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New method to locate the pith position in a wood cross-section based on ultrasonic measurements

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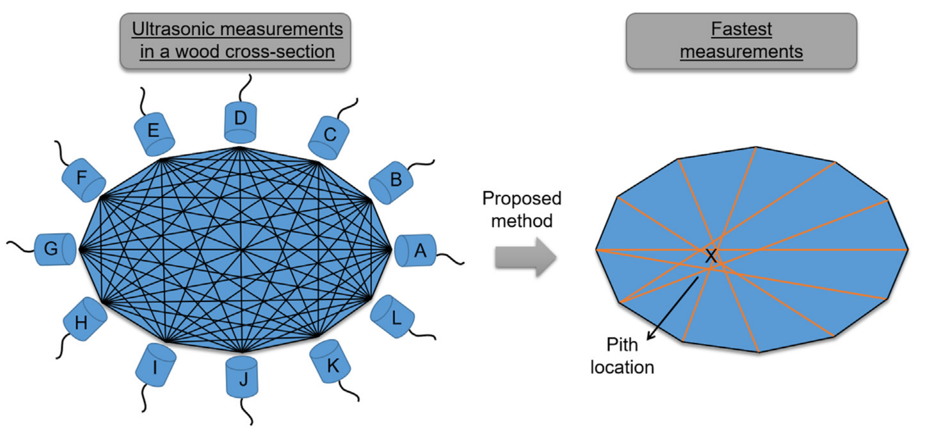
HIGHLIGHTS

- Proposal of a nondestructive method for pith detection in wood cross-section.
- Works with trees, timbers and lumbers.
- Method for detecting pith even in the case that it is outside of the cross section.

GRAPHICAL ABSTRACT



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ABSTRACT

There is a growing need for nondestructively evaluate the integrity of trees and wooden structural elements. Such an investigation can be performed with the use of different test methods. Nevertheless, in order to yield acceptable results, the test methods should consider the anisotropic nature of the wood, which includes the shape of the annual rings, and also the pith location in the cross-section. This paper presents a new method to determine the pith location of a tree or structural element made of timber or lumber based on ultrasonic tomography readings.

1. Introduction

Wood structures are submitted to an inevitable degradation process over time. In order to evaluate the actual state of the structure, or even to propose some restoration processes, test methods such as drilling resistance, stress waves transmission, stress waves

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tomography, X-ray tomography, gamma rays, among others [1–5] could be employed.

Due to the relative lower costs of equipment and simpler execution, test methods based on the drilling resistance and stress waves are the most commonly used ones in field applications. The results from these tests could be improved if the annual rings were previously located. For example, the drilling resistance test attains more accurate results when direction of the drill is perpendicular to the annual rings. If drilling is performed in another direction, several others holes must be executed in order to yield satisfactory results [5,6]. Furthermore, when drilling is not performed on a perpendicular angle to the growing rings, the drill bit may be driven by misalignment, causing friction between the drill bit and the walls of the hole. This situation can grossly affect wood density estimation [5].

As far as the test methods based on stress waves (acoustic or ultrasonic) are concerned, it is well known that stress wave velocities differ according to their propagation direction to the annual rings [7–9]. The velocity in the radial direction is usually higher than the one in the tangential direction. Therefore, stress wave velocity must be measured at a known direction; otherwise, the result will not be useful for comparative purposes.

Regarding the application of stress waves tomography to wooden materials [10–14], according to Prieto and Lasaygues [15], the tomographic models usually employed were developed for isotropic materials, despite the clear anisotropic behavior of wood.

The current best approach to consider wood anisotropic in tomography inversion was accomplish by Mauer et al. [16], which developed a correction in the experimental travel times. The proposed correction allows the use of any tomography software developed for isotropic materials. Nevertheless, this correction is only applicable in trunks; it considers the pitch position in the middle of cross section, which is not always true. According Schubert [17], when a trunk have a non-centric pith, a hollow detection could be difficult, leading to some misinterpretation. In such cases, Schubert even does not recommend the use of stress waves tomography.

Since the anisotropy is directly related to the curvature of annual rings, an anisotropic tomographic model should consider the shape of annual rings. Therefore, the prior knowledge of the annual rings shape in the cross-section would improve the results of these tests. Since the annual rings are inherently connected to the pith location in the cross-section, it is desirable to initially determine the pith location. Although it is easy to locate it when the cross-section is visible, it is a more challenging task in trees or wooden structural elements. In such cases, the pith can be located outside of the cross-section, which adds, even more, difficulty to the process.

Several researches have pointed out that it is possible to locate the pith from X-ray tomographic images [18–23]. Developed algorithms provide a precise pith position with errors, in most cases, of few millimeters. However, due to the high costs, equipment mobility issues and health risks, this technique is usually employed only in an industrial environment.

The purpose of this paper is to present a test method based on ultrasonic tomography readings that allows locating the pith of a sound section. The proposed method works for timber (unprocessed wood), as well as lumbers (processed wood), and is able to locate the pith even when it is not located inside the cross-section.

In an ultrasonic tomography of a wood cross-section, the transmitter transducer is fixed while the receiver transducer is moved along the section, yielding several ultrasonic pulse velocities (UPVs) originated from the same location but at different directions. In a wood specimen, UPV in the radial to the annual rings direction is higher than in the tangential direction [7–9]. Thus, the proposed method searches for the intersection among all the directions given by the highest UPVs values, which should reveal the pith location.

In order to verify the accuracy of the proposed method, ultrasonic tomography readings were performed on a timber specimen as well as on a lumber specimen with the pith located outside of the cross-section.

2. Proposed method to locate the pith

Initially, the transducers locations for an ultrasonic tomography of the cross-section are chosen. These locations should be uniformly distributed along the cross-section perimeter. The experimental process is identical to the one performed on a tomography study, as displayed in Fig. 1. For each reading, an UPV is calculated. It is assumed, for the purpose of this method, that the travel path is given by the shortest distance between transducers.

According to Bucur [9,24], readings obtained with transducers at a close distance should be avoided, since it does not represent accurately the tested material. Bucur [24] showed that the ratio between the transducers distance (d) and the wavelength (λ) should be greater than 5 for ultrasonic readings obtained in the longitudinal direction, same ratio proposed by Bartholomeu et al. [24]. Other researches [25–27], however, have shown that a d/λ greater than 3 is more appropriate. For readings in the radial and in the transverse direction, Bucur [9] recommends a ratio greater than 2.

Since there is not a unique d/λ limit proposed, it is recommended that the researcher should select the ones to be excluded based on the obtained UPVs.

After having acquired all UPVs, a mesh of points covering the area where the pith might be located is created. As shown in Fig. 2a, this mesh may even be expanded outside the cross-section if it is believed that the pith is not located inside the cross-section. Mesh spacing depends on the distance of neighboring reading locations (n). A value of n/2 was used in the experimental validation phase. This value can be regarded as an average distance between adjacent ultrasound readings, as presented in Fig. 2b.

For a given mesh point, the closest travel paths for each transducer location reading are made. This process creates a set of travel paths converging to the selected mesh point. Fig. 3 shows an example of an obtained set of travel paths for a mesh point, indicated by

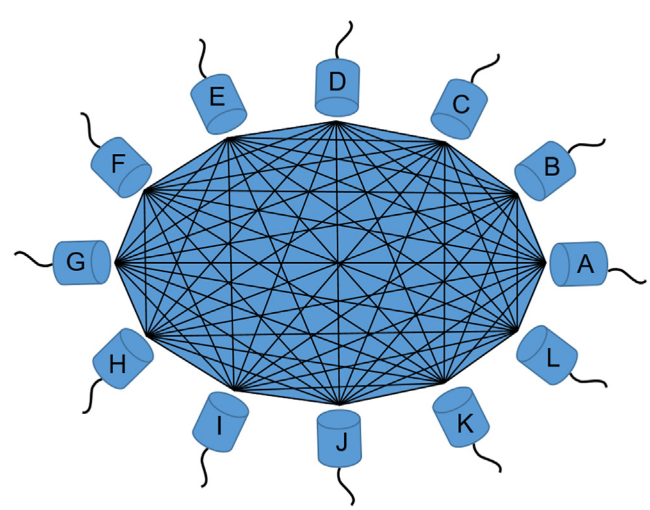

Fig. 1. Experimental configuration and assumed readings paths.