PRELIMINARY RESULTS FOR A MULTI-SENSOR NON-DESTRUCTIVE TEST OF TIMBER STRENGTH

M. L. Peterson, D. Maas*, C. Mittlestadt, S. Srinath and R. Zoughi*
Advanced Inspection and Monitoring Laboratory
Department of Mechanical Engineering
Colorado State University
Fort Collins, CO 80523-0001

* Applied Microwave Nondestructive Testing Laboratory
Department of Electrical Engineering
Colorado State University
Fort Collins, CO 80523-0001

INTRODUCTION

Several commercial instruments currently are sold for the purpose of determining the strength of timber [1]. This information is needed because of the reliance of several sectors of our infrastructure on this material. The most notable uses of large timber members are in telephone poles and bridges used on railroads. In many of these applications the strength of the timber is critical to the safety and reliability of the utilities and railroads. While the use of wood treatments has extends the useful life of timber, decay remains the primary mechanism of timber bridge deterioration [2]. Decay is defined as a process which adversely alters wood properties and can be attributed to two primary causes, biotic (living) agents and physical (non-living) agents. The mechanisms of decay are complex, however those factors which are of interest in the current effort affect the strength of the wood and thus impact the integrity of the structure.

One of the most common timber strength measurement systems is based on a correlation between the strength of timber and the ultrasonic pulse velocity [3]. While the correlation between strength and pulse velocity is not expected to be high, the instrument is at least capable of providing information on the modulus of the timber tested. The pulse velocity is measured by determining the time delay which occurs prior to the received voltage exceeding a fixed threshold. The delay measurement is referenced to the impulse which is used to excite the transmitting transducer. Significant geometrical dispersion occurs in timber members for wood elements with the dimensions of interest when using the frequencies employed. The dispersion results in changes in the shape of the leading edge of the pulse which can significantly impact the location of a voltage threshold in time. The
threshold method is also influenced by material attenuation in addition to the intended measurement of the pulse velocity. However, perhaps the most significant factor which will alter this type of pulse velocity measurement is the moisture content of the material. Because of the porous nature of wood, a very significant impact on both the density and modulus would be expected from an increase in moisture content. Because of the filling of these voids with water, not only the velocity but the attenuation of the material is significantly impacted. Any potential for the pulse velocity to be an accurate predictor of strength is affected by the ability to accurately measure the velocity and, potentially, the attenuation. While the error introduced by dispersion would impact sample to sample consistency, for a particular geometry the moisture content would be expected to be a controlling factor in the accuracy of the pulse velocity measurements.

The impact of moisture on pulse velocity is sufficiently well accepted that at least one commercial ultrasonic timber grading system uses a second method of measurement to correct for the moisture content. The commercial instrument relies on a traditional resistance measurement to determine the moisture content of the wood. The current effort considers a new approach to a similar multi-sensor evaluation of the properties of timber. This technique combines ultrasonic pulse velocity with a measurement of the dielectric properties of the wood using reflected power at microwave frequencies. This approach differs from other moisture measurement methods since the correction of the ultrasonic pulse for the impact of moisture content is performed using a method which penetrates the surface of the wood to a significant depth. The most important advantage to this approach is the ability to determine average moisture content to a specified depth in the specimen. An adaptive scheme which would adjust the power based on the reflected energy, would be required to take full advantage of this technology.

Potential applications of this technology exist in those industries in which timber represents a significant building material. Perhaps the two most important applications are electrical utility poles for distribution lines and timber bridges on railroads. Both of these industries depend on an extensive network of timber infrastructure. The cost of replacing this infrastructure with timber or any other material is prohibitive. However the safe delivery of power and goods are dependent on the integrity of these wood structures. Additional applications of timber are found in the piers and other marine applications. Interest may also exist in evaluation of live trees. Such inspections of live trees could be used either for the optimization of yield in harvest or for the evaluation of the safety of large trees in urban areas. While less extensive than a number of other civil materials, the evaluation of timber for strength is critical to the reliability of our infrastructure.

ULTRASONIC EVALUATION OF TIMBER

Ultrasonic evaluation of timber is well established in the wood sciences. A comparison of an ultrasonic method of strength grading to other methods is given by Boström [4]. Other grading methods considered by Boström include machines based on automatic deflection measurements and a gamma radiation/absorption machine. The ultrasonic instrument used by Boström is a field instrument sold as the Sylvatest. The Sylvatest employs a resistance measurement of moisture content of the material for calibration of the ultrasonic pulse velocity for water content. The need for calibration of an ultrasonic pulse velocity meter is clear based on the significant pore volume of the wood. A relatively modest effort to introduce moisture into the material can easily result in an
increase in the weight of the material by more than 10%. Clearly, this increase in density can significantly impact the velocity of an ultrasonic pulse which propagates in the material.

To correct for moisture content two probes are pressed lightly into the surface of the material to be tested. The resistance between the probes is measured and compared to a calibration curve or water versus resistance. A significant limitation in this approach is the

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Figure 1. Effect of moisture content of samples on the measured ultrasonic wave speed.

Figure 2. Effect of moisture on the microwave power reflected from the timber samples.
dependence on a surface measurement of the material to represent the bulk material properties. A significant sensitivity to recent precipitation in the region of a field sample is likely to result from this approach. Verification of the expected dependence of pulse velocity on moisture content was the first step in the current investigation. The alternative method of determining the moisture content was then investigated. Proper calibration of the power in this method would make it possible to penetrate the wood to a predetermined depth depending on the measured electromagnetic reflection coefficient.

VERIFICATION OF THE NEED FOR PULSE VELOCITY CALIBRATION

Pulse velocity measurements were obtained from two different groups of timber 4x4 inch 12 foot long samples. The moisture content in one set of 14 samples was increased by submerging one set of samples in a water bath for approximately two weeks. A control group of 7 high grade Douglas fir samples was kept in dry air (less than 20% relative humidity) during the same time period. All samples were received in a nominally dry condition. Figure 1 shows the change in wave velocity from a reference signal which results from the submersion in water. The seven dry samples form a relatively narrow distribution of wave velocities around the reference value. A separate distribution is observed around a higher value wave speed which is associated with the wood samples which had been soaked in water. While the two distributions overlap, they are clearly distinguishable and verify the need for correction of the wavespeed for moisture content of the wood.

SENSITIVITY OF MICROWAVES TO WATER ABSORPTION

While the need for a method to correct for the moisture content of the wood was clearly indicated by the ultrasonic pulse velocity results, it remains to be seen whether microwave methods are sufficiently sensitive to this factor. The same control test and control group used for the pulse velocity tests was also investigated for the sensitivity to microwave measurements of moisture content. Readings were made for a large number of locations to verify that minimal sensitivity to local changes in grain structure or local inhomogeneities would cause erroneous readings. Microwave measurements shown made use of only most straightforward instrumentation. The reflected power is measured using an X-band transmitter and detector mounted in an open ended waveguide. The power is measured using low cost instrumentation which could be integrated into a small instrumentation package.

Figure 2 clearly shows a separation of the saturated and unsaturated timber samples. The distributions do not show any overlap for the two groups considered. Local sensitivity to structure or sample variation is greater with saturated wood as seen in Figure 2 however. In addition the effect of polarization is significant for the saturated wood since the orientation of the grain will control the diffusion of water into the structure. The actual amount of water which will diffuse into the wood in a fixed period of time is controlled by the local structure of the wood. As a result the measured reflection from the wood sample would increase in variability. What is not clear from the increase in the standard deviation of the saturated timber is whether this actually represents a different level of moisture content. If diffusion is facilitated by cross grain structure, then it is likely that the higher reflection coefficients would actually represent a greater degree of saturation of the fibers. Further development of this technique would require focusing on the impact of polarization on the overall measurement, and removal of the sensitivity on probe orientation which is characteristic of a single rectangular waveguide. Several alternatives are available including the use of multiple probe orientations and the use of a probe which does not have a polarization pattern which is characteristic of the grain of the timber.
CALIBRATION OF MEASURED GAMMA TO MOISTURE CONTENT

It remains, however, to be shown that either the moisture content is single valued or may be calibrated for moisture content. The concept of dried lumber is even difficult given that dry lumber is defined by a process rather than a measurement. As a result a procedure for saturating and drying a sample was developed which was used to obtain a curve of relative moisture content versus reflected microwave power, gamma. Moisture content was values were defined based on assuming an initially dry sample. The sample was weighed and then submerged in water for two weeks. The weight of the sample was monitored for a period and the reflected power was compared to the weight of the sample.

Figure 4. Theoretical and experimental effect of water on reflected power.
A very simple model of the experiment was developed as a part of this preliminary investigation. The model used the configuration which is shown in Figure 3. The timber specimen was assumed to be completely dry on the outer layer and then to have the dielectric properties of water in the interior. While this is an obvious simplification, it is then possible to understand some of the characteristics of the measurement. The result of a comparison between experiment and this simple theory is shown in Figure 44. The maximum and minimum level of the signal is seen in both the theory and the experiment. As a result of the dielectric gap (with the properties of timber) between the waveguide and the water (the saturated material) oscillations of the reflected power are obtained in the model but not in the experiment. This is a direct result of the oversimplification of the actual conditions of the measurement. The most general shape of the curve is repeated in the experiments, however the experimental signals do not show the oscillations seen in the theory.

A better simple model could be based on the assumption of continuous pores in the material. The wood sample would be thus modeled as a series of wires with the properties of water in a dielectric medium of arbitrary properties. The properties of the dielectric domain were then matched to the amplitude of the nominally dry wood sample. In the case of this method of determining moisture content, however, the experimental relationship between the reflected power and the moisture content are more simply implemented than a theoretical description. However, the reduced sensitivity to lower levels of water saturation in the very simple model shown is a source of some concern. Development of some understanding both the sensitivity of the measurement and the sample to sample variation would be required prior to general use of the proposed method.

CONCLUSIONS

The need for the calibration of ultrasonic pulse velocity measurements has been shown. For this purpose a new method of determining the moisture content of bulk timber samples has been described. This method, unlike current resistance measures, has the potential to be adjusted for desired depth of penetration. In this way the average moisture content of the timber or the moisture content associated with a particular frequency of a surface wave may be obtained. The ability to tune the depth averaging of microwave moisture measurements makes this an ideal method for this application.

ACKNOWLEDGMENTS

This work was supported in part by the National Science Foundation through grant number EEC-9531541.

REFERENCES