**UNIVERSITI PUTRA MALAYSIA**

# DEVELOPMENT OF ULTRASONIC TECHNIQUE FOR DETECTION OF DECAY IN WOODEN CROSS-ARMS

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**DEVELOPMENT OF ULTRASONIC TECHNIQUE FOR DETECTION OF DECAY IN WOODEN CROSS-ARMS**

By
LAI SOOK KEAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

May 2002

*Dedicated to My Parent and Family Members……*

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

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**Chairman : Professor Dr. Kaida bin Khalid**

**Faculty : Science and Environmental Studies**

A simple, economic, and accurate nondestructive measurement method has been developed to determine the quality of in-service wooden cross-arms. A wooden cross-arm is part of the pylon normally used to support high-power transmission line. The measurement system uses an ultrasonic pulse, 45kHz, to propagate from transmitter to receiver. The transit time of the pulse is the basic parameter. Investigations show that the transit time is dependent on the distance between two transducers and needs a continuum medium. Other factors such as density, moisture content, fiber direction, continuity of the medium, and sample thickness also influence the propagation of ultrasound An investigation has been done to find out the optimum condition for detection methods. The optimum condition was determined through various experimental methods such as C-Method, Upper Method, Direct Method, Indirect Method, and Semi-Direct Method.

The investigation found that C-method is the best method to be used for wooden cross-arms decay detection. This method is able to detect the decay of the wood under the metal block, which is impossible by using microwave method. The transit times for

sound wood, old wood, and cracked wood fall under the ranges of 100μs to 200μs, 200μs to 500μs, and above 500μs respectively. Most of the measured results for cracked wood are above detection time limit of the device and the signal is normally very weak. The experimental results also showed that for moisture content ranging from about 10% to 30% in the wood, there is not much effect in the transit time. This range of moisture content corresponds to the moisture that can be absorbed by Chengal wood during rainy day. Most of the measurement of transit time is done in the L-L direction. It was found out that the velocity along the L-T direction is about $500ms^{-1}$. The propagation along this direction, which is parallel to the fiber direction, is 3 times higher then the T-R or R-R directions.

To complete the study, a prototype has been developed, which can be used for field-testing or maintenance work. This prototype is light, portable, easy to use, safe, and reliable.

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

**PERBINAAN ULTRASONIK TEKNIK UNTUK PENGESANAN PEREPUTAN PADA PALANG LENGAN KAYU**

**Oleh**

**LAI SOOK KEAN**

**Mei 2002**

**Pengerusi : Profesor Dr. Kaida bin Khalid**

**Fakulti : Sains dan Pengajian Alam Sekitar**

Satu kaedah pengukuran tanpa musnah yang ringkas, ekonomi, tepat dan mudah telah dibinakan untuk menentukan kualiti palang lengan kayu. Palang lengan kayu ini adalah sebahagian dari pylon yang digunakan untuk menyokong talian penghantaran kuasa tinggi. Sistem pengukuran menggunakan pemancaran denyut ultrasonik berfrekuensi 45kHz dari penghantar ke penerima, dengan masa penghantaran dianggap sebagai parameter asas. Kajian telah menunjukkan bahawa masa penghantaran adalah bergantung kepada jarak di antara kedua-dua transduser dan memerlukan satu medium kontinu. Faktor-faktor lain juga mempengaruhi pemancaran ultrasonik ini seperti ketumpatan, kelengasan, arah serabut, keselanjaran medium dan ketebalan sampel. Kajian telah dibuat untuk mendapatkan syarat optimum bagi kaedah pengesanan palang lengan kayu seperti Kaedah-C, Kaedah-Atas, Kaedah Langsung, Kaedah Tak Langsung dan Kaedah Semi-Langsung.

Kajian mendapati bahawa Kaedah-C adalah kaedah yang terbaik untuk pengesanan kereputan palang lengan kayu. Kaedah ini dapat digunakan untuk mengesan kereputan

kayu dibawah blok logam yang tidak mungkin dapat dikesan menerusi gelombang mikro. Masa penghantaran bagi kayu sempurna, kayu lama dan kayu retak masing-masing adalah dalam lingkungan dari 100μs hingga 200μs, dari 200μs hingga 500μs dan melebihi 500μs. Kebanyakan hasil pengukuran bagi kayu retak adalah melebihi had masa pegesanan peralatan dan isyaratnya sangat lemah. Keputusan kajian ini juga menunjukkan bahawa kandungan kelengasan dalam lingkungan dari 10% hingga 30% dalam kayu, kurang mempengaruhi masa penghantaran. Julat kelengasan ini adalah kelengasan yang diselang oleh kayu Chengal semasa hari hujan. Kebanyakan kajian bagi masa penghantaran adalah dalam arah L-L. Didapati bahawa sepanjang arah L-T halaju ultrasonik adalah dalam lingkungan $500ms^{-1}$. Pemancaran sepanjang arah ini yang selari dengan arah serabut adalah 3 kali ganda lebih tinggi daripada arah T-T dan R-R.

Bagi melengkapkan kajian satu prototaip dibina untuk digunakan bagi pengujian di lapangan (*field testing*) atau kerja penyelengaraan.. Prototaip ini adalah ringan, mudah alih, mudah digunakan, selamat dan boleh dipercayai.

## ACKNOWLEDGEMENTS

First of all, I would like to express my heartfelt gratitude and appreciation to Prof. Dr. Haji Kaida Khalid, the chairman of the supervisory committee, and to other members of the committee, Associate Prof. Dr. Mohd. Hamami bin Sahri, and Associate Prof. Dr Sidek bin Hj. Ab. Aziz for the contribution of their knowledge and valuable advise for my project. I would also like to thank Mr. Roslim Mohd, Lab Assistant of Physics Department, for his talents and time in teaching me the practical knowledge related to my project.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirements for the degree of Master of Science.

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Date:

## 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.

(LAI SOOK KEAN)

Date:

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| BaTi | Barium Titanate |
| $\Gamma_{ik}$ | Chirstoffel Tensor |
| C | Crack Wood |
| D% | Degradation Percentage |
| $\rho$ | Density, $kgm^{-3}$ |
| $C_{ijkl}$ | Elastic Constants |
| $C_{LL}$ | Elasticity for Longitudinal |
| $C_{RR}$ | Elasticity for Radial |
| $C_{TT}$ | Elasticity for Tangential |
| EMC | Equilibrium Moisture Content |
| FSP | Fiber Saturation Point |
| $\delta_{ik}$ | Kronecker Delta |
| PMN | Lead Metaniobate |
| PZT | Lead Zirconate Titanate |
| MOE | Modulus of Elasticity |
| MOR | Modulus of Rapture |
| MC | Moisture Content |
| MC% | Moisture Content Percentage |
| NDE | Nondestructive Evaluation |
| O | Old Wood (Serviced Wood) |

| | |
|---|---|
| $\lambda$ | Poisson's Ratio |
| $P_m$ | Polarization Vector |
| V | Pulse Velocity, $ms^{-1}$ |
| S | Sound Wood |
| $[\in_{kl}]$ | Strains Tensor |
| $[\sigma_{ij}]$ | Stress Tensor |
| TNB | Tenaga Nasional Berhad |
| t | Transit Time, $\mu s$ |
| x | Length, cm |
| $\ddot{u}_j$ | Displacement |
| $A_o$ | Amplitude of the Wave |
| $P_j$ | Unit Displacement Polarization Vector |
| $k_m$ | Wave Vector Component Along the $\chi_m$ |
| $\chi_m$ | Position Vector |
| $n_k$ | Direction Cosines |
| $\omega$ | Angular Frequency |

# CHAPTER I

# GENERAL INTRODUCTION

## Introduction

Wood can be considered as a biological substance, which is widely used in many industries due to its complex structure and durability. In a microscopic overview, the wood composite is formed in a discrete scale level to assure its high performance against different environmental conditions such as strong wind and heavy rain.

In Malaysia, wood poles and wooden cross-arms are used as line supports for power pylon towers. The design, the construction of transmission lines and wood poles for power line supports are done by Tenaga Nasional Berhad (TNB). The transmission lines are divided into three major categories: 500kV, 257kV, and 132kV, as shown in Figure 1.1. The End-Joint of a tower is constructed with a wooden cross-arm. For commercial plantations (the private sector), wood poles are used as power line supports, instead of the costly concrete or galvanized iron line supports now in use (Hussein, 1998).

The most popular uses of heavy hardwoods in this country are for heavy constructions such as wooden houses, railway sleepers, timber bridges, and power line poles based on the woods' natural durability. By far Chengal is the most popular hardwood fit for the above purposes.

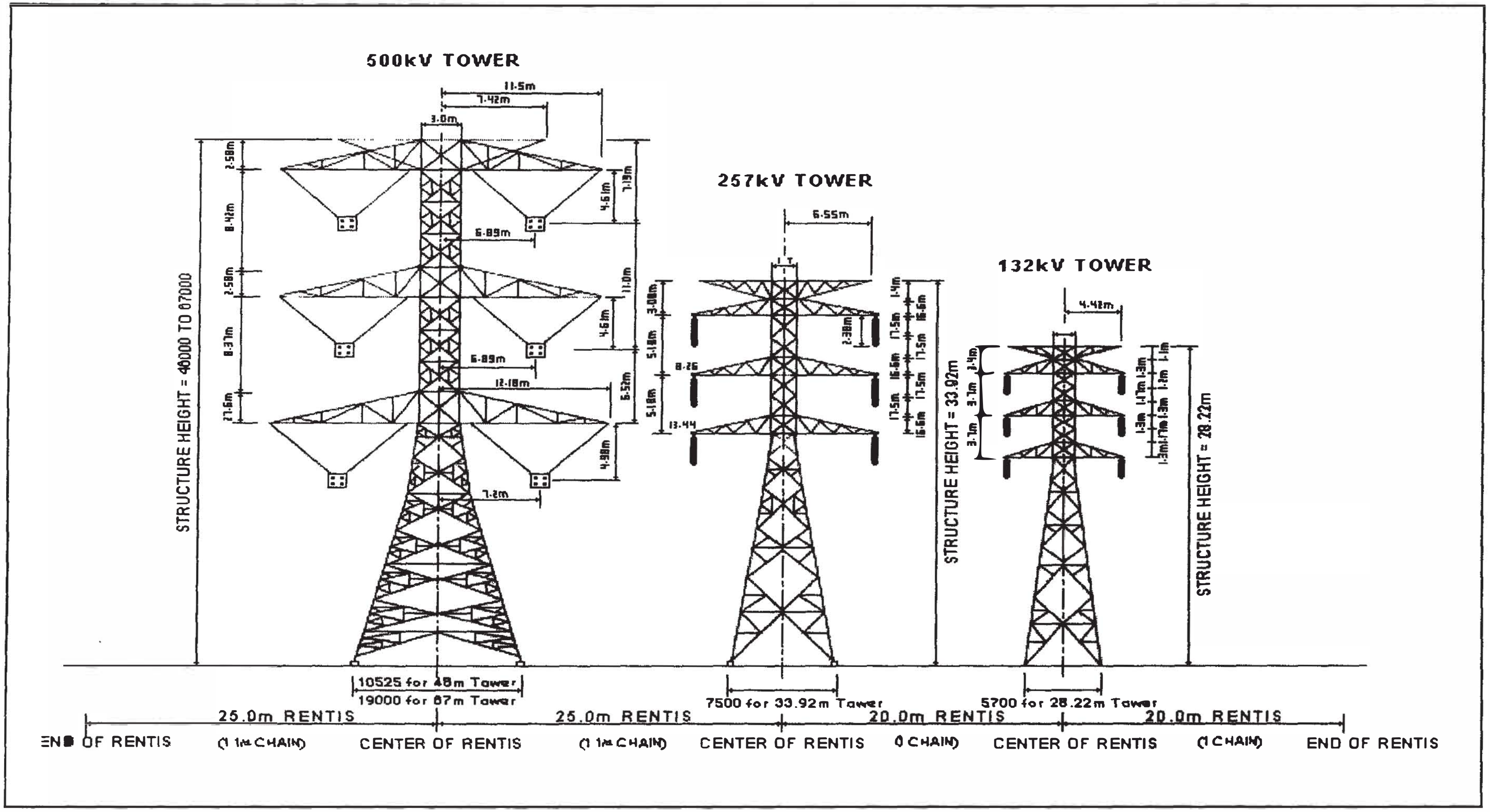


Figure 1.1: Structures of Power Pylon Towers for 500kV, 237kV, and 132kV.

The hot and humid climate in tropical countries like Malaysia facilitates the growth of fungi and other destructive microorganisms in wooden structures. Thereby, deterioration of wooden structures occurs. It takes the forms of splits, cracks, and other defects that permit the entry of fungi into the cores of the poles, rendering them unsuitable for use as line supports. For wooden structures, this nature of degradation or deterioration can inhibit the performance of the entire structure.

Hence, wooden cross-arms inspection and maintenance are essential for the following reasons:

i) Safety to life and property: wooden cross-arms should be maintained above definite minimum strength requirements. The strength value of each species of wood is different from others. The minimum strength requirements according to species of wood have been chosen for intelligent applications of woods.

ii) efficient service within the system: outages or service interruption due to pole failures should be kept to a minimum. For examples, mechanical damage may lead to a reduction in the useful life of a wooden cross-arm, and maintenance works that leave some holes after testing (quasi nondestructive method) the wooden quality condition may also lead to degradation of wood.

iii) economical operation: the number of wooden cross-arm replacements should not be excessive and the maximum useful life should be obtained from every wooden cross-arm.

Plate 1.1 shows a worker doing inspection for the end-joint of a power tower. The maintenance work is very dangerous. So, a simple method to be used for this purpose is essential. The most currently used nondestructive evaluation (NDE) methods to detect the wood defects are by vibration technique (traditional method), sonic stress wave technique, microwave technique, radiation (X-ray and gamma ray), visual inspection, and drill resistance (MC Master, 1982). As every technique has different advantages of its own for various wood defect detection condition, a simple, fast, safe, and accurate technique must be developed.

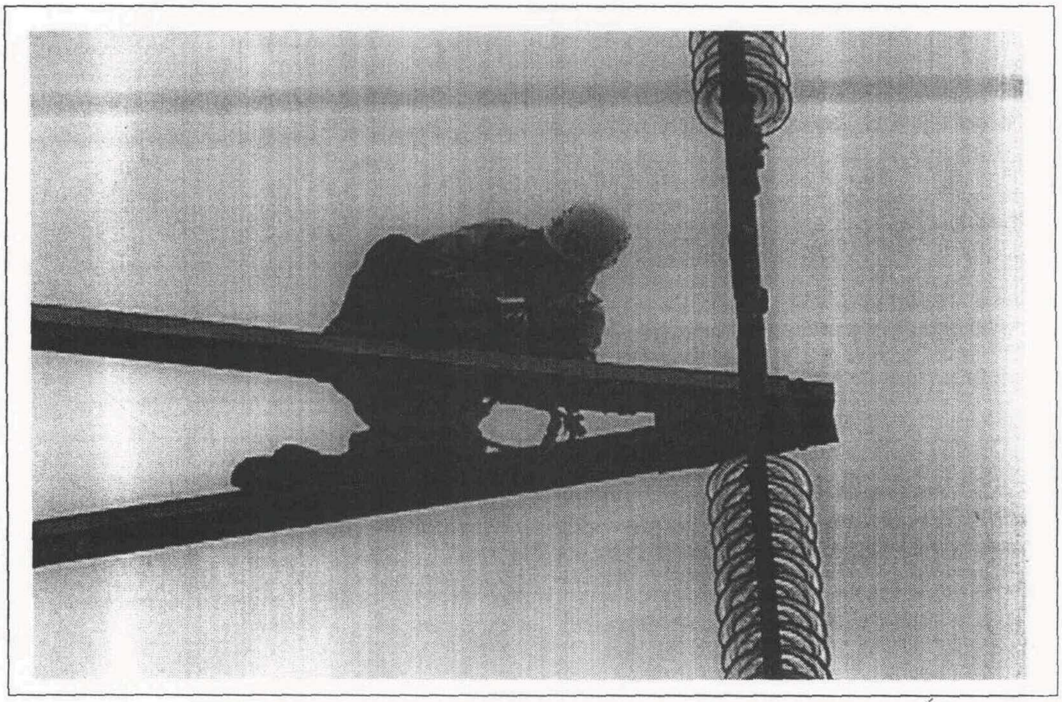

Plate 1.1: The End-Joint of a Power Tower. The worker is doing inspection for the Wooden Pole Quality Situation.