UNIVERSITI PUTRA MALAYSIA

APPLICATION OF OPEN-ENDED COAXIAL SENSOR TO DETERMINE OIL PALM FRUIT RIPENESS

YOU KOK YEOW

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APPLICATION OF OPEN-ENDED COAXIAL SENSOR TO DETERMINE OIL PALM FRUIT RIPENESS

By

YOU KOK YEOW

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

July 2006

Specially dedicated to:

My beloved

Father, Mother, and Sister,

Niece,

and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

APPLICATION OF OPEN-ENDED COAXIAL SENSOR TO DETERMINE OIL PALM FRUIT RIPENESS

By

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July 2006

Chairperson : Zulkifly Abbas, PhD

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This thesis presents a critical study on the use of an open-ended coaxial sensor for the determination of both complex permittivity and moisture content of oil palm fruits of various degrees of fruit ripeness at $(25 \pm 1)^{o}$C. The sensor was studied based on the calculation of reflection coefficient using an integral admittance approach and finite element method (FEM).

In this work, the computation of reflection coefficient of the oil palm fruits was realized using MATLAB and FEMLAB GUI software for the admittance approach and finite element method (FEM), respectively. The results were compared with the measured reflection coefficient using the open-ended coaxial sensor in conjunction with a HP8720B vector network analyzer (VNA). The sensor operating between 1 GHz and 5 GHz was fabricated from a 4.1 mm outer diameter sub-miniature A type (SMA) coaxial

stub contact panel. The measuring end of the sensor was calibrated by a transmission line procedure.

The integral admittance formulation was simplified into a series expression. The local truncation errors of the series approximation were critically analyzed. The two-dimensional FEM was used to solve the rotationally symmetric region of the open-ended coaxial line. The FEM results are closed to the measurements data than calculated admittance formulation. The maximum absolute errors of FEM and measurement results for magnitude and phase reflection coefficient are less than 0.02 and 0.1 rad, respectively, compared with 0.05 and 0.2 rad of admittance formulation and measurement results, respectively. However, the results were in good agreement that the minimum thickness of a sample under test is 2 mm.

An inverse solution based on two admittance models (lumped-parameter admittance and integral admittance formulations) has been utilized to derive complex permittivity from measured reflection coefficient. The lumped-parameter admittance or closed form capacitance model is simpler in the calculation than integral admittance model. Unfortunately, it is not accurate for high operating frequencies (>5 GHz). However, the permittivity results from both models agree with measured data using HP 85070B coaxial probe and publish values (Cole-Cole model) ranging 1 GHz to 5 GHz.

A calibration equation has been developed based on the relationship between the measured moisture content obtained by the oven drying method and the phase of the reflection coefficient of the sensor. The moisture content predicted by the sensor was in

good agreement with those obtained using the standard oven drying method with its absolute error within 5 % moisture content, when tested on 145 different fruits samples.

A model detailing two dielectric relaxation process parameters was proposed in order to represent the permittivity of oil palm mesocarp based on measured data using HP 85070B coaxial probe from 0.13 GHz to 20 GHz. The model successfully estimated the complex permittivity for various ripeness stages of oil palm mesocarp as a function of frequency, moisture and ionic conductivity, as well as the bulk density.

A dielectric measurement software has been developed to control and acquire data from the VNA using Agilent VEE. The software is also used to calibrate measurement at the aperture plane of sensor and to calculate the complex permittivity from the measured reflection coefficient between 1 GHz and 5 GHz.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGGUNAAN PENGESAN SEPAKSI HUJUNG TERBUKA UNTUK PENENTUAN KEMATANGAN BUAH KELAPA SAWIT

Oleh

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Tesis ini memperihalkan kajian kritis terhadap penggunaan pengesan sepaksi hujung terbuka untuk menentukan kedua-dua ketelusan kompleks dan kandungan kelengasan bagi buah kelapa sawit berbagai peringkat kematangan pada $(25 \pm 1)^{o}$C. Pengesan tersebut telah dikaji merujuk kepada kiraan pekali pantulan menggunakan pendekatan pengamiran admitans dan kaedah unsur terhingga (FEM).

Dalam kerja ini, pengkomputeran pekali pantulan bagi buah kelapa sawit telah dilakukan dengan menggunakan perisian MATLAB dan FEMLAB GUI masing-masing untuk pendekatan admitans dan kaedah unsur terhingga (FEM). Keputusannya telah dibandingkan dengan ukuran pekali pantulan daripada peranti deria sepaksi hujung terbuka yang bersambung dengan penganalisis rangkaian vektor HP8720B (VNA). Pengesan ini yang beroperasi antara 1 GHz hingga 5 GHz telah dibina daripada pucuk

panel sentuhan sepaksi jenis A 4.1 mm diameter luaran SMA. Pada hujung penyukat pengesan telah ditentukurkan dengan menggunakan tatacara garisan transmisi.

Formula pengamiran admitans telah dipermudahkan kepada ungkapan siri. Ralat pangkasan setempat bagi penghampiran siri tersebut telah dianalisis secara kritis. FEM dua dimensi telah digunakan untuk menyelesaikan rantau simetri putaran garisan sepaksi hujung terbuka. Keputusan FEM adalah hampir dengan data-data pengukuran daripada kiraan formula admitans. Ralat mutlak maksimum bagi keputusan FEM dan pengukuran untuk magnitud and fasa pekali pantulan adalah masing-masing kurang daripada 0.02 dan 0.1 rad, berbanding dengan 0.05 and 0.2 rad bagi formula admitans dan keputusan pengukuran. Bagaimanapun, keputusan adalah bersetuju bahawa ketebalan minimum bagi sampel yang diuji adalah 2 mm.

Penyelesaian songsang yang merujuk kepada dua bentuk model admitans (formula parameter-gumpalan admitans dan pengamiran admitans) telah digunakan untuk menentukan ketelusan kompleks daripada ukuran pekali pantulan. Parameter-gumpalan admitans atau model kapasitans bentuk tertutup adalah lebih mudah dalam kiraan daripada pengamiran admitans. Malangnya, model ini tidak jitu untuk frekuensi pengoperasian yang tinggi (>5 GHz). Bagaimanapun, keputusan ketelusan daripada kedua-dua model adalah setuju dengan data-data ukuran yang menggunakan pengesan sepaksi HP 85070B dan juga nilai-nilai yang dipaparkan (model Cole-Cole) dalam julat 1 GHz hingga 5 GHz.

Persamaan penentukuran telah dibina berasaskan kepada hubungan antara sukatan kandungan kelengasan kaedah piawai pengeringan oven dengan fasa pekali pantulan kaedah pengesan. Ramalan kandungan kelengasan oleh pengesan tersebut amat setuju dengan nilai-nilai diperolehi daripada kaedah pengeringan oven dengan ralat mutlaknya dalam linkungan 5 % kandungan kelengasan apabila diuji terhadap 145 buah sampel yang berlainan.

Model hasil tambah dua proses santaian dielektrik telah disyor supaya mewakili ketelusan mesocarp kelapa sawit berasaskan kepada data-data ukuran pengesan sepaksi HP 85070B dalam julat 0.13 GHz hingga 20 GHz. Model tersebut telah berjaya meramalkan ketelusan kompleks bagi mesocarp kelapa sawit yang berbagai peringkat kematangan sebagai fungsi kepada frekuensi, kelengasan dan kekonduksian ion, serta ketunpatan pukal.

Perisian pengukuran dielektrik telah dibina untuk mengawal dan memperolehi data-data daripada VNA dengan menggunakan Agilent VEE. Perisian ini juga digunakan supaya menentukurkan pengukuran pada satah bukaan bagi pengesan tersebut dan mengira ketelusan kompleks daripada pengukuran pekali pantulan antara 1 GHz and 5 GHz.

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I certify that an Examination Committee has met on 10 July 2006 to conduct the final examination of You Kok Yeow on his Doctor of Philosophy thesis entitled "Application of Open-Ended Coaxial Sensor to Determine Oil Palm Fruit Ripeness" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

_____

YOU KOK YEOW

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