# TECHNICAL NOTE: RESPONSES OF VERTICAL SECTIONS OF WOOD SAMPLES TO CYCLICAL RELATIVE HUMIDITY CHANGES

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(Received April 2010)

**Abstract.** This study investigated moisture responses of the surface, middle, and central portion in the thickness direction of wood samples to cyclic RH changes. Phase lag and amplitude for these sections were determined quantitatively by Fourier analysis. These data were used to suggest a mechanism for the unexpected phenomenon that moisture changes are slower than dimensional changes found in previous work.

## INTRODUCTION

In a previous study (Ma et al 2010), moisture changes and radial and tangential dimensional changes of Sitka spruce (*Picea sitchensis Carr.*) were measured in sinusoidally varying conditions of 45-75% RH for periods of 1, 6, and 24 h at 20°C. A mathematical model was developed for the dynamic sorption and moisture distributions along the thickness direction of the wood samples, which suggested that it is 0.25 of the cyclic period until the center is affected by the changing humidity, were obtained. This could be considered as good evidence to the unexplained phenomenon that moisture changes are slower than dimensional changes. This report investigated moisture responses of the surface, middle, and central sections along the thickness of the samples to cyclic RH changes, and phase lag and amplitude for these different sections were determined by Fourier analysis.

## ANALYSIS AND DISCUSSION

Figure 1 shows moisture content of the surface, middle, and central sections against time at a cyclic period of 6 h for Sitka spruce. It is clear that the phase lag increases and amplitude decreases as the position along the thickness direction of the samples changes from surface to center and the response of phase lag and amplitude for moisture content falls between the surface and middle section. To further investigate the phase lag and amplitude responses of the surface, middle, and center of wood samples quantitatively, Fourier analysis was applied to each section.

The Fourier approach introduced in the previous study (Ma et al 2010) is an effective method

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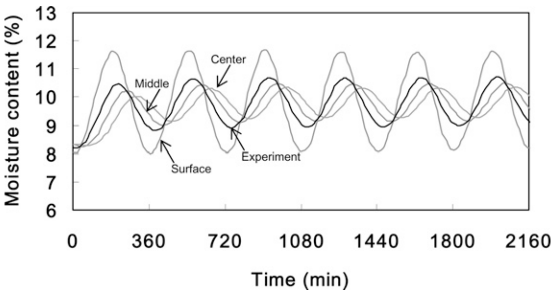


Figure 1. Moisture content of the surface, middle, and central sections along the thickness direction of wood samples with experiment results against time at a 6-h cyclic period.

to discuss the phase lag and amplitude of the observed data. The main equations used in the analysis are:

$$G(t) = \frac{G(t)_{\max} + G(t)_{\min}}{2} + \frac{(G(t)_{\max} - G(t)_{\min})}{2} \times [A_1 \sin \omega t + B_1 \cos \omega t] \tag{1}$$

where $G(t)$ is the values of moisture content for the surface, middle, or central section. $A_1$ and $B_1$ are the Fourier coefficients for the fundamental angular frequency $\omega$. $G(t)_{\max}$ and $G(t)_{\min}$ are the peak values of $G(t)$ at time t.

The phase angle φ (radians) is then calculated for the surface (S), middle (M), and center (C) by:

$$\varphi = \arctan(B_1/A_1) \tag{2}$$

Therefore, the phase lag $\phi$ (radians) can be obtained from the difference in the phase angle φ between each section and the RH.

$$\begin{aligned} \phi_S &= \varphi_S - \varphi_{RH}, \\ \phi_M &= \varphi_M - \varphi_{RH}, \\ \phi_C &= \varphi_C - \varphi_{RH} \end{aligned} \tag{3}$$

At the same time, amplitude $A$ is evaluated as follows:

$$A = \frac{1}{n}\sum_{i=1}^{n}(G_i(t)_{\max} - G_i(t)_{\min}) \tag{4}$$

where $n$ is the number of discrete equally spaced time steps at which data were analyzed.

Table 1 lists the phase lag and amplitude of the surface, middle, and central sections with corresponding experiment results of moisture content, radial and tangential dimensional changes at the three cyclic periods. It is evident that as the cyclic period increases, the phase lag decreases and the amplitude increases for all the sections of wood samples, which agrees with the result for the entire sample (Ma et al 2010). In addition, with an increase in the thickness from the surface of the samples, the phase lag increases and the amplitude decreases. Moreover, it can be found that phase lags of the surface are almost zero for the three cyclic periods, indicating an immediate equilibrium between the surface of the samples and the humidity. However, the moisture response for the whole piece of wood measured experimentally is considerably delayed by the lags of the middle and central sections. As a result, the phase lag value of experiment moisture content is greater than that of either radial or tangential dimensional changes at each cyclic period.

Table 1. Phase lag and amplitude of the surface, middle, and central sections of specimens with experiment results of moisture content, radial, and tangential dimensional changes in three cyclic periods.

| | | Moisture content | | | | Dimensional change | |
|---|---|---|---|---|---|---|---|
| | Cyclic period (h) | Surface | Middle | Center | Experiment[a] | Radial[a] | Tangential[a] |
| Phase lag | 1 | 0.07 | 1.12 | 1.91 | 0.60 | 0.53 | 0.46 |
| | 6 | 0.02 | 0.96 | 1.75 | 0.44 | 0.41 | 0.36 |
| | 24 | 0.02 | 0.83 | 1.62 | 0.31 | 0.30 | 0.27 |
| Amplitude | 1 | 1.64 | 0.65 | 0.52 | 0.79 | / | / |
| | 6 | 3.54 | 1.31 | 1.02 | 1.75 | / | / |
| | 24 | 3.61 | 1.33 | 1.03 | 1.93 | / | / |

[a] From Ma et al (2010).

## CONCLUSIONS

This report investigated moisture responses of the surface, middle, and central sections along the thickness of the samples to cyclic RH changes, and phase lag and amplitude for these different sections were determined by Fourier analysis. The difference in the phase lag among different vertical sections of the samples could be used to suggest a mechanism for the unexpected fact that moisture response acts slower than dimensional response.

## REFERENCE

Ma EN, Nakao T, Zhao GJ, Ohata H, Kawamura S (2010) Dynamic sorption and hygroexpansion of wood subjected to cyclic relative humidity changes. Wood Fiber Sci 42(2):229-236.