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Development of a strain measurement system for the study of effect of relative humidity on wood

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ABSTRACT

Wood is a widely used material in various applications where its dimensional stability is of practical interest in the design and performance of wooden materials. The change in geometry of wood depends upon the environmental conditions (such as relative humidity) as well as internal structure and composition of wood. This work presents a measurement technique and development of the associated system for the measurement of strain changes of wood samples with relative humidity. The developed system is capable of measuring the strain change and relative humidity (RH) with temperature compensation. The system comprises of strain gauge based strain measurement unit and RH sensor with its related signal conditioning circuit along with temperature sensor. The strain gauge signal conditioning is based on quarter bridge method with high precision resistors which is excited by an AC source. The whole system is centered on an 8-bit RISC microcontroller (PIC18F43K22). The built in 10-bit analog to digital converter (ADC) is used to read the strain and ambient RH. The temperature is directly read from temperature to digital converter using ZACwire™ interface. The measurement system is calibrated using a cantilever of stainless steel and is used for collecting and analyzing data of four wood samples. The uncertainties associated with the measurements are reported in the paper. Experimental results obtained for a few wood samples are presented.

1. Introduction

Humidity affects many properties of air, and of materials in contact with air. Water vapour is a key agent in both weather and climate, and it is an important atmospheric greenhouse gas. A huge variety of manufacturing, storage and testing process are humidity-critical. Humidity measurements are used wherever there is a need to prevent condensation, corrosion, mould, warping or other spoilage of products. This is highly relevant for foods, pharmaceuticals, chemicals, fuels, wood, paper, and many other products [1]. Measurement of relative humidity (water vapour present in air) is also essential for different scientific research and various situations where monitoring and control of environment is necessary. The effect of humidity is of paramount importance in wide range of application areas, such as moisture sensitive manufactured goods, textile, food processing, metrology, clinical instrumentation, integrated chips production, study of the growth of micro organism in living environment [2–4]. Baker et al. reported the effect of RH on the biocontaminant microenvironment have a spatial scale of the order of few millimeter [5]. Wood is a natural composite material with a hierarchical architecture which exhibits complex anisotropic mechanical and swelling behavior. As a hygroscopic material, wood responds to changes in environmental humidity by changing its geometry. Dimensional stability of wooden materials is of practical interest in the design of durable buildings and structures [6]. Wood exchanges moisture with air, the amount and direction of the exchange (gain or loss) depend on the relative humidity and temperature of the air and the current amount of water in the wood. Wood is anisotropic with regard to shrinkage and swelling. The magnitude of shrinkage and swelling is affected by the amount of moisture, which is lost or gained by wood [7]. Several endeavours have been practised and are still going on to study wood behavior with the changes of environmental humidity. Dominique Derome et al. studied the hysteretic swelling and shrinkage for latewood and earlywood by phase contrast X-ray tomography [8]. Ahmed et al. analyzed the estimation of the free swelling behavior of Norway spruce softwood. In this work, they predict the transverse anisotropy in the swelling behavior of softwood on the basis of periodic honeycomb unit cell model [6]. Steffen et al. determined the elastic modulus of wood cell wall material using a new in situ testing technique. This new technique

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depends on a focused ion beam system (FIB) to prepare samples. Cantilevers are cut with the FIB from wood cell and loaded with a known force [9]. Ahmad et al. documented the hygroscopic swelling and shrinkage of the central and the thickest secondary cell wall layer of wood in response to changes in environmental humidity using synchrotron radiation-based phase contrast X-ray tomographic nanoscopy. They found that the volumetric strains at the cell wall level are significantly larger than those observed at cellular tissue [10]. Hassel et al. studied the performance of a wooden block shear wall which utilizes compressed wood as a connecting element in place of the traditional metal connectors [11].

To use wood to its best advantage and most effectively in engineering applications specific characteristics or physical properties must be considered. The versatility of wood is demonstrated by a wide variety of products. This variety is a result of a spectrum of desirable physical characteristics among many species of wood [7]. Laghdir et al. developed a technique for measuring the engineering coefficients of the 3D elasticity tensor of wood. In this method semi ring extensometer is used to study the coefficients [12]. The main drawback of this technique is the screw hole effect and temperature drift while taking both the axial and transverse strain measurement simultaneously on the same specimen. In order to characterize the mechanical properties, knowledge of the stress–strain relationships in the different directions is required. For that purpose Dahl et al. developed video extensometer technique for the measurement of planer strain of wood [13]. The use of an optical measurement system applied to the mechanical characterization of thin microtome sections of spruce is reported by Sinn [14]. They presented an optical measurement system for the determination of strains and displacements of wood specimens [14].

To study the change in strain of wood with RH it is essential to have a precise measurement system for measuring both change in RH and corresponding changes in strain of the sample. Proper signal conditioning circuits are employed to increase the reliability of the developed system. In this work, strain gauges are used to measure the strain developed on the surface of wood samples due to change in RH. The developed strain measurement system is calibrated by a simple and convenient cantilever beam method using different loads. The present measurement system is capable of measuring and monitoring the RH, temperature and strain of wood samples. To measure RH and strain of wood samples analog sensors are used where as a digital sensor is used to measure temperature. The analog and digital sensors are sequentially read by PIC18F43K22 microcontroller. The system firmware for microcontroller is developed on MPLAB-IDE and suitable codes are written on C-language for handling data in the PC side.

To study the effect of RH in wood samples, different levels of RH are necessary for the experiment. There are four-types of standard humidity generator systems: (1) two-pressure humidity generator [15], (2) two temperature humidity generator [16], (3) divided-flow humidity generator, and [15,17] (4) fixed-point humidity systems [17,18]. Except for the fixed-point humidity systems, others can provide more accurate standard environment [15]. However, they are expensive and complicated. Sometime, an experimental factory setup is required to install these systems, whereas, certified fixed RH points with saturated salt solutions are easier to setup. This fixed point method is inexpensive, convenient, and easy to be reproduced in a research laboratory. It is often used as check points for humidity sensors. However, the fixed values of RH limit the applicable range of this type of setup and accuracy depends on the purity of the salts used [15]. To test the variation of strain of different wood samples with RH, four different binary saturated salt solutions are used to generate different level of humidity within desiccators. The RH and temperature inside the desiccator are continuously monitored until they reach stable level of humidity. Strain developed in the wood samples is measured when RH attains stable level.

2. System architecture

The basic block diagram of the measurement system is shown in Fig. 1.

The system is designed incorporating TSIC 506F temperature sensor, HIH5030 humidity sensor and CF350-2AA (11) C20 strain gauge which are interfaced to PIC18F43K22 microcontroller and connected to PC by RS232 communication. The outputs of humidity sensor HIH5030 and four strain gauges (CF350-2AA (11) C20) are fed to the five channels of the on-chip 10-bit ADC of the PIC18F43K22 microcontroller through signal conditioning circuit. The temperature sensor TSIC 506F is interfaced to the microcontroller by ZACwire™ [18]. A 20×4 LCD serve as a local display and RS 232 communication is employed to provide the facility for data logging. The system software for microcontroller is developed on MPLAB-IDE and suitable codes are written in C-language for handling data in the PC side.

3. Implementation

For implementing the system different modules are developed separately and finally integrated together for proper functionality. Signal conditioning circuits are designed to get voltage output in the input range of the integrated ADC of the microcontroller for the entire dynamic range of the sensors. Proper algorithm is developed to read the sensors and to get desired measurements of strain developed in wood samples along with temperature compensation for RH measurement. The developed code is implemented on the microcontroller. The measured values are displayed locally on 20×4 LCD and transmitted via RS232 communication to PC.

3.1. Sensors

For the measurement of temperature, low power TSIC 506F is used which provides digital output and accuracy of ±0.1 K combined with long term stability. The ZACwire™ interface compatible sensor TSIC which is a factory calibrated temperature sensor and the digital output (T) of the sensor is given by [18]

$$T = \left[\frac{D}{2047} \times (T_H - T_L) + T_L\right] \tag{1}$$

where D is the 8 bit data from the temperature sensor and $(T_H - T_L)$ being the temperature range of the sensor with $T_L = -10$ °C and $T_H = 60$ °C.

HIH5030 is used for the measurement of relative humidity. The HIH-5030 series low voltage humidity sensors operate down to 2.7 V_{dc}. The accuracy of the humidity sensor is ±3%. The output voltage V_{out} and RH is related by the following equation at 25 °C [19]

The output voltage V_{out} and RH of the humidity sensor HIH-5030 are related by the following equation at 25 °C [19]

$$RH = \left[\frac{V_{out}}{0.00636 \times V_{supply}} - 23.82\right]\% \tag{2}$$

Temperature compensated $(RH)_T$ and is given by the following equation [19]

$$(RH)_T = \left[\frac{RH}{(1.0546 - 0.00216T)}\right]\% \tag{3}$$