Coaxial-Probe Contact-Force Monitoring for Dielectric Properties Measurements

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Abstract. A means is described for measuring and monitoring the contact force applied to a material sample with an open-ended coaxial-line probe for purposes of measuring the dielectric properties of semisolid material samples such as fruit, vegetable, and animal tissues. The equipment consists of a stainless steel sample cup, load cell and associated strain meter, and an aluminum alignment sleeve to ensure that the force acting on the sample is properly transferred to the load cell. The assembly (sample, sample cup, load cell, and spacer in the alignment sleeve) rests on a platform with position adjustable vertically to raise the assembly and provide contact of the sample with a rigidly mounted coaxial probe above the sample holder. The strain meter to which the load cell is connected displays the force between the probe and the sample to facilitate monitoring this contact force. Use of a consistent contact force helps to reduce the variation in results of dielectric properties measurements by this technique.

Keywords. Contact force, Coaxial probe, Dielectric properties measurement, Load cell, Strain meter.

Dielectric properties, or electrical permittivities, of materials are important in describing the interaction of those materials with electric fields. These properties of materials have been discussed in detail previously (Nelson, 1965; 1973), and available data on dielectric properties of agricultural products have been tabulated for reference (Nelson, 1973; Tinga and Nelson, 1973; ASABE Standards, 2009).

The dielectric properties of usual interest for agricultural applications are the dielectric constant $\varepsilon'$ and the dielectric loss factor $\varepsilon''$, real and imaginary parts, respectively, of the relative complex permittivity $\varepsilon = \varepsilon' - j \varepsilon''$, i.e., the permittivity relative to free space. Other dielectric properties often used are the loss tangent, the tangent of the loss angle of the dielectric material, $\tan \delta = \varepsilon'' / \varepsilon'$, and the conductivity, $\sigma = \omega \varepsilon_0 \varepsilon''$, where $\omega$ is the angular frequency, $\omega = 2 \pi f$, where $f$ is frequency in Hz, and $\varepsilon_0$ is the permittivity of free space, $8.8542 \times 10^{-12}$ farad/m.

The most common uses of the dielectric properties are in radio-frequency and microwave dielectric heating of materials and in rapid measurement of moisture content through sensing the dielectric properties of grain and seed. These applications have been described in earlier publications (Nelson, 2006; 2008). Other potential applications include the sensing of product quality attributes other than moisture content, and in these studies, the use of dielectric spectroscopy, i.e., the measurement of dielectric properties over wide frequency ranges has been particularly helpful (Nelson, 2004; Nelson, 2005b; Guo et al., 2007; Nelson et al., 2007; Zhuang et al., 2007).

For dielectric spectroscopy studies, the open-ended coaxial-line probe technique for dielectric properties measurements on materials has been commercially developed and is in wide use for such measurements (Blackham and Pollard, 1997). The technique is particularly applicable to liquids and semisolid materials. For solids, it requires a plane, well-finished surface to avoid serious errors resulting from poor contact and air space between the probe and material sample. The technique can be used for measurements on ground or powdered materials, but particle size must be small in relation to the diameter of the coaxial-line probe, and permittivity and density relationships need to be taken into account (Nelson, 2005a). Air pockets must also be avoided in measurements on liquids and semisolids. In measurements on semisolid materials such as fruit and vegetable and animal tissues, variability in measurements has been noted because of variation in the force holding the probe in contact with the material. Thus, use of a consistent force is advisable, but no suitable method for this has been available. A system for achieving this objective through monitoring that force has been designed and is described in this article.

Description of the Force-Monitoring System

Equipment has been designed and assembled that permits the force of the probe acting on the sample to be measured and monitored for consistency during the dielectric properties measurements. It employs a suitable commercial load cell and strain gauge meter, a stainless steel sample cup [described previously as part of a sample temperature control system (Nelson et al., 1997)], an aluminum alignment sleeve, and an adjustable platform fitting on a ring stand clamp which...
supports the assembly below the fixed coaxial probe (fig. 1). Thus, the alignment sleeve keeps the sample cup resting on the contact point of the load cell, and an electronic strain gage meter provides the necessary excitation for a Wheatstone bridge strain gage built into the load cell and displays the force acting on the load cell, which represents the force acting on the sample from contact by the coaxial probe. The strain gage meter has a "tare" button that can be used to set the display to zero before the probe is brought into contact with the material sample by raising the supporting platform for the load cell sample assembly. Thus, the force of the probe on the sample can be maintained at a consistent value for successive measurements, reducing the variability in repeated measurements.

The alignment sleeve, sample cup, load cell, aluminum spacer, and adjustable platform clamp are shown separated in figure 2. A sectional drawing of the total assembly is shown in figure 3. The alignment sleeve was machined to provide a slip fit for the sample cup and load cell so that, when assembled, the sample cup rests on the center projection of the load cell and can move freely applying the vertical force directly to the load cell. The aluminum spacer rests directly on the clamp circular support platform and supports the load cell in the alignment sleeve so that the electrical leads of the load cell can exit the alignment sleeve, through the slot milled in the lower portion of the sleeve, above the lip of the clamp platform (fig. 1), thus limiting any force on the load cell to that applied by the sample cup.

**LOAD CELL AND STRAIN GAGE METER**

A low-profile 1-in. diameter compression disc load cell (Omega Engineering LCGC Series, Stamford, Conn.) and Omega Engineering DP25B-S Strain Meter were used for the force measurement and monitoring system. The meter provided the required dc voltage supply for the strain gage circuit in the load cell, the measurement circuit and digital display, and versatile programming functions. For this application, a load cell with a range of 0 to 150 g was selected. Once the load cell was connected to the strain meter, and the strain meter was configured and scaled according to the manufacturer's instructions, the meter displayed the grams force acting on the load cell (fig. 4). To monitor the contact force applied by the coaxial probe to the sample, the sample was placed in the sample cup, and the tare button was pressed on the strain meter, providing a zero reading on the digital display. When the sample was brought into contact with the coaxial probe for dielectric properties measurement, the strain meter displayed the contact force between the sample and the probe. By rotating the knurled circular platform while holding the alignment sleeve stationary, the contact force between the probe and the sample can be adjusted to the desired value.

**FUNCTIONAL TEST OF FORCE MONITORING SYSTEM**

To check the functional operation of the force monitoring system, an aluminum disc was machined to rest on top of the sample cup providing a plane platform to support standard
analytical balance weights, which would provide known forces acting on the load cell. A small circular projection, of slightly less diameter than the inside diameter of the sample cup was machined on the bottom of the disk to fit inside the sample cup and keep the disc platform in position on the sample cup.

After the platform was placed on the sample cup, the tare button on the strain meter was used to set the reading to zero, weights were added in 15-g increments, and resulting readings of the strain meter were recorded over the 0- to 150-g range. Mean values and standard deviations for ten repetitions of the test are listed in table 1. The combined weight of the sample cup and aluminum platform was 32.4 g.

Resulting data were subjected to the descriptive statistics computations of SigmaPlot 11. Mean values for the strain gauge system were about 1% to 3% greater than the standard weights applied up to 105 g. Beyond this value the differences were up to 5% greater. However, with the 32.4-g collective weight of the sample cup and platform, the total force applied to the load cell exceeded the calibrated 0- to 150-g range for the highest three weights applied. The accuracy of the system and the repeatability, as judged by the standard deviations and standard error are certainly satisfactory for monitoring the force applied to samples for dielectric probe measurements of the dielectric properties of semisolids and tissues of biological materials.

CONCLUSIONS

A means can be provided, with commercially available strain gauges, for measuring and monitoring the contact force applied to a material sample with an open-ended coaxial-line probe for purposes of measuring the dielectric properties of semisolid material samples such as fruit, vegetable, and animal tissues. An aluminum alignment sleeve was designed and constructed to ensure that the force acting on the sample is properly transferred through a stainless steel sample cup to a load cell. The assembly (sample, sample cup, load cell and spacer, in the alignment sleeve) rests on a platform that can be adjusted vertically to raise the assembly and provide contact between the sample and a rigidly mounted coaxial probe above the sample holder. A strain meter to which the load cell is connected displays the force between the probe and the sample. Accuracies of 1% to 3% were obtained in the range from 0- to 120-g force, with satisfactory repeatability for monitoring the contact force of coaxial probes applied to samples for dielectric properties measurements.

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REFERENCES


