

Microwave Based Moisture Measurement System for Granular Materials: A Review

Lalita Gupta

Abstract: In the recent years, development of a non-destructive and non-contacting type moisture measurement system has attracted considerable interest. Because of their inherent nature of being nondestructive, non-conductive medium and having deep penetrative properties, Microwaves have been the traditional choice in this kind of research. This paper is a comprehensive review of Microwave Based Measurement System used for grains and pulses. In this paper, moisture measurement and calibration techniques for the system are presented. The objective of the paper is to provide the readers a broad perspective of microwave based techniques for measurement of moisture in bulk in silos or in sacks.

Keywords: Bulk density, Complex Permittivity, Moisture Measurement, Temperature Compensation

I. INTRODUCTION

The amount of moisture in stored grain is an important factor which affects food safety. Therefore, a timely and accurate detection of the moisture content in stored grain is of great importance. Electromagnetic wave has a strong trait of penetrating, which is able to detect the moisture content of grain inside the heap in the case of non-destructive. The moisture content of materials determines their suitability for storage, commerce and industrial processing. If the moisture content of grains is too high, they are deemed unfit for storage and must be dried to avoid decay. Traditionally, oven drying and weighing of samples was done for moisture measurement. In [1], a well defined protocol specifies weighing the sample initially. The sample is then oven dried and weighed again. The difference in weights divided by the initial weight gives the moisture content. However, in the drying process, not only water but also other volatile substances get evaporated leading to erroneous results. Another method conventionally used was the Karl Fischer test. This method is destructive and time consuming. The concept of using microwaves for moisture measurement evolved out of the need to overcome the above limitations. Moisture measurement using microwaves is real time, non-destructive and more accurate. However this method also suffers from errors resulting due to bulk density and temperature variations. Both these factors have to be either eliminated or compensated during calibration.

II. PROPERTIES OF MOISTURE (WATER)

Water has a bipolar structure i.e. while water molecules are neutral as a whole; one end of the water molecule tends to have a positive charge while the other has a negative charge. In such molecules,

The electric field of microwaves causes oscillations. These oscillations lead to loss due to absorption and reflection of energy. Higher the moisture content, greater will be the loss. Distilled water has a high dielectric constant of about 80.10 at 20°C due to the dipole moment and can be polarized. The electrical properties (dielectric property and loss tangent) of any material also depend on the frequency of operation. Complex permittivity is given as:

$$\epsilon(w) = \epsilon'(w) - j\epsilon''(w) \tag{1}$$

Here, $\epsilon'(w)$ is the real part of permittivity and represents the stored energy within the material and $\epsilon''(w)$ is the imaginary part of permittivity and represents dissipation of energy within the medium. The negative sign of the imaginary part denotes loss of energy [2].

III. MEASURING PHASE SHIFT AND ATTENUATION

The sample under test i.e. the sample for which moisture content has to be determined has to be first prepared. This sample preparation involves spraying distilled water on the grains, storing them in sealed jars for 72-96 hours. The samples are mixed periodically by rotating the sealed jars thus ensuring uniform moisture throughout the sample [3].

The sample is then placed in a sample holder of uniform thickness. Horn antenna is used to transmit microwaves into the sample. The transmitted waves undergo reflection and absorption due to the moisture in the sample and are received by another horn antenna at the other end of the sample holder as shown in the figure. Microstrip patch antennas can also be used instead of horn antennas leading to light weight system as reported in [5]. However, horn antennas offer the advantages of high gain and high directivity as compared to microstrip patch antennas which is crucial in for accurate measurements [4].

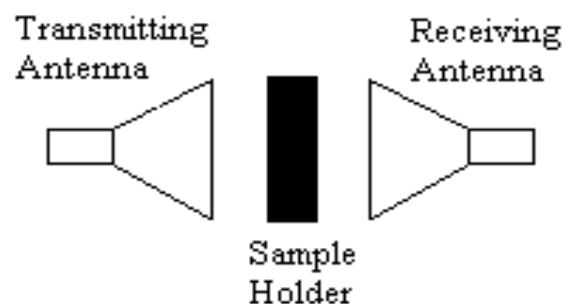


Fig. 1. Schematic diagram showing horn antennas and sample holder for moisture measurement

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Attenuation and phase shift are determined by comparing the reference microwave signals measured without the sample and those obtained after the sample is placed between the two antennas.

IV. CALIBRATION FOR DETERMINING MOISTURE CONTENT

A graph of ΔA and $\Delta\Phi$ plotted against the moisture content shows an approximately linear relationship as shown in Fig. 2 and Fig. 3 [7].

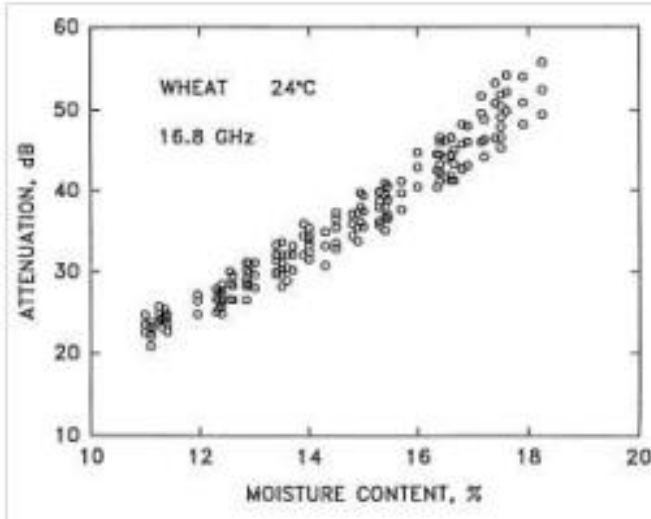


Fig. 2. Attenuation vs. Moisture Content [7]

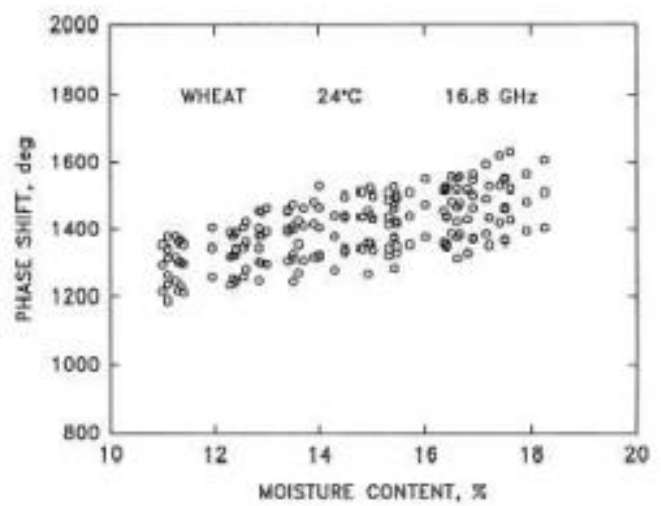


Fig. 3. Phase Shift vs. Moisture Content [7]

In [8] a third order polynomial regression model was proposed to describe the relation between receiving antenna measurements and the moisture content. If the moisture content is denoted by MC, V is the output of the voltage detector connected to the receiving antenna and ρ is the bulk density in g/cm³, then the polynomial for determining the moisture content is given by:

$$MC = -1.0896 \times 10^{-8}V^3 + 6.4620 \times 10^{-6}V^2 + 4.6 \times 10^{-4}T + 0.1845 \times \frac{100}{\rho} \quad (2)$$

However, as can be seen, the moisture content varies with the bulk density and this has to be compensated while developing the regression model. There was a need to develop models which were independent of bulk density. The ratio method was then developed as reported in [7]. The method involved using a function which was ratio (R) of the two parameters ΔA and $\Delta\Phi$. Since, both ΔA and $\Delta\Phi$ depend on bulk density (Fig. 4), their ratio, R is essentially independent of bulk density (Fig. 5).

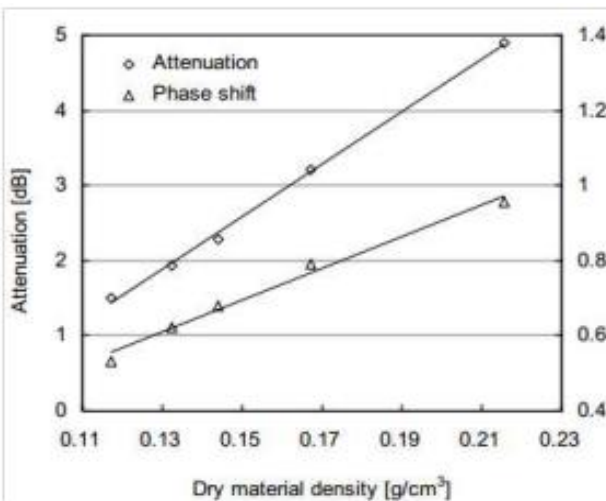


Fig. 4. Attenuation and Phase Shift vs. Bulk Density [9]

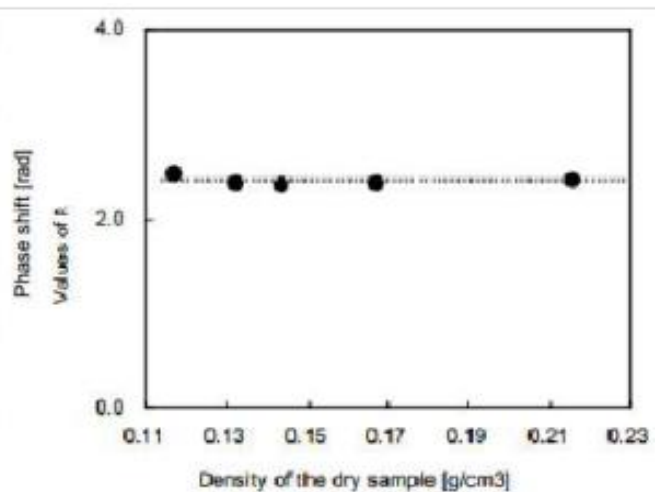


Fig. 5. Ratio R vs. Bulk Density [9]

$$R = \frac{\Delta A}{\Delta\Phi} \quad (3)$$

$$MC = \frac{(10^3R+12.768)-0.1438T}{0.01185T+2.1003} \quad (4)$$

A linear polynomial regression model was proposed specifying the calibration equation for moisture content in terms of R. The equation also considered the dependence of R on temperature (T) [7].



V. CONCLUSION

The review of microwave based measurement technique shows clear advantage of using horn antennas over patch antennas due to the requirement of high directivity though being bulky. The calibration based on only attenuation needs to be temperature and bulk density compensated. The two parameter ratio method of calibration is simple and achieves bulk density independence. However, it is more suitable for transmission techniques. The density independent calibration method is the most suitable method. This method is related to dielectric properties of the material under test and hence can be used regardless of the measurement techniques. Along with bulk density independence, it is easily temperature compensated and can also be used for calculating bulk density thus eliminating the need of a separate device for bulk density measurement.

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