moisture measurements with the moisture value of the same sample obtained by a standard dry-oven technique. Data collected from the standard imported meter, which uses readings from the dry oven technique, was compared with the data obtained from the developed MGMM (Figure 5).

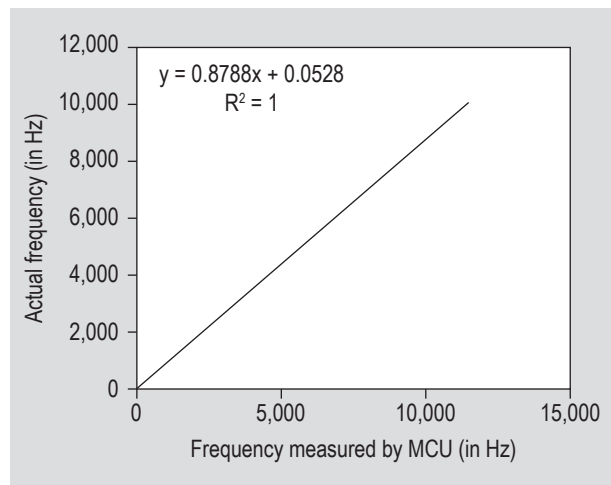


Figure 4. Plot between standard frequency vs. measured frequency by microcontroller unit (MCU).

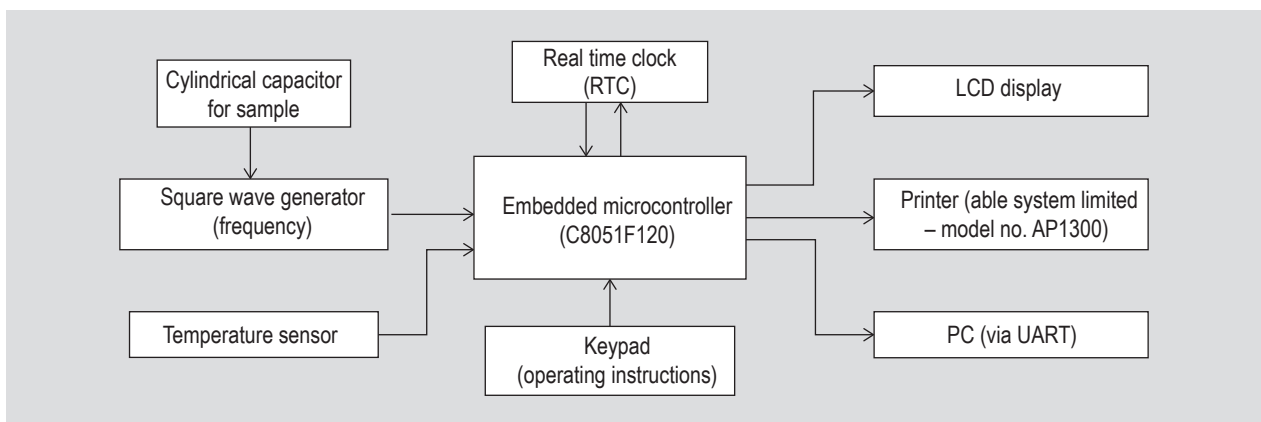


Figure 3. Block diagram for a multi-grain moisture meter.

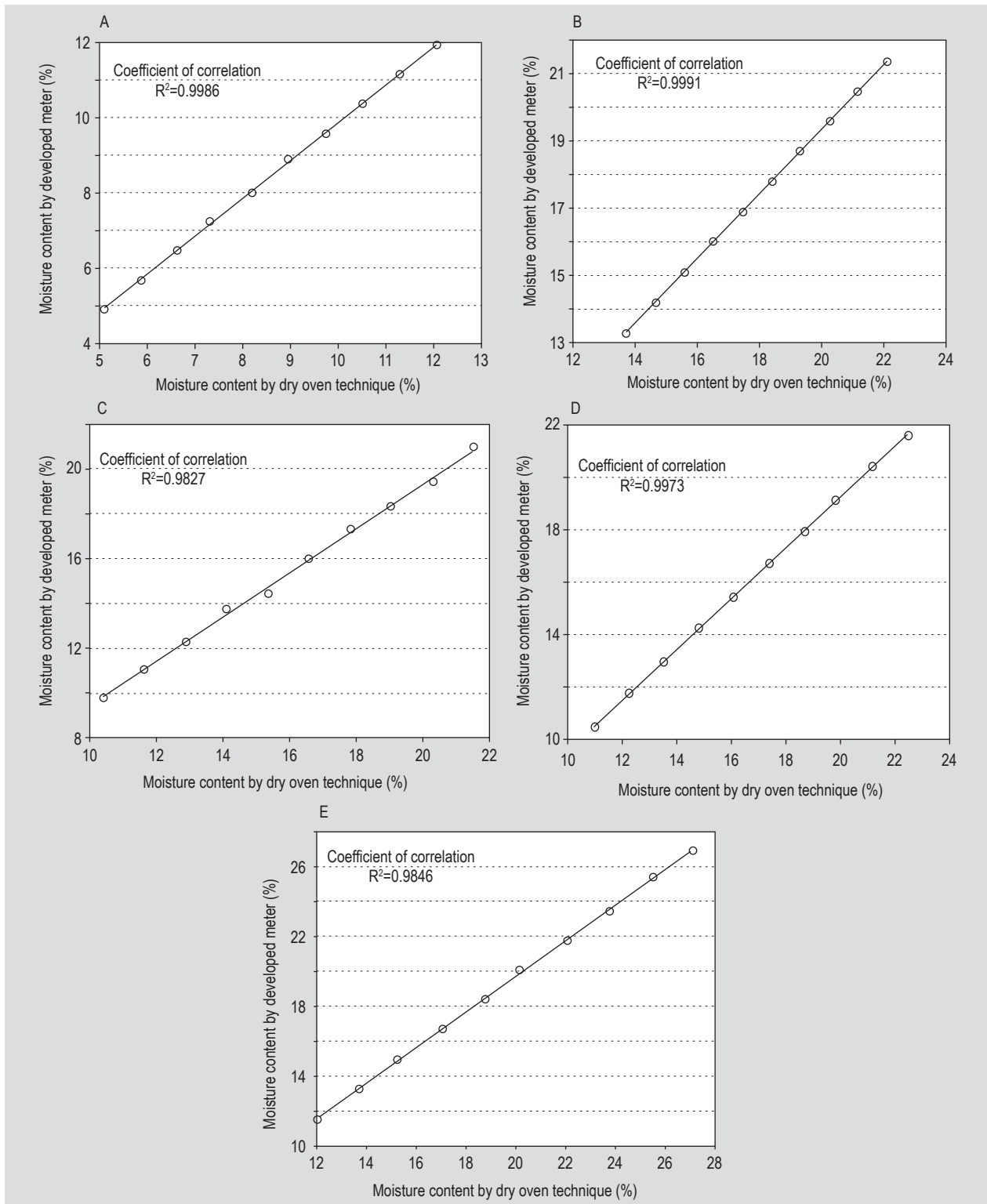


Figure 5. Validation plots of developed multi-grain moisture analyser. (A) Mustard. (B) Moong. (C) Urad. (D) Masoor. (E) Chick pea.

A comparison of moisture values obtained from the developed MGMM and the standard dry oven method was done to evaluate the performance of the MGMM for different grains viz. mustard, moong, masoor, chick pea, urad and wheat (Figure 6).

The results obtained show a high degree of correlation between the data obtained from the developed meter and the standard meter using the dry oven technique. The measurement accuracy of the capacitive sensor was found to be 1%.

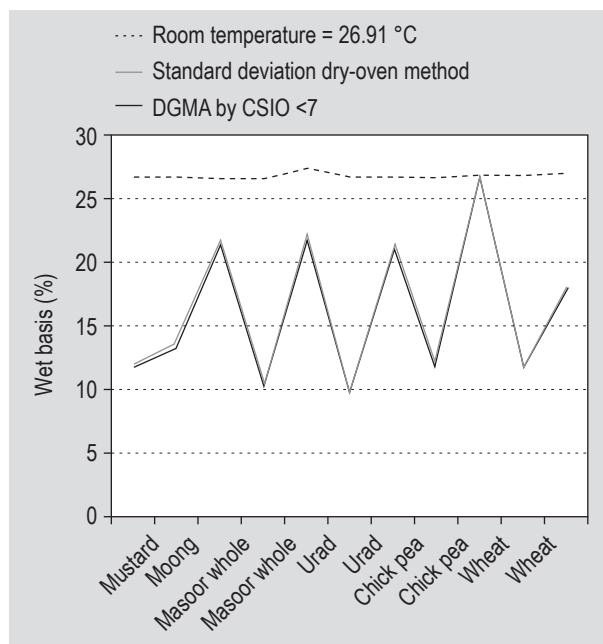


Figure 6. Performance evaluation of a multi-grain moisture meter (CSIO = Central Scientific Instruments Organisation; DGMA = digital grain moisture analyser).

4. Conclusions

Performing fast and accurate moisture measurements is of great importance in trading, storing, and processing grains. Capacitive sensors are considered accurate and one of the fastest measurement techniques. This paper deals with the development of a MGMM based on the capacitance variation technique (concentric cylinder type) sensor which is designed to sense the MC in cereal grains in terms of frequency. Moisture values for various types of cereal grains measured by MGMM were compared with the moisture values obtained by the standard dry oven method. A good correlation was observed between the results from the two methods. The effect of temperature on the frequency of the square wave output is compensated by using an NTC thermistor. A unique algorithm for the measurement of effective change in frequency combined with a special coating applied on the side walls of the measuring cylinder to avoid conductance losses helped to produce the accuracy desired in any commercially available moisture measurement device.

References

- Babankumar, S.B., Thakur, R. and Singla, M.L., 2012. Evaluation of calibration of moisture meter for Indian wheat by microwave oven drying technique and commercial moisture meter. *Transactions of the Institute of Measurement and Control* 34: 539-545.
- Bansod, B.S. and Thakur, R., 2011. Performance evaluation of digital grain moisture analyser for Indian wheat. *Journal of Scientific and Industrial Research* 70: 41-44.
- Briggs, L.J., 1908. An electrical resistance method for the rapid determination of the moisture content of grain. Bureau of Plant Industry, Circular no. 20, U.S. Department of Agriculture, Washington, D.C., USA.
- Brockelsby, C.F., 1951. An instrument for estimating the moisture content of grains and other materials by the measurement of electrical conductance. *Cereal Chemistry* 28: 83-94.
- Burton, E. F. and Pitt, A., 1929. A new method for the rapid estimation of moisture in wheat. *Canadian Journal of Research* 1: 155-162.
- Campbell, M.J., Dahn, D.C. and Ryan, D.A.J., 2005. Capacitance-based sensor for monitoring bees passing through a tunnel. *Measurement Science and Technology* 16: 2503-2510.
- Chugh, R.K., Stuchly, S.S. and Rzepecka, M.A., 1973. Dielectric properties of wheat at microwave frequencies. *Transactions of the ASAE* 16: 906-909.
- Jarimopas, B., Nunak, T. and Nunak, N., 2005. Electronic device for measuring volume of selected fruit and vegetables. *Postharvest Biology and Technology* 35: 25-31.
- Kandala, C.V.K., Nelson S.O. and Lawrence, K.C., 1989. Non-destructive electrical measurement of moisture content in single kernel of corn. *Journal of Agricultural Engineering Research* 44: 125-132.
- Matthews, J., 1963. The design of an electrical capacitance-type moisture meter for agricultural use. *Journal of Agricultural Engineering Research* 8: 17-30.
- Nelson, S.O., 1977. Use of electrical properties for moisture measurement in grains. *Journal of Microwave Power* 12: 67-72.
- Ragni, L., Gradari, P., Berardinelli, A., Giunchi, A. and Guarnieri, A., 2006. Predicting quality parameters of shell eggs using a simple technique based on the dielectric properties. *Biosystems Engineering* 94: 255-262.
- Thakur, R., Chatterji S., Kumar A. and Bansod B.S., 2011. Studies on electrical properties as a function of moisture content. *Quality Assurance and Safety of Crops and Foods* 3: 198-204.