UNIVERSITI PUTRA MALAYSIA

METHOD OF MOMENT ANALYSIS USING OPEN-ENDED COAXIAL SENSOR IN DETERMINATION OF CORN REFLECTION COEFFICIENT

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By

HOJJATOLLAH SOLEIMANI

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

August 2010

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DEDICATION

To my mother

And

In memory of my father

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

METHOD OF MOMENT ANALYSIS USING OPEN-ENDED AXIAL SENSOR IN DETERMINATION OF CORN REFLECTION COEFFICIENT

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August 2010

Chairperson : Zulkifly Abbas, PhD

Institute : Mathematical Research

The present thesis is a critical study on the use of an open-ended coaxial sensor for the estimation of moisture content of corn with various degrees of fruit ripeness at $(25 \pm 1)^{oC}$. The fruit's state of ripeness depends on moisture content. The permitivity is in direct relation with the amount of water in corn texture' in other words, The higher the amount of water in the corn texture is, the higher the permittivity goes. An open-ended co-axial line has been used as an electromagnetic sensor or probe for various industrial and scientific applications. These applications are based on the principle that the characteristics of the echo signal produced by the co-axial opening depend upon the

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sample material terminating the probe. Thus, if the aperture admittance characteristics can be precisely formulated, then the electrical parameters of the sample can be found.

The sensor was studied based on the calculation of reflection coefficient using an integral admittance approach and Method of Moment (MOM). The Method of Moment is one of the most important general methods which are used for solving electromagnetic-field problems. It begins with a brief mathematical foundation of the general method.

Then, the various specializations are described, accompanied with relevant references to illustrate the pitfalls and shortcomings, as well as the advantages, as compared to other methods. So finally, their algorithms are easily programmable on computer.

The computation of reflection coefficient of the corn was programmed using MATLAB software for the admittance approach and Method of Moment (MOM). The results were compared with the measured reflection coefficient using the open-ended coaxial sensor in conjunction with a vector network analyzer (VNA). The sensor operating between 1 GHz and 5 GHz was fabricated from a 2.05 mm and 0.65 mm, outer and inner diameters respectively. 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 MOM was used to solve the rotationally symmetric region of the open-ended coaxial line. The MOM results are closed to the measurements data than calculated

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admittance formulation. The maximum absolute errors of MOM 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.

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 114 different corn samples.

The model successfully evaluated the complex permittivity for different ripeness stages of corn mesocarp as a function of frequency, moisture and ionic conductivity, as well as the bulk density.

The software is also used to calculate reflection coefficient from complex permittivity in frequency between 1 GHz and 5 GHz.

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

ANALISIS KAEDAH MOMEN TERHADAP PENDERIA HUJUNG TERBUKA DALAM PENENTUAN PEKALI PANTULAN JAGUNG

Oleh

HOJJATOLLAH SOLEIMANI

August 2010

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Tesis ini mengemukakan kajian kritikal tentang penggunaan pengesan sepaksi hujung terbuka untuk menganggar kandungan kelembapan jagung pada peringkat matang yang pelbagai pada suhu $(25\pm1)^{o}$ C. Pengesan sepaksi hujung terbuka telah digunakan sebagai deria atau pengesan untuk pelbagai aplikasi industri dan saintifik. Aplikasi ini adalah berdasarkan prinsip sifat isyarat gema yang terhasil dari sepaksi terbuka bergantung kepada bahan yang menamatkan pengesan. Oleh itu, jika sifat kebenaran masuk bukaan boleh diungkapkan dengan tepat, maka parameter elektrik bagi sampel boleh diketahui.

Pengesan telah dikaji berdasarkan pengiraan pemalar pantulan menggunakan pendekatan kamiran kebenaran masuk dan Kaedah bagi Ketika (MOM). Kaedah ini adalah salah satu

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daripada kaedah umum yang penting yang mana digunakan untuk menyelesaikan masalah medan elektromagnet. Ia dimulakan dengan asas matematik yang mudah bagi kaedah umum tersebut. Kemudian, pelbagai pengkhususan digambarkan, diiringi oleh rujukan yang relevan untuk menjelaskan kesukaran dan kelemahan, termasuk juga kelebihan, berbanding kaedah yang lain. Akhirnya, algoritma terbabit diprogramkan dengan mudah dalam komputer.

Perkomputeran bagi pemalar pantulan jagung telah diprogramkan menggunakan perisian MATLAB untuk pendekatan kebenaran kemasukan dan Kaedah bagi Ketika (MOM). Keputusannye telah dibandingkan dengan pemalar pantulan yang diukur menggunakan pengesan sepaksi hujung terbuka bersama dengan analisis rangkaian vektor (VNA). Deria ini beroperasi diantara 1GHz dan 5GHz yang mana telah dihasilkan pada diameter dalam dan luar masing-masing 2.05mm dan 0.65mm. Hujung pengukur deria telah dilaraskan melalui prosedur garis pemancaran.

Formula kamiran kebenaran kemasukan telah dipermudahkan kepada ungkapan bersiri. Ralat pemendekan setempat bagi anggaran siri-siri telah dianalisis dengan kritikal. MOM dua dimensi telah digunakan untuk menyelesaikan kawasan simetri putaran bagi garisan sepaksi hujung terbuka. Keputusan bagi MOM adalah hampir kepada nilai ukuran berbanding nilai yang telah dikira daripada formulasi kebenaran kemasukan. Ralat mutlak yang maksimum bagi MOM dan keputusan pengukuran bagi magnitud dan fasa pemalar pantulan adalah kurang daripada 0.02 dan 0.1 rad berbanding dengan formulasi kebenaran kemasukan dan keputusan pengukuran masing-masing adalah 0.05 dan 0.2 rad.

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Persamaan yang selaras telah dihasilkan berasaskan hubungan di antara kandungan kelembapan yang diukur dengan yang diperoleh daripada teknik pengeringan oven dan fasa pemalar pantulan bagi deria. Kandungan kelembapan yang dianggar oleh deria adalah berkadar baik dengan kandungan kelembapan yang telah diperoleh menggunakan teknik pengeringan oven dengan nilai multak ralat diantara 5% kandungan kelembapan apabila diuji dengan 114 sampel jagung yang berbeza.

Model ini telah berjaya menilai permitiviti kompleks bagi peringkat kematangan mesocarp jagung yg berbeza bagi fungsi kepada frekuensi, kelembapan dan konduktiviti ion, dan juga ketumpatan bahagian utama. Perisian juga digunakan untuk mengira pemalar pantulan daropada permitiviti kompleks dala frekuensi antara 1 GHz dan 5 GHz.

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I certify that an Examination Committee has met on to conduct the final examination of Hojjatollah Soleimani on his Doctor of Philosophy thesis entitled "METHOD OF MOMENT ANALYSIS USING OPEN-ENDED COAXIAL SENSOR IN DETERMINATION OF CORN REFLECTION COEFFICIENT" in accordance with the 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.

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This thesis was submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I 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 and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

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HOJJATOLLAH SOLEIMANI

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