UNIVERSITI PUTRA MALAYSIA

CAPACITANCE-BASED TOMOGRAPHY OF FIBERBOARDS AND WOOD

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By

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DEDICATION

To My Parents

My Wife, Son and Daughters,

Brothers and Sisters

And

My Supervisor Professor Dr. Kaida Khalid

&

My Friend PhD. Student Lab-Mate Mr. Ghretli, Mohd

For Their Guidance, Advice and Endless Supports

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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May 2005

Chairman: Professor Kaida Khalid, PhD

Faculty: Science

In industry today, there is a need for designing modern instruments for quantitative and qualitative inspection of wood, wood-based materials and finished products. Development of technologies using electric fields requires a profound knowledge of the dielectric properties of wood. One of the promising techniques is the Electrical Capacitance Tomography (ECT).

Constructing a capacitive tomographic profile of wood and fiberboards has several applications in industry and agriculture. In this study a technique based on multi-frequency square- wave pulse signal is being used to probe the sample. The output signal is amplified, filtered and used to build property surface profiles for different local lumber samples. Analysis of the effect of different stimulating frequency on the overall contour shape of different samples is compared and the appropriate frequency is singled

out. Details on how this technique can be utilized to develop a capacitive sensor are also explained.

Two capacitive sensors were designed with different dimensions for the sensing plate. The capacitive output of the sensors can be related to the different properties of the material under test (MUT). In this study, the sensors were tested for moisture content, thickness variations and local defects present in the sample material.

Both sensors were tested on local lumber samples and fiberboards. Contour plots were obtained for the output of the system, which represent the gradient changes in the wood moisture content as the probe moves across the material under test. The sensor with the smaller dimension probe proved to be superior in resolving the details of the sample and distinguishing the knots and defects of the sample. The larger probe is more accurate in determining the bulk moisture of the samples and more sensitive to thickness variations. The measurement accuracy of the moisture content percentage and thickness variation is about ± 2.88% and ± 0.035 cm respectively.

Even though the proposed sensors offer less accuracy than expensive LRC laboratory analyzers and limited in frequency selection and voltage input to MUT, nonetheless they are inexpensive to make, lighter in weight and can be easily implemented in –site or on-line processing.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TOMOGRAFI BEASID KAPASITANBAGI PAPAN SERAT DAN KAYU

Oleh

ABDALLA IMHMED BAHBOH

Mai 2005

Pengerusi: Professor Kaida Khalid, PhD

Fakulti: Sains

Industri kini amat memerlukan rekabentuk peralatan moden untuk menyelia kualiti dan kuantiti kayu, bahan atau produk yang berasaskan kayu. Pembangunan teknologi yang melibatkan medan elektrik memerlukan pengetahuan asas tentang cirri-ciri dielektrik bagi kayu. Salah satu teknik yang boleh digunakan ialah teknik tomografi kapasitan elektrik (ECT).

Pembinaan profail tomografi kapasitan bagi kayu dan papan serat biasanya diaplikasi dalam indutri dan pertanian. Dalam kajian ini, teknik yang berasaskan isyarat denyut gelombang segiempat pada pelbagai frekuensi digunakan untuk menguji sampel. Nilai isyarat output yang telah dibesar, dan ditapis digunakan untuk membina bahan profail pemukaan bagi sampel papan lapis tempatan dan satu frekuensi yang bersesuaian diperolehi. Perincian bagaimanan teknik ini boleh digunkan untuk membangunkan pengesan kapasitan juga turut disampaikan.

Dua pengesan kapasitan direka dengan bentuk berbeza sebagai plat pengesan. Output pengesan kapasitan boleh dihubungkan kepada ciri berbeza pada bahan yang diuji (MUT). Dalam kajian ini, alat diuji bagi mengesan kandungan kelengasan, variasi ketebalan, dan kecacatan tertentu pada bahan sampel.

Kedua-dua alat pengesan turut diuji pada sampel papan lapis dan papan serat. Plot kontur yang di perolehi untuk sistem output, mewakili perubahan gradian dalam kandungan kelembapan kayu apabila alat penguji digerakkan merentasi bahan yang diuji. Alat pengesan dengan penguji berdimensi kecil membuktikan ianya boleh digunakan untuk peleraian terperinci sesuatu sampel dengan menampakkan simpulan dan kecacatan pada sampel. Penguji berdimensi besar lebih jitu dalam menentukan luas kelembapan sampel dan lebih sensitif terhadap perubahan ketebalan. Kejituan pengukuran bagi kelengasan dan ketebalan masing-masing adalah ± 2.88% dan ± 0.035 cm.

Walaupun pengesan yang dicadangkan memperihalkan kejituan yang rendah berbanding pengenalisis makmal LRC yang mahal, voltan input dan pemilihan frekunsi yang tehad kepada bahan yang diuji, tetapi ianya murah untuk dibina, lebih ringan dan mudah diimplimentasi dalam sebarang pemprosesan.

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CHAPTER I

INTRODUCTION

THE ELECTROSTATIC FIELD IN DIELECTRIC MEDIA

An ideal dielectric material is one which has no free charges. Nevertheless, all material media are composed of molecules, these in turn being composed of charged entities (atomic nuclei and electrons), and the molecules of the dielectric are certainly affected by the presence of an electric field. The electric field causes a force to be exerted on each charged particle, positive particles being pushed in the direction of the field, negative particles oppositely, so that the positive and negative parts of each molecule are displaced from their equilibrium positions in opposite directions. These displacements, however, are limited (in most cases to very small fractions of a molecular diameter) by strong restoring forces which are set up with the changing charge configuration in the molecule. The overall effect from the macroscopic point of view is most easily visualized as the displacement of the entire positive charge of the dielectric relative to the negative charge. The dielectric is said to be polarized.

A polarized dielectric, even though it is electrically neutral on the average, produced an electrical field, both at exterior points and inside the dielectric as well. As a result, we are confronted with what appears to be an awkward situation: the polarization of the dielectric depends on the total electric field in the medium, but a part of the electric field is produced by the dielectric itself. Furthermore the distant electric field of the dielectric

may modify the free charge distribution on conducting bodies, and this in turn will change the electric field in the dielectric.

THE INTERACTION BETWEEN ELECTROMAGNETIC FIELD AND WOOD

Wood is a natural material with a complex structure and composition. Interaction between the alternating electromagnetic field and wood makes it possible to elucidate specific properties of this material. The electromagnetic field consists of two components: electric and magnetic fields. The influence of these components on wood is different. The influence of the magnetic on wood is negligible and is not taken in consideration for practical purposes. The influence of the electric field on wood is very strong as the interaction between them results in the creation of electrical currents in the material.

Under the action of alternating electric field, the wood reveals its dielectric properties, which more often are characterized by two main indices: by the dielectric constant ($\acute{\varepsilon}$) and by the dielectric loss tangent ($tg\partial$). The dielectric constant of a material shows how many times the force of interaction between the electric charges in the given medium is less than that in a vacuum. The dielectric constant of wood is equal to ratio of the capacity a condenser with the separator made of wood and the capacity of the vacuum capacitor of the same dimension and form (Torgovnikov, 1993).

The dielectric loss tangent of wood defines the part of the power applied to the wood that is absorbed by the material under the influence of the electric field. This part of the power is known to be transformed into thermal energy. The loss tangent is numerically equal to the ratio between the active current and the reactive current in the material or to the real and reactive powers ratio. One additional index is used in order to characterize the dielectric properties of wood and wood materials, viz. the dielectric loss factor ε''. $\varepsilon'.tg\partial$. The values of ε', ε'', and $tg\partial$ are always dimensionless, and their magnitude does not depend on the chosen system of units or the form of the equations.

Polarization Phenomena of Wood

All materials are divided into three electrical groups: conductors, dielectric, and semiconductors. The conductors are characterized as materials with considerable electronic and ionic conductivity values. The dielectrics differ from the conductors by their low specific conductivity. Another principle distinction resides in the fact that the temperature coefficient of electric resistance of the dielectric is negative while that of the conductors is positive. Concerning the specific conductance, the semiconductors occupy an intermediate position between the dielectrics and conductors. By the character of the temperature dependence of conductivity, the semiconductors are close to the dielectrics.

It is assumed that conductors have a specific resistance in the range from about 10^{-8} to 10^{-5} ohm.m, semiconductors in the range from 10^{-6} to 10^{+9} ohm.m, and

dielectrics in the range from 10^{+7} to 10^{+17} ohm.m (Tareev 1982). Oven-dry wood has specific resistance ranging from 10^{13} to 10^{15} ohm.m and is classified as a polar dielectric. As the wood moisture content increases, the specific resistance of wood becomes lower, and its conductivity approaches that of the semiconductors. When the moisture content exceeds the cell wall's saturation point, the wood may have an ionic conductance. Under the influence of an electromagnetic field, the electric properties of wood are defined by polarization processes that take place because of the interaction between the molecules of the wood substance and the external field. In this case, moist wood as well as dry wood are considered polar dielectrics.

One of the most important intrinsic properties of wood is its polarization ability. The polarization effect caused by the change in the arrangement in the space of the electrically charged particles of the wood substance under the influence of an external electric field. Under this condition, wood acquires an electrical moment.

In a theoretical examination of the properties of wood, an elementary volume is assumed to exist. This elementary volume should comprise as many structural units as are necessary for considering (with due accuracy) the assumed volume of wood as a homogeneous body. At the same time the chosen volume should be sufficiently small so that the change in physical properties of the fields along its length could be neglected, and the properties can be considered uniform.

Sobloev (1979) proposed that substance elements of a size above 0.1mm should be regarded as macrostructural elements of wood. According to this suggestion, this category should be attributed such elements as layers of early wood and latewood, rays of medium and large width, large resin canals, and large vessels. In this case, the assumption that the elementary volume should be not less than cm^3 can be accepted. This volume should comprise a sufficient quantity of macroelements, and the indices of physical properties of the specimen should reflect not only the combined properties of the microelements but also the properties of the macroelements. When investigating the dielectric properties of wood, it is necessary to take into account the macrostructure of the wood and therefore the samples size should be equal to or larger than the macrostructural elementary volume, i.e., ≥ 1 cm^3(Torgovnikov, 1993).

Since the polarization of the material requires the displacement of particles, each having a finite mass, it is clear that the strength of the polarization must decrease with increasing frequency. That is, the particle's inertia tends to prevent it from "following" rapid oscillations in the applied field. The existence of several different types of polarization makes a complete analysis somewhat involved. For a qualitative understanding of polarization, however, it is sufficient to consider only the electronic polarization and to note that the other types exhibit a similar frequency response.

In the analysis of the electronic polarization, it is convenient to regard the heavy positive nucleus as being fixed in space and surrounded by an electron cloud of charge e and mass m which oscillates back and forth in response to the applied electric field E, the electron cloud moves in response of three forces: the force due to the applied field, the

restoring force due to the coulomb attraction of the positive nucleus, and frictional forces which result in dissipation of energy and consequent damping of oscillations.

Sensors

In a measurement system the sensor is chosen to gather information about the measured quantity and convert it to an electric signal. A priori it would be unreasonable to expect the sensor to be sensitive to only to the quantity of interest and also to expect the output signal to be entirely due to the input signal. No measurement is ever obtained under ideal circumstances; therefore we must address real situation.

Sensors Classification

A great number of sensors are available for different physical quantities. In order to study them, it is advisable first to classify sensors according to some criterion.

In considering the need for the power supply, sensors are classified as modulating or self-generating. In modulating (or active) sensors most of the output signal power comes from an auxiliary power source. The input only controls the output. Conversely, the self-generating (or passive) sensors output power comes from the input.

In considering output signals, we classify sensors as analog or digital. In analog sensors the output is changes in a continuous way at a macroscopic level. The information is