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Measurement of Moisture in Wood for Application on Rehabilitation of Old Buildings

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Abstract: There are a lot of historic buildings whose construction is based on timber frame walls. Most of the constructed buildings during the nineteenth and early twentieth century were based on walls of timber frame with vertical support element. These timber frame elements are affected both by the moisture content, such as the time variation of it. The maintenance of these buildings could be significantly improved if was known the interaction of the wall timber framing with hygrothermal climate variations. To determine the moisture content of the wood there are two types of meters on the market: one hand capacitance meters which consist of two side ends and the moisture content is measured locally between two peaks. On the other hand, there are meters based on the variation of electromagnetic transmittance of timber depending on the moisture of it. The second one is very expensive and difficult to handle. This work presents a new non-intrusive capacitive sensor that measures the global moisture content in the section of the wall timber framing and therefore it accuracy is similar to those obtained by electromagnetic transmittance meters, but due to it is a capacitive sensor, it has a low cost and an easy operation.

Keywords: capacitive sensor; moisture; wood; non-intrusive; rehabilitation; building

1. Introduction

Wood, as building material, presents in certain circumstances decay problems and damages in its structure, being, also, decay process an irreversible process [1]. These problems are caused, among others, by fungi and insects, and it is habitual to find them both at the same time in the same construction [2].

One of the causes that favour the growth of xylophagous fungi is moisture, besides other environmental factors [3]. Wood has a critical moisture level, which exceeded, there is a risk of fungi development [4]. This moisture level is called Fiber Saturation Point (FSP). Some authors place at 18%-20% the minimum moisture percentage in wood needed to suffer the attack of xylophagous fungi, being 25%-55% the optimum interval [5]. Regarding xylophagous insects, their growth is influenced by various parameters: wood species, wood moisture, environmental temperature and existence of rot fungi in wood [6].

Some authors have studied caused damages in constructions with historical value [7, 8]. To face the rehabilitations of buildings with wooden framework, optimizing and improving the proceedings to perform, knowing as much as possible the moisture of that wood is necessary. The use of non-destructive techniques permits the substitution of part of the damaged structure instead of the whole section, thus avoiding economical and environmental costs [7].

Papez [9] measure moisture by 3 methods. One of them, gravimetric method, is a direct method, but it cannot be employed in a real structure because it would lead to the break of the structure. The other two are indirect methods and are performed by local resistive and capacitive sensors.

For their part, Morales [7] use ultrasound technique as non-destructive method in evaluation of wooden structures considering that variation of ultrasonic propagation speed gives us information about loss in density in deteriorated wood. Hervé [10] use another non-destructive technique to evaluate deterioration in wood through its density study developing a map created from X-ray tomography.

Nevertheless, in spite of the aforementioned works, none of them has reached the required specification and sensitivity to be able to confront rehabilitation in building field in a fast, effective and economical way. Therefore, in this work we have carried out a non-intrusive transportable capacitive sensor, which is able to measure in situ moisture of a wooden beam on site, where wood will act as dielectric. In this way, we can establish moisture content of the wood piece and act accordingly to rehabilitate the building.

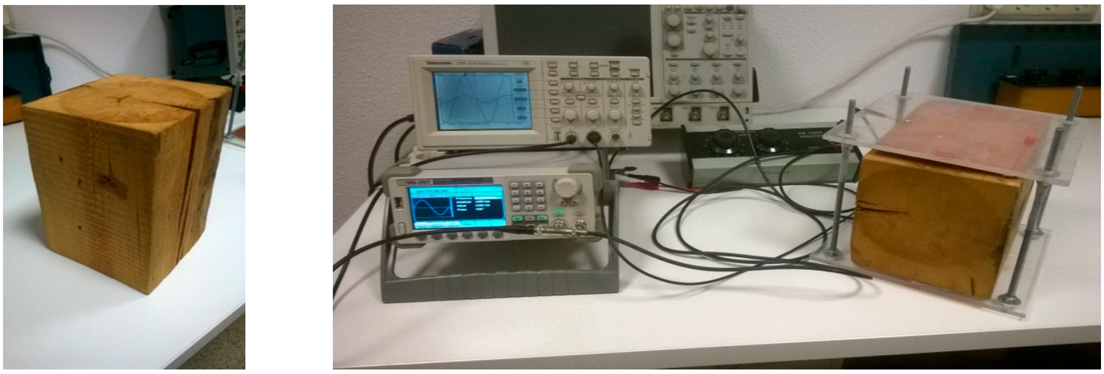
2. Experimental Section

2.1. Measurement Equipment

The sensor consists of two parallel rectangular copper sheets, which dimensions adjust themselves to wood dimensions, and they are attached to a rigid support which permits to keep the sheets in a parallel way between them under all circumstances. The circuit consists of a sine-wave generator of variable frequency and a phase change detector between the applied signal to the circuit and the collected signal at the exit of a second-order resonant circuit, so that by a frequency sweep, the resonant frequency is obtained (Figure 1). This resonant frequency is directly related to the capacitance of the sensor (Equation (1)):

$$\omega = \frac{1}{\sqrt{LC}} \rightarrow C = \frac{1}{L\omega^2} \quad (1)$$

So that it is possible to correlate the capacitance value with the water content in wood.



(a) (b)

Figure 1. (a) Piece of wood. (b) Measurement equipment with the piece of wood.

2.2. Conditioning of woods

The woods, which are Pinus sylvestris L. species, have two origins. Ones are part of a beam of a building in rehabilitation and others are part of beams of fresh wood. They have a 16 x 16 cm section and 25 cm stretches are cut to the execution of the experiment. This length is enough for the used sensor sheets and it is not too big to ease its use and/or handling in the laboratory. Thus, the measured samples have dimensions of 25 x 16 x 16 cm^3. These samples were dried until their anhydrous state according to EN 13183-1:2002 standard by their introduction in an electric oven Contem SELECTA. They were kept there for 30 days while they were weighed daily (according to the standard) till the weight variation was fewer of 0.1% in consecutive weightings. Once conditioned, the woods were moistened in a controlled way till exceeding thoroughly the Fiber Saturation Point (FSP). Afterwards, the woods were kept at environmental conditions and the moisture measurements of the woods were made daily. The woods were drying in these conditions till the amount of water in the woods was in equilibrium with environmental conditions. When the woods reached this point, the moisture measurements were made while the woods were drying in the electric oven till they recovered the anhydrous state.

2.3. Measuring and moisture measurement

Once exceeded the FSP, measurings commenced. The followed procedure was to weigh the woods to calculate their moisture content by comparison with their dry weight according to EN 13183-1:2002 standard (Equation (2)):

$$Moisture\ (\%) = \frac{m_1 - m_0}{m_0} x100 \quad (2)$$

Where m_1 is the mass of the sample and m_0 is the mass of the sample in anhydrous state. Then, the obtained answer of our sensor was measured. The measurements were made in a room at constant temperature to avoid the possible influence of temperature both on electronic measurement and on the wood itself. Of every sample of wood and for every moisture content, 20 measurements have been made, so that it has been possible for us to apply statistic techniques to results to minimise errors.

3. Results and Discussion

3.1. Capacitance in relation to wood moisture

3.1.1. Capacitance in relation to moisture of wood from building in rehabilitation

Measurements in wood from building in rehabilitation are shown in Figure 2. In this figure, it can be observed that capacitance variation in relation to wood moisture follows a parabolic behaviour according to Equation (3), and, also, as it was expected, given that relative permeability ($\mathcal{E}_r = \mathcal{E}/\mathcal{E}_0$) of water is 80 and in the case of the wood is 20, capacitance increases as moisture content of the sample grows.

$$y = 0.029x^2 + 0.114x + 104.4 \tag{3}$$

The coefficient of correlation of Figure 2 curve is 0.992, which indicates that experimental datums are adjusted to the proposed behaviour law in a really good way.

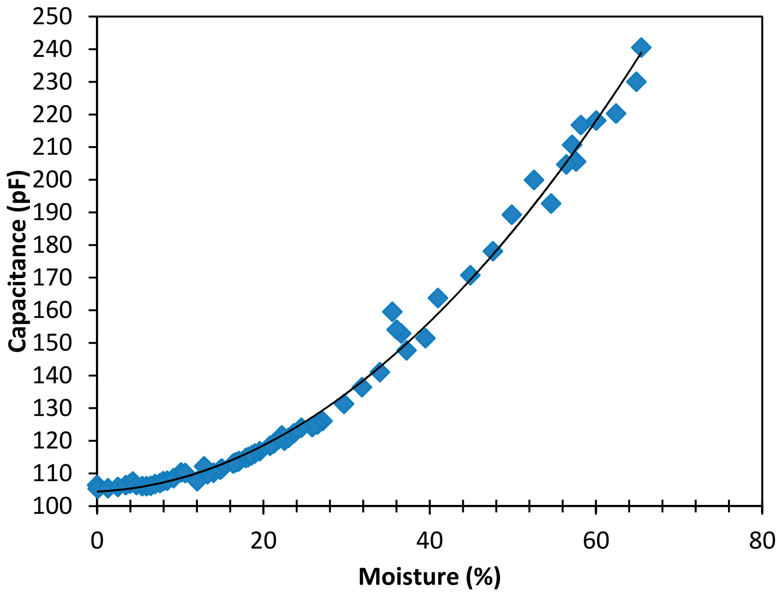


Figure 2. Relationship between capacitance (pF) and moisture content (% according to the standard) of sample of wood from building in rehabilitation.

3.1.2. Capacitance in relation to moisture of fresh wood

With fresh wood samples was followed the same procedure it was followed with wood from building in rehabilitation. Obtained results are shown in Figure 3. Although experimental datums also present a parabolic behaviour, adjusting to Equation (4), this wood presents a coefficient of correlation of 0.988, which is worse than the obtained for the wood from building in rehabilitation.

The most probably explanation can be the fact that fresh wood contained resin in larger quantities than the wood from building in rehabilitation. During the initial desiccation process (to bring samples to anhydrous state) we observed a loss of resin (dregs of resin appeared under the tested samples). This could cause variations in the content and in the state of resin (in desiccation tests of woods this resin was affected in its state and even in its quantity and presence in wood) and, thus, its permittivity could be affected. In woods from building in rehabilitation was not observed residue when desiccation process was made, and, thus, we deduced that there could not be a loss of resin.

$$y = 0.012x^2 + 0.342x + 1.547 \quad (4)$$

3.2. Relationship between capacitance and moisture

Dielectric properties of wood increase with the growth of moisture content in a non-linear way [11]. This explains why in Figure 2 and Figure 3, capacitance increased with the moisture content in a parabolic way. From the parabolic behaviour, it is deduced that, when we increase one percentage point in wood moisture at high concentrations of moisture, capacitance grows more than when that same increase is applied at low concentrations of moisture.

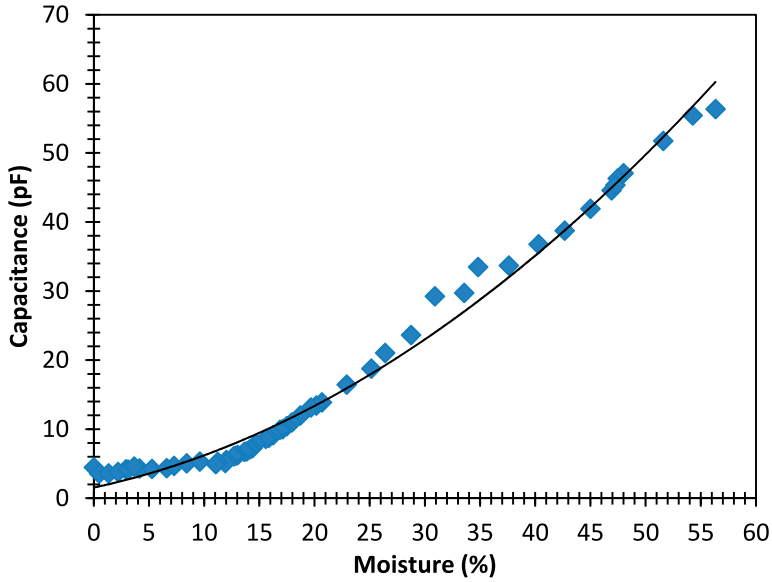


Figure 3. Relationship between capacitance (pF) and moisture content (% according to the standard) of sample of fresh wood.

As can be seen in the results (Figure 2), our system has a measuring range better than commercial. Specifically, this sensor has a range of up to 65 % moisture in wood, while the capacitive and resistive sensor used in [9] has a measuring range up to 50 % and 30 % moisture respectively.

Though the capacitive sensor uses the dielectric properties of wood by altering the capacity to moisture in the material, and as the dielectric constant of dry wood is between 2 and 7, the dielectric constant is a function of the wood density and species. Thus, for a given wood its dielectric constant depends on the quantity of water it possesses. Thus, calibrating the sensor previously by the method of variation of the mass described in section 2.3, our device can be used for any type of wood.

4. Conclusions

Capacitance measurement as an indirect method to know the total moisture of a wood beam section produced as a result parabolic behaviour answers both in the case of wood from a building in rehabilitation and for the case of fresh wood. The capacitance increased as the water percentage in wood increased, and in a bigger proportion at high contents of moisture than at low contents. A parabolic behaviour law has been established between sensor answer (transducer capacitance) and the moisture percentage content in wood.

The obtained coefficients of correlation are very high, although in fresh wood this coefficient is a little fewer than in wood from building in rehabilitation. This difference between them could be on account of anisotropic character of wood together with resin content of fresh wood.

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Conflicts of Interest

The authors declare no conflict of interest.

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