WOOD RESEARCH
54 (3): 2009
55-60

IMAGING PROCESSING FOR KNOT DETECTION IN WOOD USING MICROWAVES

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ABSTRACT

This work presents the acquisition and processing of data for the detection of knots in solid wood samples. The data were obtained by means of a microwave system based on an emitter (frequency: 10.5 Ghz; power: 10 mW). A diode detector array was used to obtain a matrix of voltage data corresponding to each wood sample. The data collected for each wood sample were correlated using statistical variables; these data were saved and processed. The results of this treatment are shown as tomographic images and an improvement in the image resolution of the knots in comparison with a previous work was observed.

KEY WORDS: microwaves, knot detection, imaging processing

INTRODUCTION

In wood processing, knots are widely known to be one of the principal types of defects that impact the cut process, affecting the yield in the exploitation of the material. Thus, real knowledge about the defects, both in logs and solid wood, is important economic information for the evaluation and classification process (Harless et al. 1991). Different techniques have been used to study defects such as knots (Quinn 1998, Karsulovic and Gaete 2000, Arstrand 1996, Hauffe and Mahler 2000, Funt and Bryant 1987, Tanaka and Divos 2000) in order to implement an on-line, automatic detection system. In particular, the microwave technique has been used for the above mentioned purposes by different researchers, obtaining good results with solid wood (Martin et al. 1987, Choffel and Martin 1996 a,b, Kaestner 2002, Lundgren et al. 2007) and logs (Kaestner and Baath 2000), Johansson 2001, Haapalainen et al. 2007). In Chile, some previous works using microwaves have shown hopeful results for detecting solid wood knots in *Pinus radiata* D. Don (Baradit et al. 2004, 2006). Nevertheless, the design and construction of a system for an industrial application depends on the speed of the detection process as well as the accuracy of the imaging resolution and reconstruction. This work provides an alternative data treatment for better knot imaging reconstructions as compared with a previous study (Baradit et al. 2006).

The detection of irregularities like knots using microwaves is based on the physical interaction between the electric field and water molecules contained in the wood fibers (Baradit et al. 2004, 2006). This interaction results in a high energy attenuation when the electric field is oriented along the fibers due to absorption of energy by water molecules. On the contrary, attenuation is low when the propagation of the electromagnetic wave is through knots due to the fiber disorder. This effect can be observed by measuring the voltage values in microwave diodes in wood samples with or without knots.

It is well known that the electromagnetic wave satisfies the homogenous vector wave equation for the magnetic and electric fields. Based on the Maxwell equation for the electric field, the corresponding equation is:

$$\nabla^2 \vec{E} - \frac{1}{\varepsilon\mu}\frac{\partial^2 \vec{E}}{\partial t^2} = 0 \tag{1}$$

where ε and μ are the absolute permittivity and permeability of the medium.

Since wood is considered to be a dielectric material with losses, the electric permittivity is complex (Torgovnikov 1989) and can be expressed as:

$$\tilde{\varepsilon} = \varepsilon - j\frac{\sigma}{\omega} = \varepsilon' - j\varepsilon'' \tag{2}$$

Where ε is the electric permittivity, δ the conductivity, and ω the frequency of the electromagnetic wave. In this situation, the propagation constant is also complex and equal to:

$$\tilde{\gamma} = j\omega\sqrt{\mu\tilde{\varepsilon}} = j\omega\sqrt{\mu\varepsilon}\left(1 + \frac{\sigma}{j\omega\varepsilon}\right)^{1/2} \tag{3}$$

and can be expressed as:

$$\tilde{\gamma} = \alpha + j\beta \tag{4}$$

Thus, if z is the direction of wave propagation, the electric field can be written as:

$$\vec{E} = \vec{E}_0(x,y)e^{-\alpha z}e^{j(\omega t - \beta z)} \tag{5}$$

where α is the attenuation constant, related to both the conduction losses and losses due to shock absorbance by the molecules, and β is the phase constant (Daian et al. 2005).

In wood, the dielectric properties can be written using the next permittivity tensor:

$$\varepsilon = \begin{pmatrix} \varepsilon_T & 0 & 0 \\ 0 & \varepsilon_R & 0 \\ 0 & 0 & \varepsilon_L \end{pmatrix} \tag{6}$$

where the diagonal elements are complex value quantities. The relationship between the diagonal elements is $\varepsilon_T \leq \varepsilon_R \leq \varepsilon_L$, which makes wood a biaxial medium. Here, $\varepsilon_T \approx \varepsilon_R$; since both parameters lie in the plane orthogonal to the fibbers, the dielectric properties of this plane can be considered to be independent of orientation. This approach allows the classification of wood as a uniaxial medium.

Due to its anatomical structure, the wood fiber, located along the growing longitudinal direction of the tree, can contain water molecules in the fiber walls as well as inside the fibers (lumen). This determines the relative moisture content of the wood. These water molecules are one of the main causes of electromagnetic energy attenuation, since the electric field delivers a great part of the energy. This energy is dissipated like caloric energy so that the use of a polarized electric field oriented along the wood fibers leads to energy dissipation. On the other hand, the energy losses in the knots are not largely due to fiber disorders. This physical phenomenon is used here in to detect knots in solid wood (Baradit et al. 2004, 2006). In conjunction with the propagation of the electromagnetic wave through the wood, different physical phenomena take place between the sample walls such as absorption, diffraction, multiple reflections, and others. Nevertheless, the energy transmitted is related to the dielectric properties of the wood, considered to be means with losses, causing its complex permeability (Torgovnikov 1989).

MATERIAL AND METHODS

Pinus radiata wood, with and without knots, was selected and conditioned to 12% humidity content. The sample dimensions were 600 x 100 x 10 mm. Fig. 1 shows an image of knots resulting from the data processing based on the voltage values obtained in a previous study (Baradit et al. 2006). In this image, the clear zones represent the knots in the wood. The microwave system used in the present work is similar to the one implemented in Baradit et al. (2006) and includes a Gunn diode microwave generator (15 mW and 10.5 GHz) and a horn antenna. The detected signals in the diodes were digitized and conditioned according to the block diagram shown in Fig. 1.

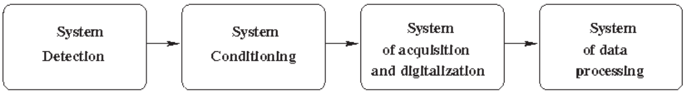

Fig.1: Diagram of the data acquisition and processing system

These digitized signals were stored, forming a data matrix as follows:

$$Y_{ij}(n) = A_{ij}(n) X_{ij}(n) + B_{ij}(n) \tag{7}$$

where i,j is the measurement position of the diodes, $Y_j(n)$ is the operation voltage, $A_j(n)$ is the gain of the diode, $X_j(n)$ is the voltage of each diode, and $B_j(n)$ is the offset of each diode.

RESULTS AND DISCUSSION

The results of this data treatment process by means of the matrix construction with the values obtained by the diode arrangement are shown in Figs. 2 and 3. These images were obtained using Matlab. The image resolution is better than that obtained in a previous work (Baradit et al. 2006). This can be observed in the 2D and 3D images in Fig. 2, which were built using the median values. The 2D image in Fig. 3 was obtained using the average matrix values.

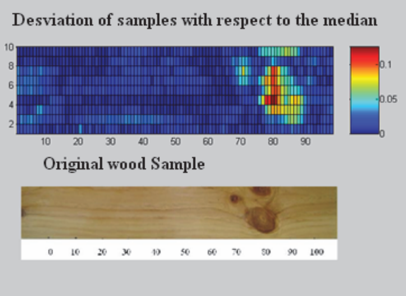

Fig. 2: Deviation of samples with respect to the median

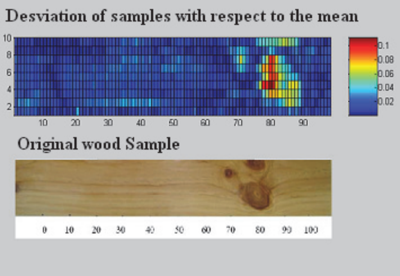

Fig. 3: Deviation of samples with respect to the mean

In both images, the high voltage values are variations with respect to the median and mean values, which show the presence of knots (red: knot center; blue: clear wood).

CONCLUSIONS

This work focuses on the use of the polarized microwave field and diode detector array. However the diodes are limited by their technical characteristics and size making it difficult to detect irregularities smaller than those studies herein. On the other hand, the sensitivity of knot detection is improved due to new adjustments made to the diode array. This is the result of the incorporation of new variables in the signal processing such as the offset and amplification factor for each diode. Due to this the matrix of voltage data models better the images of the wood samples.

A future work will attempt to modify the geometric disposition of the diode array so that it allows on-line detection of these defects on a laboratory scale.

ACKNOWLEDGEMENT

This work was sponsored by the Research Council via research project 056207 and by the FAPEI fund, Universidad del Bio-Bio, Concepción, Chile.

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