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Application of an ultrasonic wave propagation field in the quantitative identification of cavity defect of log disc

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ABSTRACT

This study introduced the concept of the ultrasonic propagation field in wood and verified its applicability through experiments conducted on a log disc. A green *Betula costata* log section was used in the ultrasonic propagation measurements. An ultrasonic wave detector (RSM-SY5) was used to measure the ultrasonic propagation time (UPT) on the cross section of the log sample. After the ultrasonication was completed on the non-defective log, five man-made cavities with diameters of 4, 8, 12, 16 and 20 cm were made sequentially in the heart of the same log and utilized in the ultrasonic test. The even UPT values were then approximately outlined as isolines. Based on the UPT isolines, the ultrasonic propagation field in the log disc was simulated using MATLAB software, and the cavity was identified by overlapping the ultrasonic wave fields from different directions. The size of the cavity defect was proven to be effectively determined by overlying the maps of the ultrasonic wave propagation field through a cross section of the wood. The results indicated that the accuracy of detection values for cavity sizes with diameters of 4, 8, 12, 16 and 20 cm were 83.2%, 84.8%, 94.0%, 95.8% and 96.2%, respectively.

1. Introduction

Internal wood decay is a common structural defect in trees, logs, utility poles and construction timber. Each year, wood decay causes significant economic loss (Wiedenbeck et al., 2004). Thus, detecting decay in trees and logs can be of great benefit in assessing wood quality and utilizing forest resources (Habermehl, 1982). Foresters can prescribe silvicultural treatments to improve forest management based on the information obtained through decay detection, thus helping to maintain healthy forests (Wang et al., 2007a,b). The applicability of ultrasonic radiation, an emerging non-destructive technology, has been widely demonstrated for assessing wood quality and detecting decay (Wang et al., 2009a,b; Gao et al., 2012). The measurement of ultrasonic wave propagation in wood provides the basis for a nondestructive evaluation of the wood elastic and viscoelastic properties. The ultrasonic wave technique for wood quality assessment is based on wave velocity or transmission time measurements in either the radial or tangential direction. This method is typically used as the primary indicator in examining the conditions of wood quality, grade and defects. (Gao et al., 2013; Wang, 2011).

The direct transmission technique for ultrasonic measurement in non-destructive wood testing is related to the measurement of the ultrasonic propagation time (UPT). Wood materials that can be examined using ultrasonic waves include trees, logs, small clear specimens of solid wood, wood-based composites and engineered products. Direct transmission is believed to be the most appropriate ultrasonic testing technique for quality assessment and decay detection in these types of wood. Ultrasonic tomography of the imaging technique, which can provide an image of any discontinuity, is performed with both velocity (travel time) and attenuation as the contrast-producing parameters (Bucur, 2003; Tomikawa et al., 1990). This technique led to the development of a system for detecting heartwood and rotted zones using transducers.

Li et al. (2012) used acoustic tomography and CT to detect internal decay in trees and logs. This method allowed the users to visualize the velocity distribution of the acoustic waves as the waves propagated through the cross section of a tree. Because the ultrasonic wave propagation in wood is directly related to mechanical anisotropy, the velocity mapping of a cross section could serve as a diagnostic image to detect internal decay in trees (Bucur, 2005). Through velocity mapping via two-dimensional ultrasonic tomography, severe decay can be visualized and cavities located (Wang et al., 2001, 2009a,b; Divos and Divos, 2005). Ultrasonic

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wave propagation in wood depends on the grain direction and the excitation and is associated with the mechanical anisotropy. The ultrasonic variability in a cross section was particularly affected by the decay or cavities in wooden tree trunks or logs (Larsson et al., 2004).

As an acoustic nondestructive testing method, ultrasonic measurement has advantages in the evaluation of wood materials. Based on its applicability and efficiency for assessing wood quality and detecting decay, this study aims to investigate the behavior of ultrasonic wave propagation in wood when the wave encounters a cavity or holes. In addition, the applicability of the ultrasonic wave propagation field to quantitatively detecting the cavity defects of a log is discussed and demonstrated. Lastly, a reasonable interpretation for the application of the ultrasonic technique to two-dimensional decay scanning is provided.

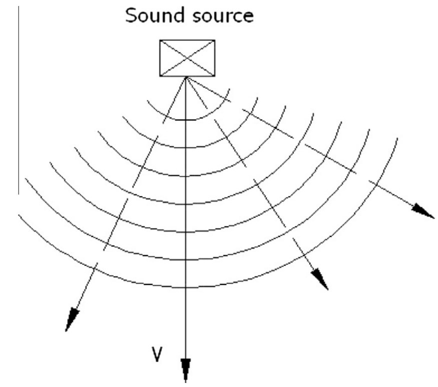

Fig. 1b. Wave surface of the ultrasonic wave as it travels in the wood.

2. Theoretical considerations

2.1. Concept of ultrasonic wave spread field

The natural orthotropic feature of wood is characterized by highly anisotropic properties. Bulk waves are the principal wave types used to measure wood properties and are characterized by the direction of propagation and the particle motion—i.e., for longitudinal waves, the particle trajectory is in the direction of propagation; for transverse waves the particle motion is perpendicular to the direction of propagation; for Rayleigh waves the particle trajectory is elliptical in the plane that is perpendicular to the tested surface and parallel to the direction of propagation (McSkimin and Chambers, 1964). The ultrasonic velocities of bulk waves can be used to describe the anisotropy within wood in various ways. For the direct transmission technique of ultrasonic measurement, an ultrasonic pulse is transformed from an electronic signal, travels through the specimen and is received by receiver; the pulse is then transformed back into an electronic signal, which can be visualized on an oscilloscope. The time delay, defined as the time that elapses between the emission and reception, is measured on the oscilloscope over the path length of the ultrasonic signals. The ultrasonic measurement principle is simple, and the time measurement is accurate (with an error below 1%) (Bucur and Bohnke, 1994; Bucur, 1995).

If one assumes that the wave surface of a sound source transmits along a specific direction and is conveniently detected by the sensor in its propagation area, then overlaying the waves from different directions can yield a packet of ultrasonic wave points at its typical wave surface if the sound source has a limited area

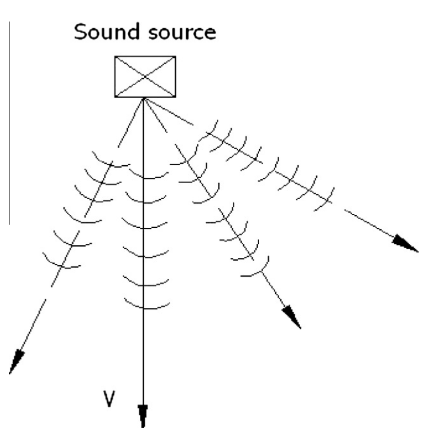

Fig. 1a. Propagation direction of the wave packet sent by a sound source.

(Pellerin and Ross, 2002). Based on the Huygens theorem, the possible interference path directions are shown in Fig. 1a when the sound source is taken as the focus of a series of point wave sources. The wave packet transmits along each direction, but the velocity vector coordinates only with the phase vector (Bodig, 2001). In Figs. 1a and 1b, a sound wave is introduced and spread around; each point of the wave surface in the medium can be taken as a sub-wave source of the secondary spherical wave. A number of point sources constitute a plane wave. Therefore, when an ultrasonic wave transmits in timber, a wave surface will emerge from the sound source along the direction of the velocity vector (Fig. 1b). Layers of the wave surface spread apart like the filled curves from the same UPT of the wave to yield ultrasonic wave spread or a propagation field.

2.2. Applicability of an ultrasonic wave field spread for detecting wood defects

During the propagation of an ultrasonic wave, the transmission paths alter when they encounter different media, and the spread field curves with regularity and twists due to variations in the acoustic impedance. By comparing this phenomenon with the spread field for ultrasound wave propagation in solid wood, defects can be located. By overlaying the profiles with the alteration curves from different directions, the defect edge can be infinitely approximated and information, such as the location and size of the defect, can be determined.

3. Materials and methods

3.1. Experimental materials and device

The samples were obtained from Fangzheng Forestry Bureau, Harbin (long. 125°42′–130°10′E, lat. 44°04′–46°40′N), China. A 50-cm-long *Betula costata* log section with a 38-cm diameter was produced from a standing tree. The log section, with both ends coated, was stored in condition room for two months. The relative humidity and the temperature of the condition room were at 68% and 20 °C respectively and was then sawn into 10 cm-thick discs in good condition, i.e., with no defects, for use in the ultrasonic measurements. The measured density of the non-defect disc was 880.99 kg/m^3 before it was made into cavity disc. After the ultrasonic measurements were completed on an intact wood disc, the disc was immediately made into a cavity defect wood disc with man-made cavities of different diameters (4, 8, 12, 16 and 20 cm) in its heart. Though the wood disc lost moisture during the ultrasonic measurements, the moisture level was equal to the ambient humidity. When the whole series experiments were completed