UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MICROWAVE INSTRUMENTATION SYSTEM FOR THE DETERMINATION OF MOISTURE CONTENT IN OIL PALM FRUITS

LEE KIM YEE

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DEVELOPMENT OF A MICROWAVE INSTRUMENTATION SYSTEM FOR THE DETERMINATION OF MOISTURE CONTENT IN OIL PALM FRUITS

By

LEE KIM YEE

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

February 2008

To my beloved family and friends,

and specially for in loving memory of my mother……

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

DEVELOPMENT OF A MICROWAVE INSTRUMENTATION SYSTEM FOR THE DETERMINATION OF MOISTURE CONTENT IN OIL PALM FRUITS

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LEE KIM YEE

February 2008

Chairperson : Zulkifly Abbas, PhD

Faculty : Science

This thesis describes the development of a microwave instrument for moisture content determination of oil palm fruits. The developed PC-based Six Port Reflectometer provides a simple, fast and accurate solution to the more expensive and bulky Vector Network Analyzer for monitoring the ripeness of oil palm fruit at various stages based on the moisture content measurement. The Microwave Office software (MWO) was used to design and analyzed the Six Port Reflectometer. Various coaxial sensors were simulated using FEMLAB to study the reflection coefficient of the sensor corresponding to the moisture content and ripeness stage of oil palm fruit. The developed Six Port Reflectometer operating at 2 GHz consists of a stripline ring junction, three diode detectors and an Analog to Digital converter. Two types of coaxial sensors were selected for this work: the open ended coaxial and monopole sensors. A computer software was developed using Agilent Visual Environment Engineering (VEE) graphical programming for hardware control and implement all computation work. The performance of the developed Six Port Reflectometer in reflection coefficient measurement was tested. The empirical equations which relate the measured reflection coefficient and moisture content were found. The comparison of a batch of 200 fruit samples was done and it is found that the empirical equations is in the best agreement with the samples follow by finite element method (FEM) simulation and capacitance model. The monopole sensor phase shift measurement was found to be the best for moisture content measurement of oil palm fruits with 3.5% mean error. In bunch measurement, the apical region has the highest accuracy of moisture content measurement with 2.7% mean error followed by equatorial region, 3.0%, and basal region, 5.8%. For whole bunch moisture content measurement, the mean error was found to be 3.8%. The uncertainty of the developed Six Port Reflectometer system is calculated to be 5.5% for reflection coefficient measurement. This study shows that the Six Port Reflectometer is suitable for moisture content measurement of oil palm fruit and bunch. It is simple, fast, accurate, and a portable instrumentation system. It is suitable for early quality check of fruit and bunch ripeness.

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

PEMBANGUNAN SISTEM INSTRUMENTASI MICROGELOMBANG UNTUK PENENTUAN KELENGASAN DALAM BUAH KELAPA SAWIT

Oleh

LEE KIM YEE

Februari 2008

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Tesis ini memperihalkan tentang pembangunan sistem peralatan mikrogelombang untuk menentukan kandungan kelegasan dalam buah kelapa sawit. Meter pantulan Enam Pangkalan mikrogelombang berkomputer yang menyediakan penyelesaian mudah, cepat dan tepat berbanding Penganalisis Rangkaian Vektor yang mahal dan besar untuk penentuan kematangan buah kelapa sawit berasaskan pengukuran pekali pantulan. Perisian Microwave Office (MWO) telah digunakan untuk reka-bentuk dan analisis meter pantulan Enam Pangkalan. Pelbagai peranti deria sepaksi disimulasi dengan menggunakan FEMLAB untuk mengkaji pekali pantulan dengan berpandukan kelegasan dan tahap kematangan buah kelapa sawit. Meter pantulan Enam Pangkalan yang beroperasi pada 2 GHz yang dibina ini terdiri daripada satu simpang cincin garislucutan, tiga pengesan diod, satu litar penukaran analog ke digital. Dua jenis pengesan sepaksi telah dipilih untuk kerja ini iaitu: pengesansekutub dan sepaksi hujung terbuka. Satu program komputer telah dihasilkan dengan mengunakan perisian program bergambar Agilent VEE untuk mengawal perkakas dan menerapkan semua kerja pengiraan dalam meter pantulan Enam Pangkalan. Prestasi dari meter pantulan Enam Pangkalan yang dihasilkan telah diuji. Persamaan empirika yang menghubungkan pekali pantulan yang terukur dan kelegasan telah diperolehi. Perbandingan telah dilakukan dengan data pengukuran kumplan 200 biji buah kelapa sawit dan didapati persamaan empirika ini adalah dalam persetujuan terbaik diikuti dengan simulasi kaedah unsur terhingga (FEM) dan model kapasitan. Pengukuran anjakan fasa bagi peranti deria sekutub didapati adalah yang terbaik untuk mengukur kelegasan dalam kelapa sawit dengan purata ralat 3.5%. Dalam pengukuran tandan, bahagian pucuk mempunyai ketepatan tertinggi dengan 2.7% purata ralat diikuti dengan bahagian pertengahan, 3.0%, dan bahagian hujung, 5.8%. Bagi pengukuran kelegasan keseluruhan tandan purata ralat adalah sebanyak 3.8%. Ketidapastian sistem meter pantulan Enam Pangkalan adalah sebanyak 5.5% dalam pengukuran pekali pantulan. Ia adalah ringkas, cepat, tepat dan adalah sistem instrumentasi mudah alih. Ia sesuai untuk pemeriksaan awal kualiti kematangan buah dan tandan.

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I certify that an Examination Committee has met on 7th January 2008 to conduct the final examination of Lee Kim Yee on his Doctor of Philosophy thesis entitled "Development of a Microwave Instrumentation System for the Determination of Moisture Content in Oil Palm Fruits" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is 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 at any other institution.

LEE KIM YEE

Date: 18 February 2008

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LIST OF ABBREVIATIONS

ε	permittivity
ε^*	complex permittivity
ε_r^*, ε_r	relative complex permittivity
ε_o	permittivity of vacuum $(\mathrm{F/m})$
ε'	real part of permittivity or dielectric constant
ε''	imaginary part of permittivity or loss factor
ε_∞	optical permittivity
ε_s	static permittivity
ε_c	relative permittivity of coaxial line (PTFE)
ε_w^*	complex permittivity of water
ε_f^*	complex permittivity of fiber
ε_o^*	complex permittivity of oil
ε_r	Substrate permittivity
j	square root of -1
μ_o	free space permeability $(\mathrm{H/m})$
μ	permeability $(\mathrm{H/m})$
σ	conductivity $(\mathrm{S/m})$
γ	propagation constant (m^{-1})
t	time (s)
T	temperature $({}^\circ\mathrm{C})$

ω	angular frequency $(\mathrm{rad/s})$
τ	relaxation time (s)
τ_o	proportionality factor of Arrhenius equation (s)
tan δ	loss tangent
v_w	volume fraction of water
v_f	volume fraction of fiber
v_o	volume fraction of oil
ρ_w	relative density of water
ρ_f	relative density of fiber
ρ	radius coordinate of point at aperture probe
ρ_o	relative density of oil
η	intrinsic impedance of medium
$\vec{H}$	magnetic field / magnetic intensity $(\mathrm{A/m})$
H_ϕ	Azimuthal component of magnetic field for coaxial line
f	frequency
λ	wavelength
Γ or S11	reflection coefficient
$\lvert\Gamma\rvert$ or |S11|	magnitude reflection coefficient
$\Gamma_{AA'}$	measured reflection coefficient at the plane AA'
ϕ	angle coordinate of point at aperture probe (rad)
a	inner radius of coaxial probe (m)

b	outer radius of coaxial probe(m)
$\frac{\mathrm{B}(0)}{\mathrm{Y}_{\mathrm{o}}}$	normalized susceptance
B	susceptance(S)
c	velocity of light
C_o , C	static value of the fringe-field capacitance(F)
C_f	fringe-field capacitance of coaxial line(F)
C_T	total fringe-field capacitance of coaxial line(F)
D	physical length of the probe(m)
G	conductance(S)
$\frac{\mathrm{G}(0)}{\mathrm{Y}_{\mathrm{o}}}$	normalized conductance
m_w	mass of water
m_f	mass of fiber
m_o	mass of oil
mc	moisture content
oc	oil content
P	protruding inner conductor
U	uncertainty
Y	aperture admittance
Y_{o}	characteristic admittance of coaxial line
$\tilde{\mathrm{Y}}$	normalized admittance
z	distance from the center point of aperture probe (m)