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ELECTRIC FIELD MODELLING FOR WOOD MOISTURE METER

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Electric field modelling results for a capacitive moisture meter are presented. The sensor is assumed to consist of two disk-shaped electrodes with a thin dielectric insulator between electrodes and the wooden plate. Capacitance of these two electrodes depends on surounding environment. By measuring the capacitance of the sensor it is possible to find wood moisture contents. Sensor capacitance dependences on wood thickness and permittivity are obtained as modelling results.

Keywords: moisture meter

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1. Introduction

This article presents numerical calculation of electric field distribution around disk-shaped electrodes in the presence of a wooden plate. The main goal of the work is to use calculation data as a starting point for capacitive moisture meter design. There is a large variety of wood moisture meters in the market, but the need to make it a part of more general equipment forces redesign of a moisture meter.

The wood moisture contents measurements via measuring the electrical characteristics of wood are the most used methods. These methods are based on resistance, dielectric constant, and power loss factor measurement. The most primitive method of wood moisture contents measurement is the oven-dry procedure until constant mass is reached. This way is used for equipment verification and calibration purposes. Experimental moisture contents measurement methods are more sophisticated and give more complex data. For instance, the nondestructive moisture gradient measurement may be performed using a medical X-ray computer tomograph or NMR (nuclear magnetic resonance) tomograph [1]. Microwave moisture measurement methods are still a subject of research. In spite of that, nondestructive microwave measuring methods have some advantages, which make them attractive for industrial applications [2].

The dielectric constant of wood is a complex quantity

$$\varepsilon = \varepsilon' - \mathrm{i}\varepsilon'',$$

where $\varepsilon'' = \varepsilon' \tan\delta$ is power loss factor. Furthermore, wood is an anisotropic material and moisture distribution is nonuniform. Resistive and capacitive moisture measurement methods always give some integral value of moisture contents. In order to deal with this situation, considerable simplifications must be assumed. Our numerical modelling attempts to give an estimate of capacitance of a given configuration of electrodes, which is a sensor of a capacitive moisture meter. Due to the nature of electric field to decay moving away from electrodes, the sensor has a limited sensitivity depth. The object of numerical modelling also was to give an estimate to this sensitivity depth.

The following assumptions are made:

- the sensor electrodes are assumed to be infinitely thin and disk-shaped (see Fig. 1);
- there is a thin insulating plate with $\varepsilon = 8$ between electrodes and the wooden plate;
- permittivity of wood is assumed to be real $\varepsilon = 3{-}30$;
- the wooden plate is assumed to have dimensions much larger then the dimensions of electrodes;
- the measurement frequency is assumed to be low enough so that the quasi-static approach is valid.

2. Theoretical basis of the calculation

The axial symmetry suggests the use of cylindrical coordinates $\{\rho, z\}$. Following the method of secondary

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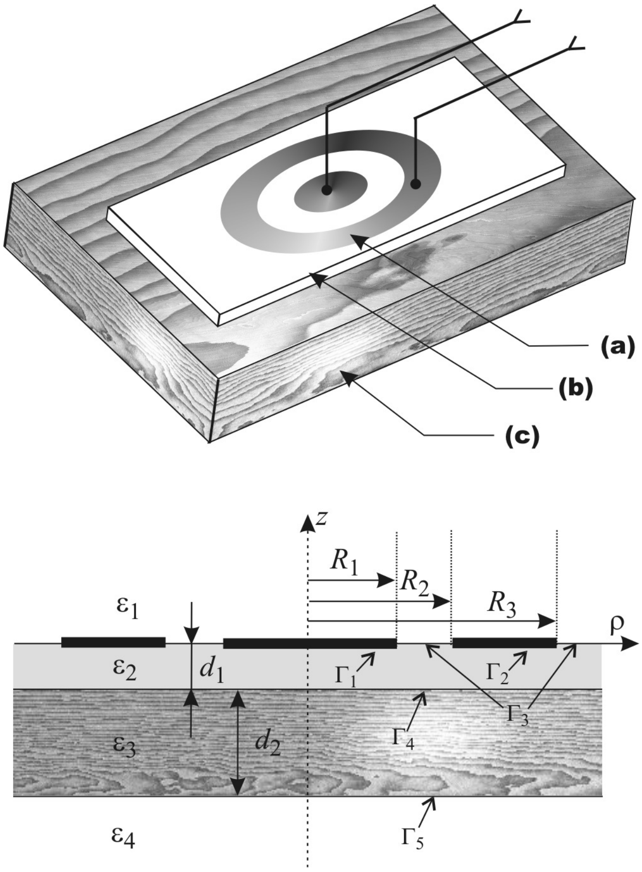

Fig. 1. Schematic plot of the sensor and cross-section in the $\rho{-}z$ plane: (a) electrodes, (b) thin insulator, (c) wooden plate.

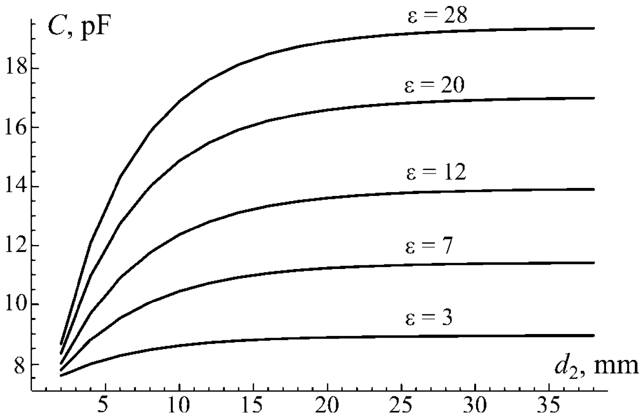

Fig. 2. Sensor capacitance as a function of the wooden plate thickness. The gap is considered to be $R_2 - R_1 = 1$ cm.

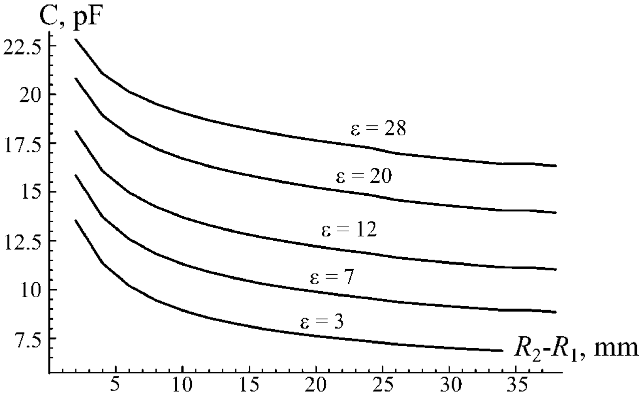

Fig. 3. Sensor capacitance as a function of the gap. Wooden plate thickness is $d_2 = 2$ cm.

sources, the electrostatic potential may be expressed as follows:

$$\varphi(p) = \int \psi(p')G(p,p')\,\mathrm{d}s', \tag{1}$$

where p and p' are the sets of source and field coordinates, respectively. Function $\psi(p')$ denotes the density of sources, kernel $G(p,p')$ is the electrostatic potential of a charged ring [3]

$$G(p,p') = \frac{4\rho' K(k)}{4\pi\varepsilon_0\sqrt{(\rho'+\rho)^2+(z'-z)^2}}, \tag{2}$$

$$k^2 = \frac{4\rho\rho'}{(\rho'+\rho)^2+(z'-z)^2}. \tag{3}$$

$K(k)$ is the complete integral of the first kind.

The potential (1) must keep the constant values on the surfaces of the conductor. Let us denote these values as φ_1 and φ_2. In the case of a capacitor, the electrode conductors are charged by the same magnitude and opposite sign charge. Let us consider the charge to be 1 C, then the capacity is defined as

$$C = \frac{1\ [\mathrm{C}]}{\varphi_2 - \varphi_1}. \tag{4}$$

The integral equations that the potential satisfies are determined by the boundary conditions. The boundary condition on the conducting surface states that the potential must be constant on it. Therefore,

$$\int_\Gamma \psi(p')G(p,p')\,\mathrm{d}s' = \begin{cases} \varphi_1, & \text{if } p \in \Gamma_1, \\ \varphi_2\,, & \text{if } p \in \Gamma_2, \end{cases} \tag{5}$$

where Γ_1, Γ_2 denote the surface of the inner and the outer electrode, respectively; $\Gamma = \Gamma_1 \cap \Gamma_2 \cap \Gamma_3 \cap \Gamma_4 \cap \Gamma_5$. The integral equation for a boundary of two dielectric surfaces is given by [4]

$$2\pi\psi(p) + \frac{\varepsilon_- - \varepsilon_+}{\varepsilon_- + \varepsilon_+}\int_\Gamma \psi(p')\frac{\partial}{\partial n}G(p,p')\,\mathrm{d}s' = 0,$$

$$p \in \Gamma_3, \Gamma_4, \Gamma_5, \tag{6}$$

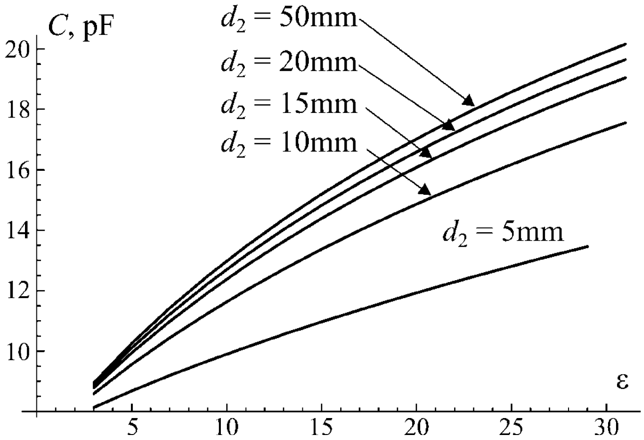

Fig. 4. Sensor capacitance as a function of wooden plate relative permittivity. The gap is taken $R_2 - R_1 = 1$ cm.

where ε_- and ε_+ denote relative permittivity in such a way: $\varepsilon_+ = \varepsilon_1$ and $\varepsilon_- = \varepsilon_2$ for the boundary Γ_3, $\varepsilon_+ = \varepsilon_2$ and $\varepsilon_- = \varepsilon_3$ for the boundary Γ_4, $\varepsilon_+ = \varepsilon_3$ and $\varepsilon_- = \varepsilon_4$ for the boundary Γ_5. Equations (5) and (6) define the unknown function $\psi(p)$. Although, the additional relations are necessary for unknowns φ_1 and φ_2. These relations follow from the requirement that the charge of electrodes be of the same magnitude and of opposite signs. As far as we considered the charge to be $+1$ and -1, these additional relations may be expressed as

$$(\varepsilon_1 + \varepsilon_2) \int_{\Gamma_1} \psi(p') \, \mathrm{d}s' = 1 \tag{7}$$

and

$$(\varepsilon_1 + \varepsilon_2) \int_{\Gamma_2} \psi(p') \, \mathrm{d}s' = -1. \tag{8}$$

The set of integral equations was solved by approximating them with linear equations. For this purpose the regions Γ_1, Γ_2, Γ_3, Γ_4, and Γ_5 were divided into intervals where the unknown $\psi(p)$ was assumed to be constant. So, if the regions are divided into N intervals, the N discrete values of $\psi(p)$ are obtained as a solution of the integral equations. The set of $N + 2$ linear equations must be solved. The additional two equations are Eqs. (7) and (8).

3. Modelling results

We used $N = 130$ discretization points, i.e. the set of integral equations was approximated with a set of 132 linear equations. The modelling method cannot deal with the situation when the insulator and the wooden plate extend to infinity in x and y directions. So, regions Γ_3, Γ_4, and Γ_5 were truncated at $10R_3$. The insulator layer between electrodes and the wooden plate was assumed to have 1.5 mm thickness and $\varepsilon_2 = 8$. Radiuses of electrodes were taken to be $R_1 = 1.5$ cm and $R_3 - R_2 = 1$ cm, while the gap $R_2 - R_1$ between electrodes was varied.

Figure 2 presents sensor capacitance modelling results when the thickness of the wooden plate was varied. Different permittivities of wood are also considered. These results give an estimate of the sensitivity depth when the gap between electrodes is 1 cm. The larger values of ε correspond to the better dried wood.

Figure 3 illustrates the capacitance dependence of the gap between electrodes. The wider gap results in the greater electric field penetration depth into the wooden plate. On the other hand, the sensor with wider gap has a smaller capacitance, and a cable connected to the sensor may have dominating capacitance. This figure is usefull to find the compromise.

If it would be known how the permittivity depends on the moisture contents (and other factors, e.g., temperature), Fig. 4 could serve as a gauge curve for a moisture sensor.

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MEDIENOS DRĖGMĖMAČIO ELEKTRINIO LAUKO MODELIAVIMAS

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Santrauka

Pateikti elektrinio lauko modeliavimo rezultai yra skirti talpiniam medienos drėgmėmačiui kurti. Singuliariųjų integralinių lygčių metodu buvo modeliuojamas elektrinio lauko pasiskirstymas ir apskaičiuojama jutiklio talpa. Medienos talpinis drėgmėmatis yra sudarytas iš keleto elektrodų, kurių talpa priklauso nuo juos supančios aplinkos, šiuo atveju – nuo medienos savybių. Bandyta įvertinti, kaip jutiklio talpa keistųsi, esant įvairiems medienos storiams, kaip talpa priklauso nuo medienos dielektrinės skvarbos, kaip gylis, kuriame jutiklis dar būtų jautrus aplinkai, priklauso nuo atstumo tarp elektrodų. Taikyti supaprastinimai ir prielaidos: laikyta, kad dažnis, kuriam esant matuojama talpa, yra pakankamai mažas ir elektrinio lauko pasiskirstymą kiekvieną akimirką galima laikyti statiniu; laikyta, kad medienos dielektrinė skvarba turi tik realiąją dalį; jutiklio konstrukciją sudaro du disko formos elektrodai. Rezultatai pateikti grafikų pavidalu: jutiklio talpos priklausomybės nuo medienos storio, medienos dielektrinės skvarbos ir nuo plyšio pločio tarp elektrodų.