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DEVELOPMENT OF MICROWAVE REFLECTED TYPE MOISTURE METER FOR WOODEN CROSS-ARMS

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By

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Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Science and Environmental Studies Universiti Putra Malaysia

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Dedicated to My Father and Mother ...

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

DEVELOPMENT OF MICROWAVE REFLECTED TYPE MOISTURE METER FOR WOODEN CROSS ARMS

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May 2000

Chairman : Associate Professor Dr. Kaida bin Khalid

Faculty : Science and Environmental Studies

A simple, cheap, accurate, portable and easy to operate microwave reflected type moisture meter has been developed to determine the moisture content and consequently to assess the quality of the in service wooden cross-arms. The investigation shows that the dielectric properties of the Chengal wood are dependent on the moisture content (MC) at microwave frequencies. The moisture in wood contributes in two different forms, one below fiber saturation point (FSP) and the other above FSP. Both dielectric constant and dielectric loss factor for Chengal wood increases slowly when the MC increases from zero up to FSP and increases rapidly with MC above FSP.

Investigation was made to find the optimum conditions for the sensor design. The optimum condition for best sensitivity of the sensor was determined through experimental and theoretical methods. It was found out that the sensitivity can be controlled by thickness of protective cover and the optimum thickness is about 1mm. The investigation to find out the minimum thickness of the cross-arms section to avoid interference was discussed. It was found that the minimum thickness for the

cross-arms to reach a semi-infinite length was about 50mm. The operating principles of the sensor are based on the plane wave propagation theory and the dielectric mixture theory. The details of Weiner's mixture model were discussed and it was used as the theoretical model to predict and convince the experimental results.

In the actual service condition, moisture content of Chengal wooden cross-arms varied within certain range. For decayed wood, its MC varying between Equilibrium moisture content (EMC) to about 45% of dry basis and the sound wood MC between EMC to about 30% of dry basis. It was quite hard for the cross-arms to achieve higher level of MC. Once the cross-arms achieve a higher level of MC, it may take about 20 hours to return to EMC level. The densities of severely decayed, partly decayed and sound wood were different from each other even from the same species of wood. The densities were found to vary between 680kgm^{-3} to 820kgm^{-3}. The reflected power signal for severely decayed, partly decay and sound wood at EMC were less than 0.05, 0.05 to 0.10 and 0.13 to 0.15 respectively. It was found that the microwave reflected type sensor can determine the decay stage of the wooden cross arms at EMC.

A HP-basic program was written to develop the meter scale for microwave moisture meter. The meter scale contains two types of reading. They are MC reading and stage of decay reading. The mean error were 2.3% and 1.1% for severely decayed and sound wood respectively and the maximum error were found to be 5.4% and 3.9% respectively.

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

PEMBINAAN METER KELENGASAN JENIS PANTULAN MIKROGELOMBANG UNTUK PALANG LENGAN KAYU

Oleh

NG KOK CHEONG

Mei 2000

Pengerusi : Profesor Madya Dr. Kaida bin Khalid

Fakulti : Sains dan Pengajian Alam Sekitar

Sebuah meter kelengasan jenis pantulan mikrogelombang yang ringkas, murah, tepat, mudah alih serta mudah digunakan telah dibina untuk mengukur kandungan air dan juga paras pereputan bagi kayu palang yang sedang digunakan. Menurut kajian, didapati bahawa sifat dielektrik kayu Chengal bergantung kepada kandungan kelengasan (KK) pada frekuensi mikrogelombang. Kelengasan kayu menyumbang kepada dua keadaan yang berbeza iaitu pada keadaan di mana KK kurang daripada takat tepu gentian (TTG) dan melebihi TTG. Pemalar dielektrik dan faktor kehilangan dielektrik kayu Chengal menunjukkan peningkatan secara perlahan apabila KKnya kurang daripada TTG sementara peningkatan sifat dielektrik adalah lebih cepat apabila KWAnya melebihi TTG. Kajian telah dibuat untuk menentukan syarat optimum bagi pembinaan sesebuah pengesan. Syarat optimum untuk kepekaan terbaik bagi pengesan telah ditentukan secara ujikaji dan teori. Kajian telah menentukan bahawa kepekaan pengesan boleh dikawal dengan ketebalan pelindung dan didapati ketebalan optimum bagi pelindung perspek adalah lebih kurang 1mm.

Perbincangan juga telah dibuat di atas kajian untuk menentukan ketebalan minimum bagi kayu palang supaya tidak berlaku interferens. Ketebalan minimum bagi sesebuah kayu palang untuk mencapai panjang semi-infinit telah ditentukan lebih kurang 50mm. Prinsip pengoperasian pengesan adalah berdasarkan kapada teori perambatan gelombang satah serta teori dielektrik campuran (*dielectric mixture theory*). Model Weiner telah dibincangkan secara mendalam dan ia digunakan untuk meramal dan menyakinkan lagi keputusan ujikaji.

Dalam keadaan sebenar, KK bagi kayu palang jenis Chengal berubah dalam sesuatu julat tertentu. KK untuk kayu reput berubah dalam julat antara KK seimbang (*equilibrium moisture content*) ke lebih kurang 45% (asas kering), sementara KK untuk kayu sempurna berubah dalam julat antara KK seimbang ke lebih kurang 30% (asas kering). Didapati bahawa adalah sukar bagi sesebuah kayu palang untuk mencapai tahap KK yang tinggi. Apabila kayu palang mencapai tahap KK yang tinggi, ia memerlukan masa lebih kurang 20 jam untuk menurun ke tahap KK seimbang. Ketumpatan bagi kayu reput, kayu separa reput dan kayu kukoh adalah berbeza antara satu sama lain walaupun berasal dari spesies kayu yang sama. Ketumpatannya masing-masing didapati berubah di antara julat 680kgm^{-3} hingga 820kgm^{-3}. Isyarat bagi kuasa pantulan (*reflected power*) kayu reput, separa reput dan kayu kukoh adalah masing-masing kurang daripada 0.05, 0.05 ke 0.10 and 0.13 ke 0.15. Menurut kajian ini, didapati bahawa meter kelengasan jenis pantulan mikrogelombang dapat menentukan tahap pereputan bagi sesebuah kayu palang pada keadaan KK seimbang.

Sebuah pengaturcaraan berdasarkan bahasa HP-basic telah ditulis untuk membina skala rujukan bagi meter kelengasan mikrogelombang. Skala rujukan yang dibina mengandungi dua jenis bacaan iaitu skala berdasarkan peratusan KK and skala berdasarkan tahap kereputan kayu. Ralat purata bagi kayu reput dan kayu sempurna masing-masing ialah 2.3% and 1.1% sementara ralat maksimum adalah masing-masing 5.4% and 3.9%.

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ε^*	Relative permittivity
ε'	Dielectric constant
ε''	Dielectric loss factor
ε_m	Complex material permittivity
ε_0	Free air permittivity
μ^*	Relative permeability
t	Transmission coefficient
Γ	Reflection coefficient
R^2	Reflected power
R_∞^2	Reflected power at semi-infinite length
d_∞	Semi-infinite length
P	Power
I	Current
D	Relative density
ρ	Density
σ	Conductivity
f	Frequency
ω	Angular frequency
η	Intrinsic impedance
γ	Propagation constant
α	Attenuation constant
β	Phase constant
E	Electric field strength
H	Magnetic field strength
$\tan\theta$	Loss tangent
θ	Loss angle
S_{11}	Scattering parameter (port 1 to port 1)
S_{12}	Scattering parameter (port 2 to port 1)
S_{21}	Scattering parameter (port 1 to port 2)
S_{22}	Scattering parameter (port 2 to port2)

V	Volume
v	Volume fraction
MC or MC_{db}	Moisture content (dry basis)
MC_{wb}	Moisture content (wet basis)
m_d	Mass of dry material
m_m	Mass of moist material
m_w	Mass of water
EMC	Equilibrium moisture content
FSP	Fiber saturation point
KWA	Kandungan wap air
TTG	Takat tepu gentian
l, x, d	Material thicknesses
r	Correlation coefficient
r^2	Coefficient of determination
AC	Alternating current
DC	Direct current
L	Longitudinal
R	Radial
T	Tangential
RF	Radio frequencies
%	Percentage
π	=3.141592654
j	$=\sqrt{-1}$
Type A	Severely decayed wood
Type B	Partly (Incipient) decay wood
Type C	Sound wood
MMM-WCA	Microwave Moisture Meter for Wooden Cross-Arms
IEEE	Institute of Electrical and Electronic Engineering
TNB	Tenaga Nasional Berhad

CHAPTER I

GENERAL INTRODUCTION

Introduction

Generally, wood consists of many different elements and substances. Oven-dry wood consists of two main components: cell wall substance and air in the cell lumen. In moist wood with the moisture level below fiber saturation point (FSP), an additional component exists. This additional component is the bound water. When moisture level exceeds the saturation point, there exists a fourth component, namely free water. The moisture content at which a given cell has lose all of its cavity water and contains only water vapor in the cavities but the cell wall is fully saturated by water vapor is referred as the FSP. Generally, FSP range from 18% to 35% dry basis.

In Malaysia, some of the power lines are constructed with wooden poles and wood cross-arms. Normally Chengal woods are used extensively for this purpose (Plate 1.1). When wood is exposed to weather, not only its surface undergoes changes also its cell wall substances tend to be continuously exposed to chemical and biological changes. Therefore, the weathered and normal sound woods have their own different dielectric properties values although they originate from the same wood species. Plates 1.2 and 1.3 show the samples of weathered and normal sound wooden cross-arms respectively. As a result of weathering, the wood surfaces tend to absorb more moisture as compared to the normal sound wood. The moisture will sustain in the weathered wood for some time before reaching equilibrium moisture