Determination of the moisture content of wooden materials by the electrical resistance method using Trotec T2000

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Abstract

Wood contains different mass ratios of water so determining the moisture content of wood is important information for monitoring the condition of a living tree through the process of drying and preparation of the raw material throughout the entire exploitation life of the wooden product. Wood is a dielectric by nature, but it conducts electricity thanks to the presence of water. The electrical resistance of wood is strongly correlated with the amount of moisture contained in the wood itself, along with the specifics of the variety and other parameters. Special instruments, hygrometers can be used to determine moisture in wood, or standard methods of measuring electrical resistance can be applied. In this research, a Trotec T2000 moisture meter with an external temperature probe was used to measure moisture in two different types of wood under different conditions. Measurements were made at different input temperatures of the instrument for known resistances and the influence of temperature correction of the instrument on the measurement result. At the same time, the influence of the measurement directly on the measurement result and the value of the measured moisture in dependence on the measurement depth was observed.

Keywords: *wood moisture; electrical resistance; measurement; Trotec T2000*

1. Introduction

Nowadays, wood as a material has multiple applications in the manufacture of furniture, carpentry, structural elements in construction, etc. The use of solid wood as firewood in developed countries has decreased significantly, which is due to the increasing value of the raw material, but also due to the development of awareness of environmental protection.

In addition to other physical properties, the water content in wood is of particular importance for its properties such as strength, elasticity, stability of shape, workability, and durability. Moisture has the most significant influence on the properties and lifespan of wood raw materials and wood products (Carll & Wiedenhoeft, 2009). With regard to electrical conductivity, wood is considered an insulator, however, this and other works have proven that the water content significantly affects the resistance and conductivity of wood due to the presence of electrolytes that, dissolved in water, transmit electric current. Water in wood is present throughout the life of the tree, in the raw material - logs and lumber, and in the finished product. For this reason, the water content of wood as a material is already considered during the first exploitation operation, i.e. felling of wood, where the dormant vegetation phase with the least water content is most often selected, and most often it is winter. Since the water content in wood affects the electrical conductivity, it can be assumed that the electrical resistance of wood is inversely proportional to the water content, but in addition to the water content, other physical properties such as density, the content of chemical substances, temperature affect the electrical resistance of wood. The density and substance content are specific to the variety and climate, so these values are mostly constants, while the water content and temperature are variables that can be considered when measuring and determining the water content in wood. Determining the moisture content (water) is therefore necessary in the process of applying and processing wood. This paper covers the measurement of humidity using the method of measuring the electrical resistance of wood.

1.1 Electrical properties of wood

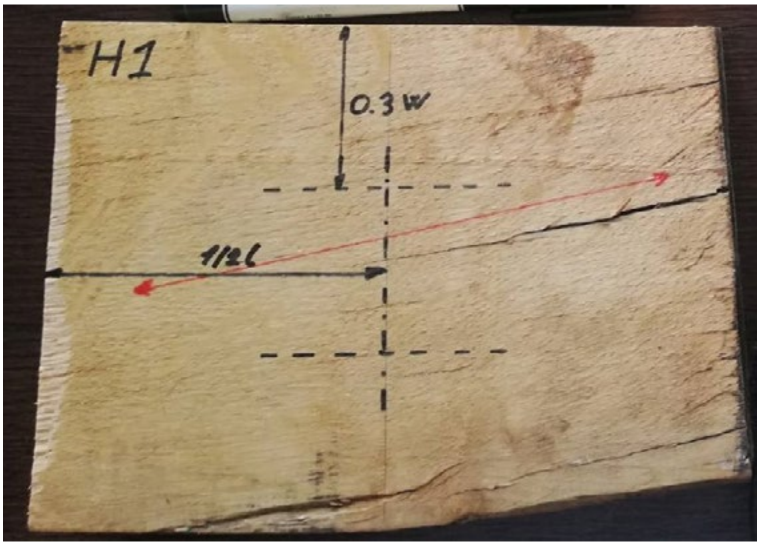
Among the electrical properties, wood has electrical resistance and potential. Water significantly affects both electrical properties of wood, and the water content can be determined by measuring these values. The electrical resistance of wood depends not only on the water content but also on the temperature, the direction of the fibers, and the content of water-soluble salts. Unlike metal, wood has a negative temperature coefficient and its electrical resistance decreases with temperature (Glass & Zelinka, 2021). In addition to electrical resistance - conductivity, wood also has a dielectric constant. Water affects the dielectric constant, and by measuring the dielectric constant, the water content in wood can also be measured.

2. Measurement of moisture content of wood

The water content in wood is expressed as a percentage ratio of the mass of water in the wood and the mass of absolutely dry wood. There is a standard DIN EN 13183-2 (Pervan, Klarić & Slivar, M 2013) for the measurement of wood moisture using the electrical resistance method. Among other things, the standard describes the selection of the measurement location according to the dimensions of the wood sample, and the number of repetitions of the measurement depending on the number of samples, and recommends the use of insulated electrodes considering the possible surface moisture of the wood.

Figure 1 shows a piece of wood with a marked place of measurement with regard to the dimensions of a sample shorter than 600 mm according to DIN-EN-13183-2:2002 made by the authors.

Figure 1: Determination of the measurement location according to DIN-EN-13183-2:2002



Source: Authors

The importance of moisture measurement is that by measuring wood moisture along with the volume and known specific mass of dry wood of a variety, the total mass can be easily calculated. Given that the moisture content in a freshly felled tree can be as much as 140 % (Jergović, 2016,) the total mass of the log can significantly affect the technical conditions, and the cost of handling and transporting the wood.

2.1 Determination of wood moisture content

There are numerous devices on the market for determining the water content in wood. These devices are based on two different electrical properties of wood: dielectric constant and electrical resistance. Both sizes are strongly influenced by water content. In this work, a measuring device based on measuring the electrical resistance of wood Trotec T2000 was used. The Trotec T2000 instrument is a multipurpose electronic device for measuring multiple physical quantities with the use of appropriate probes. Trotec 2000 measures: air temperature, air humidity with a capacitive sensor, surface temperature with a PT100 sensor, humidity of wood and mineral materials by capacitive and electrical resistance methods, and measurement of the humidity of mineral porous materials by ultrasonic method. In the measurements described in this work, a simple handle with 12 mm and 20 mm long nail electrodes was used for 7 mm and 20 mm depth measurements. The instrument has factory-programmed curves for more than 2000 types of wood, which are classified in 24 groups. Group selection is done manually in the instrument menu according to the attached printed tables. All more detailed technical data and specifications can be found in practice manual.

Figure 2 shows the Trotec T2000 moisture meter in the corresponding measuring case with electrodes for measuring humidity by electric resistance, attachments for dielectric and ultrasonic humidity measurement. At the bottom right is a thermo-hygrometer, above it is a Trotec TP4 pyrometer (left) and an ultrasonic SDS probe for T2000-3000 (right).

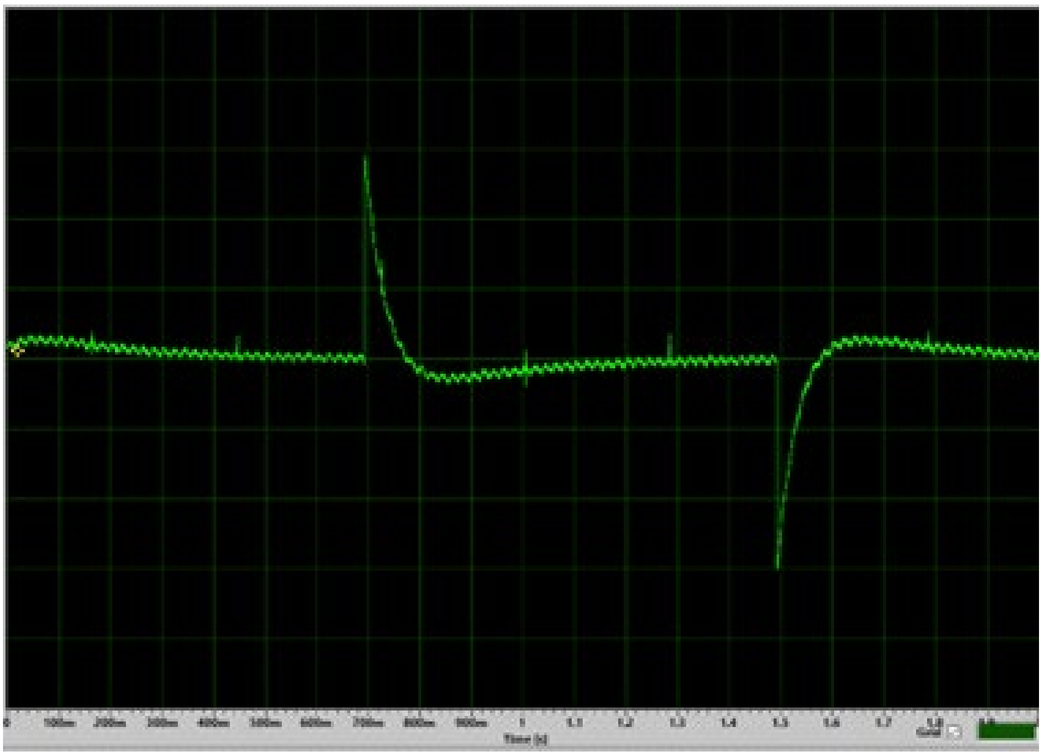
Since no data was found on the electrical output parameters of the measurement, the hygrometer electrodes were connected to an analog and digital voltmeter with the aim of determining the measurement voltage. With the analog instrument, it was observed that the voltage varies in short intervals (jumps of the instrument pointer), and with the digital instrument, the values in the range from -5 V to + 5 V changed rapidly. Based on these observations, the pulse shape of the output voltage was assumed, and the output signal was recorded with an oscilloscope. The appearance of the output signal confirmed the suspicions, as shown in Figure 3. The output signal gives pulses of voltage around 6 V with a total duration of less than 0.1 s and a period of 0.8 s. The pulses are alternately inverted (+/-6 V). The small sinusoidal waveform visible in Figure 3 originates from 50 Hz network noise.

Figure 2: Measuring device Trotec T2000 with measuring electrodes and probes

Source: Authors

The T2000 instrument automatically calculates the temperature correction of the measurement according to the factory-programmed variety curve and data from the built-in temperature sensor or the external PT100 probe that is connected to the instrument. Measuring with an external PT100 probe is much more practical than using the built-in sensor because it allows you to measure the temperature of the wood while the built-in sensor measures the temperature of the instrument. If the temperature of the instrument and the sample is not the same, the result will not be adequate. In practice, it is not always possible to have the same temperature of the sample and the instrument, which significantly complicates the accuracy of the measurement.

Figure 3: Output voltage on measuring electrodes T2000 – Winscope



Source: Authors

Considering the property of the negative temperature coefficient of wood, i.e. the property of decreasing electrical resistance with increasing temperature, information about the temperature of the measured wood is important for the accuracy of the measurement result.

Through regression analysis in previous research (Forsén & Tarvainen, 2000), the relationship of electrical resistance as a function of wood moisture was determined as follows:

$$\log[\log(R+1)] = a \cdot u + b$$

where R is the resistance (MOhm) and u the moisture content (%), a and b are coefficients specific to the wood variety and u indicates the moisture content of the wood.

2.2 Hygrometer accuracy

The accuracy of the hygrometer depends largely on the resistance curve for a specific wood variety, which is entered into the instrument's settings at the factory. The wood resistance curve must be selected manually before each measurement where the measurer needs to know or recognize which wood he is measuring. In addition, the accuracy of the measurement is influenced by the accuracy of the sample temperature measurement. Different hygrometers have different distances between the two electrodes, and research has shown that the distance between the electrodes does not affect the measurement result (Forsén & Tarvainen, 2000). During the research, different data were found on the influence of the position of the electrodes in relation to the age on the measurement result. In previous research (Forsén & Tarvainen, 2000), measurements prove that there is no influence of the direction of measurement on the measurement result, that is, the influence is negligible. In this paper, the influence of the direction of the electrodes according to the years on the measurement result was investigated.

After connecting the conductors with the appropriate electrodes and turning on the instrument, the interface is started with two displayed values: temperature (the internal sensor is activated automatically if the PT100 probe is not connected) and humidity. The temperature is displayed in degrees Celsius and the moisture content in the mass ratio (%) according to the equation:

$$u = m_{water}/m_{wood} \cdot 100\%$$

u – moisture content of the wood
m_{water} – mass of water in wood
m_{wood} – mass of oven-dry wood

This paper will present the results of measurements with two different input temperature instruments for known resistances. For known resistances, carbon resistors of 20 kΩ, 300 kΩ, and 1000 kΩ are used, which are connected in series in steps of 20 kΩ, 20 kΩ, 20 kΩ, 100 kΩ, 100 kΩ, 100 kΩ, 300 kΩ, 300 kΩ, 300 kΩ, and 1000 kΩ. Figure 4 shows the instruments used in the measurement and the series connection of the resistors.

Figure 4: Testing the influence of temperature correction T2000

Source: Authors

The thermo-hygrometer was used to compare the values of the air temperature and the built-in hygrometer thermometer. The resistors are connected in series in order, so that the smallest value is 20 kΩ, and the largest value is 2260 kΩ, wherein each measurement of one of the resistors from the series mentioned above is added in series. First, the values were measured at a temperature of 27 °C for both varieties and then at 12 °C.

In addition to the T2000 hygrometer, a Trotec TA300 thermal anemometer and a pyrometer were used to monitor the temperature of the instrument's surroundings (cooler). The first measurement was performed at a stable and known ambient temperature. The thermo-hygrometer was used to compare the values of the air temperature and the built-in hygrometer thermometer. For the second measurement, it was necessary to bring the temperature sensor of the instrument to a lower temperature and repeat the measurement in the same order. Since the sensor is located in the case of the instrument, the instrument was left in a refrigerator at a temperature of 12 °C. The temperature of the refrigerator was measured with a Trotec TA300 thermometer. The resistance measurement started when the temperature on the display of the hygrometer corresponded to the temperature of the thermometer. The procedure of measuring known resistances is repeated in the same sequence.

Figure 5: Moisture measurement of a fresh 30 mm section

Source: Authors

The moisture content of the beech matrix was measured at the place where the samples were taken. A T2000 hygrometer with a built-in temperature sensor was used. For the measurement sample, two metric beech trees were randomly selected from an uncovered firewood stack. The tree was felled in February 2020, and the trunks were immediately cut into metric and delivered to the place of measurement. It took seven months from cutting to measurement. The roof is exposed to atmospheric influences, partially shaded by the canopy. One front side of the syllabary is facing southeast and the other side is facing northwest and is always in the shade. The humidity of the sun-exposed and shaded side of the meter was observed. After measuring the humidity of both sides of both samples, one sample was shortened by 30 mm with a chainsaw.

The measurement with a hygrometer and an ohm meter is repeated on the new cross-section surface which is shown in Figure 5. Then the same sample is shortened again by 25 mm, and this section will be used in further descriptions. The Trotec BP20 thermal pyrometer is used to measure the surface temperature. The electrical resistance across the hygrometer electrodes was measured with a universal measuring instrument.

3. Results of measurements and analysis

From the data in Table 1, the influence of the temperature correction of the instrument on the measurement result for a known resistance is visible. For a temperature difference of 15 °C, the difference in the measured value is 3.1 %, which is more than a 12 % deviation. It is interesting to note that the deviation percentage decreases with resistance. From this measurement, it can be concluded that the built-in temperature sensor of the Trotec T2000 instrument is not a reliable solution except in conditions where the sample and the instrument are at the same temperature, which is not always the case in practice.

Table 2 shows that the results for the same measurement depth for the form and the log and for the sunny and shaded side are within ± 0.2 %, which is significantly less than the established measurement error of the hygrometer (± 2.5...± 4.0) from research (Forsén & Tarvainen, 2000). The results of the measurements between the two depths, 10 mm and 40 mm, differ significantly, both for the shape and the log, the sunny and the shaded side.

Table 2 shows that shape and sunlight do not significantly affect the measurement result. The depth of the measurement significantly affects the measurement result and should definitely be considered when choosing the measuring electrodes or the measurement position. During the measurement, the problem of the influence of the sun on the measurement was observed. The measurement was made in the morning, the sun's rays warmed the surface of the wood on which it was measured in a short time during the measurement (5 minutes), which could easily be read with a pyrometer. The hygrometer also heated up suddenly in the sun, and the built-in thermometer showed values of more than 30 °C even though the air temperature was around 16 °C. The humidity values are the same for the sunny and shaded sides.

Table 1: The influence of the temperature correction of the instrument

	Measurement of a tir tree						
	resistance R (kΩ)	temperature T1 (°C)	temperature T2 (°C)	humidity u1 at 27 °C	humidity u2 at 12 °C	Δu = u2- u1	Δu/u2
1.	20	27	12,2	86,5 %	96,0 %	9,5 %	9,90 %
2.	40	27	12,2	70,0 %	78,0 %	8,0 %	10,26 %
3.	60	27	12,2	60,6 %	67,0 %	6,4 %	9,55 %
4.	160	27	12,2	41,4 %	46,0 %	4,6 %	10,00 %
5.	260	27	12,2	34,9 %	39,4 %	4,5 %	11,42 %
6.	360	27	12,2	31,6 %	35,8 %	4,2 %	11,73 %
7.	660	27	12,2	26,5 %	30,2 %	3,7 %	12,25 %
8.	960	27	12,2	24,3 %	27,8 %	3,5 %	12,59 %
9.	1260	27	12,2	23,2 %	26,5 %	3,3 %	12,45 %
10.	2260	27	12,2	21,2 %	24,3 %	3,1 %	12,76 %

Table 2: Amounts of the measured values of the moisture content of the beech

	Amounts of the measured values of the moisture content of the beech meter (u)							
	Sunny side				Shadow side			
	Depth of measurement							
	form 10 mm	log 10 mm	form 40 mm	log 40 mm	form 10 mm	log 10 mm	form 40 mm	log 40 mm
1.	13,9 %	13,9 %	30,1 %	30,0 %	14,1 %	14,0 %	30,2 %	30,1 %
2.	13,8 %	13,7 %	30,0 %	29,9 %	14,0 %	13,9 %	30,0 %	30,2 %
3.	14,0 %	13,8 %	30,2 %	30,1 %	14,0 %	14,1 %	29,9 %	30,0 %
average	13,9 %	13,8 %	30,1 %	30,0 %	14,0 %	14,0 %	30,0 %	30,1 %

Two temperature values were considered that were significantly different from the actual temperature at the measurement depth. In this case, measurement with an external probe would give a surface temperature reading that does not correspond to the temperature at the measurement depth. From this observation, it can be concluded that one should avoid measuring the humidity of wood that is under the direct influence of the sun due to the possible wrong reading of the temperature and therefore the wrong temperature correction.

3.1 Influence of the measurement direction

Measurements were also performed in three different directions: radial, tangential, and longitudinal in order to observe the influence of the measurement direction on the measurement result, which is shown in Figures 6, 7 and 8.

The measurement direction refers to the position of the electrodes in relation to the wood, not the direction of the current, which is perpendicular to the direction of the electrodes. The humidity in the air of oak wood was measured, dimensions l, w, h (mm): 70, 50, 25, according to DIN EN 13183-2.

The instrument was tuned for curve 12 (European oak and fir). The temperature of the internal sensor of the instrument was 28.3 °C - 28.4 °C, and the temperature of the sample was 28.2 °C measured with a thermo pyrometer Trotec BP20, from which it can be concluded that the temperature of the instrument corresponds to the temperature of the wood sample. A total of six measurements were made for each direction and the results are shown in Table 3.

From the obtained data, it is evident that the position of the electrodes with regard to age has no significant influence on the measurement result, which is in accordance with previous research (Forsén & Tarvainen, 2000, Fernandez-Golfin, J. I et al., 2012).

Figure 6:
Tangentially direction

Figure 7:
Longitudinally direction

Figure 8:
Radial direction

Source: Authors

Table 3: Influence of the measurement direction on the humidity measurement result

	Fir tree		
	Radially	Tangentially	Longitudinally
1.	9,5 %	9,8 %	9,5 %
2.	9,3 %	9,0 %	9,2 %
3.	9,7 %	8,9 %	9,1 %
4.	9,5 %	9,7 %	9,8 %
5.	9,6 %	9,3 %	9,7 %
6.	9,4 %	10,3 %	9,5 %
av.	9,5 %	9,5 %	9,47 %

4. Conclusion

Wood as a naturally porous material contains different mass ratios of water as a live tree, semi-finished product, raw material, and finished product. Determining the water content of wood is important technical and technological data, and it can be determined with electronic devices. Most hygrometers automatically calculate the result according to the selected resistance curve and temperature correction. More practical are moisture meters with an external contact temperature probe with which we directly measure the temperature of the measured wood or with manual entry of the temperature value. The measurement of wood moisture by the electrical resistance method is defined by the EN 13183-2 standard.

According to the research from this paper, the direction of the measurement with regard to age does not affect the measurement result, but the position of the electrodes with regard to the shape and dimensions of the sample and the depth of the measurement can affect the result.

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Sažetak

Drvo sadrži različite masene omjere vode pa je određivanje vlažnosti drva važan podatak za praćenje stanja živog stabla kroz proces sušenja i pripreme sirovine tijekom cijelog eksploatacijskog vijeka drvenog proizvoda. Drvo je po prirodi dielektrik, ali provodi elektricitet zahvaljujući prisutnosti vode. Električni otpor drva u velikoj je korelaciji s količinom vlage sadržane u samom drvetu, uz specifičnosti sorte i druge parametre. Za određivanje vlage u drvetu mogu se koristiti posebni instrumenti, higrometri, ili se mogu primijeniti standardne metode mjerenja električnog otpora. U ovom istraživanju korišten je mjerač vlage Trotec T2000 s vanjskom temperaturnom sondom za mjerenje vlage u dvije različite vrste drveta u različitim uvjetima. Mjerenja su obavljena pri različitim ulaznim temperaturama instrumenta za poznate otpore i utjecaj temperaturne korekcije instrumenta na rezultat mjerenja. Pritom je promatran utjecaj mjerenja izravno na rezultat mjerenja i vrijednost izmjerene vlage u ovisnosti o dubini mjerenja.

Ključne riječi: *vlažnost drveta; električni otpor; mjerenje; Trotec T2000*