Annals of Warsaw University of Life Sciences-SGGW
Forestry and Wood Technology No. 110, 2020: 131-139
(Am. WULS-SGGW, Forestry and Wood Technology 110, 2020)

Calibration of ultrasound tester delay time by cutting a wooden beam

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Abstract: Obtaining precise and reliable test results requires specific tools on one hand, and at the same time, reliability of the results should not be questioned. One of the necessary steps to achieve this goal is the calibration of the measuring device before the test. This article describes an experiment involving calibration of the device by an independent method called cutting beam calibration carried out on the ultrasonic material tester UMT 01. The standard calibration of this device is carried out by using a dedicated metal disc as a template. Calibration of the tester consisted of determining the time delay of the measured signal. The obtained results were used to prepare charts and to determine of signal time delay, called ***correction***, which also allowed determining the velocity of ultrasonic wave in the tested material in three ways. The experiment was conducted on samples of three species of wood: Norway spruce, Scots pine and sycamore. The velocity of ultrasonic wave from research was compared with literature data.

Key words: ultrasonic, velocity, wave, wood, time delay, calibration, Norway spruce, Scots pine and sycamore wood

INTRODUCTION

Physical, chemical and mechanical tests allow determining the structure and properties of tested materials. Analysis of test results helps to see how the structure affects material properties. Thanks to technological developments tests of materials are carried out using increasingly advanced research techniques as well as complex research equipment.

Destructive, non-destructive and semi-destructive methods are used in testing various materials including wood and wood-based composites. Although destructive methods provide wider and more detailed information about the material, in practice, mainly non-destructive methods are used.

Non-destructive material properties testing use the following methods: visual, radiological, acoustic and ultrasonic [Dybeł et al. 2015]. In the field of ultrasonic acoustic research known methods are: impulse response method, hammer method, seismic method, ultrasonic tomography and acoustic emission. These methods are used for detection of material defects in construction, metallurgy and other domains such as medicine [Matausek 1961, Mackiewicz et al. 2001, Onoszko 2012, Runkiewicz 2018].

The ultrasonic method is one of the acoustic methods of examining properties of various materials, including wood and wood-based materials. Ultrasonic testing (UT) is a non-destructive testing technique based on ultrasonic wave propagation in the object or material being tested. The method uses ultrasounds, acoustic waves with frequencies above the human hearing limit in the range from 20 kHz to 1 GHz [Śliwiński 2000].

Measurement of the time movement of the acoustic waves at specified length allows calculating the velocity of sound waves (ultrasounds) in the material in a given direction. On the basis of data obtained during tests, such as ultrasonic wave velocity and wood density, it is possible to calculate the dynamic modulus of elasticity and other wood properties [e.g. Kotarbiński 1970, Dzbeński 1984, Bekhta et al. 2001, Moliński and Fabisiak 2001, Kozakiewicz 2002, Kurowska et al. 2016, Hadinata nad

Kozakiewicz 2020]. In this case, the accuracy of the measurements is one of the criteria of testing quality. To achieve this goal, it is necessary to calibrate the testing device. The purpose of calibration is to correctly determine the characteristics, accuracy and measurement consistency of the tested measuring device [RUNKIEWICZ 2018].

According to the definition, calibration (in Polish : *kalibracja* or *wzorcowanie*), is a procedure consisting of precise determination of the relationship between the values indicated by the tested device and the values indicated by the standard or a given calibration method [PUCHAŁA et al. 2012] .In some devices, where this possibility and need exists, the measuring system is adjustable. This possibility is incorrectly called "auto-calibration" (in Polish *samowzorcowanie*).

The adjustment consists of positioning the device according to the specifications given by the manufacturer or the data obtained after calibration [GUM 2015]. Adjustment should not be confused with calibration, because it is an additional procedure. However, in the case of these tests, the measuring device did not allow for adjustment.Test and measurement devices are subject to factory calibration confirmed by a relevant certificate with the expiry date. Some devices also require each bench calibration carried out immediately before measurements. The calibration and tests should be carried out in the shortest possible time, under the same conditions, on the same device as well as by the same operator or team.

The UMT 01 ultrasonic tester uses ultrasonic waves with a frequency of 40 kHz to 2 MHz, depending on the settings and probes used. The standard calibration is performed with use of a standard disc and is intended to determine the time delay for the whole research kit. In the UMT01 tester the calibration is performed by using dedicated metal discs calibrated to 2 μs or 25 μs. The time delay is then used to correct the total time of the ultrasonic wave run through wood samples .Then, the ratio of the length of the test sample (distance between the heads of the ultrasonic probes) to the corrected time is the velocity of the ultrasonic wave in the tested material.

Wood as an anisotropic material creates some difficulties during testing, but at the same time presents an interesting research challenge. The tests were carried out using wood with a similar macroscopic structure along the entire length of the sample, and measurements carried out in the longitudinal direction. The run times of longitudinal ultrasonic waves in one direction were studied. The tests were supposed to answer the question if the calibration without the factory standard is possible and what is the accuracy of this type of calibration?

MATERIALS AND METHODS

In an independent method called *cutting a wooden beam calibration method* used in the tests, involving shortening the sample and measuring uncorrected ultrasonic wave run times at ever smaller measuring lengths (Fig. 1).

The charts of the relationship between time and the sample length allowed determining the delay time of the signal path. The tests were conducted on samples of three species of wood: Norway spruce, sycamore and Scots pine (the name of wood according to EN 13556:2003).

Figure 1. Example of a Norway spruce wood sample after alternate cutting off the beam ends

In the tests there were used wooden beams with a cross-section of 20 x 20 mm. The initial length of sycamore and Norway spruce samples were 300 mm and 750 mm in case of Scots pine sample. Additionally, the effect of lack of polyacrilic gel on the accuracy of ultrasonic wave time measurement was investigated. The polyacrilic gel applied to the face surfaces of the ultrasonic heads acted as a coupling substance [Kozakiewicz 2002, Hadinata and Kozakiewicz 2020]. The mean density and moisture content of the samples used in the experiment was determined (Table 2).

The calibrated ultrasonic material tester UMT 01 was connected to the computer using a parallel LPT port. The specialized software (UMTLink) was dedicated for UMT1 tester. The tester with computer is shown in the picture (Fig.2).

The ultrasonic cylindrical heads were used in the test: transmitting and receiving 004T40 (for 40 kHz, transducer size 40 mm). The tester settings allowed to obtain optimal signals recorded on the device for changing lengths of the tested sections from 750 mm to 15 mm for Scots pine wood and from 300 mm to 15 mm for sycamore and Norway spruce wood. The settings used during the experiment were: impulse mode transmitting system, 4V transmitting impulse amplitude, 12Hz repetition frequency, 60V energy, 40dB gain.

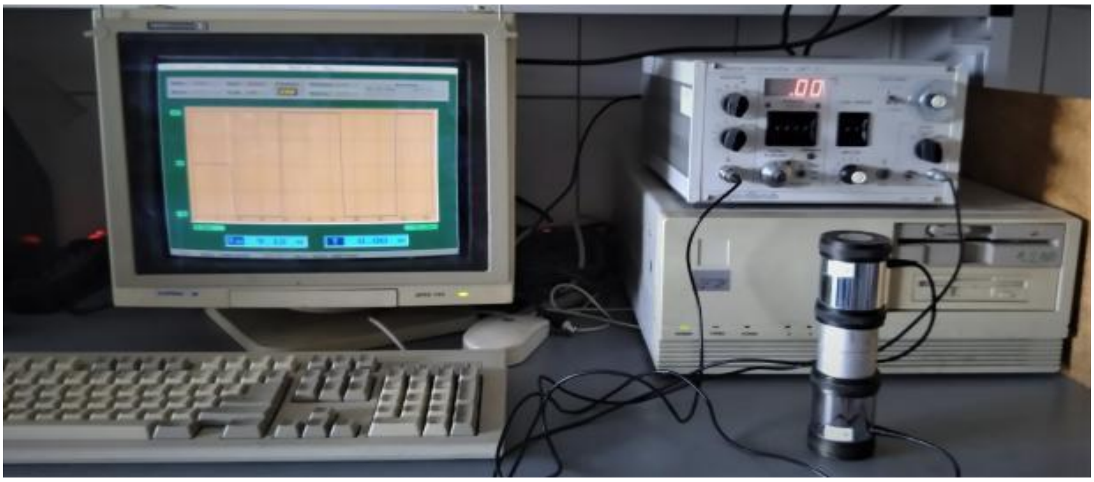


Figure 2. Test stand: UMT 01 tester with ultrasonic heads, computer with specialized software UMTLink

The middle section, created during alternate cutting off the beam from both sides, was placed between the ultrasonic probes and subjected to the measurement of wave run time. The alternate cutting eliminated the possibility of systematic error in work on one imprecise cut surface which could soak up the gel. The reading took place on the scale of a computer monitor. The charts were made on the basis of the measured *ti* times and lengths of the *Li* sample sections. Linear regression patterns for the experimental points of this chart determined the delay time b (absolute term) and inverse of the velocity of the ultrasonic wave a (slope of a straight line):

$$y = ax + b \tag{1}$$

$$t = aL + b \quad (2)$$

y=t – total wave run time;
x=L – length of wood sample;
a – regression factor (slope of a straight line), and 1/a is the velocity of the ultrasonic wave);
b – absolute term being the correction of the signal transition time, i.e. the delay Δt time;

For each linear regression the determination factor R2 and the wave velocity in tested wood species samples was calculated:

$$v = \frac{1}{a} \quad (3)$$

One of the methods of its calculation was based only on the slope of a straight line. The second method of calculation consisted of averaging the velocities, obtained in individual measurements, taking into account the time delay:

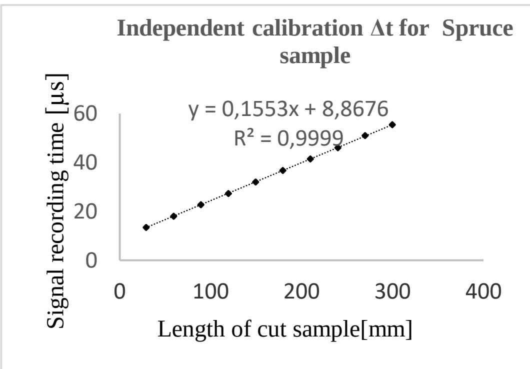
$$v_i = \frac{L_i}{t_i - \Delta t} \quad (4)$$

This method allowed a simple calculation of the standard deviation.

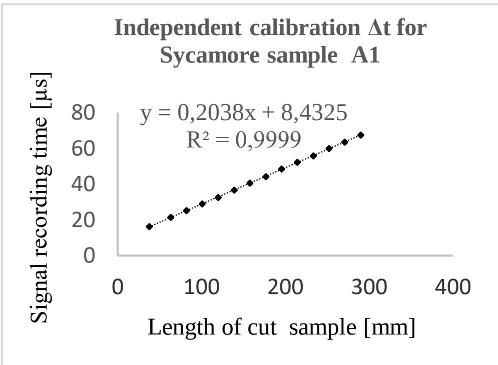
In addition, the time delay obtained from standard calibration by using factory standard was used. As a result, the velocity for each sample was calculated by as many as three methods. On the basis of several linear regressions for different samples and wood species, it was possible to average the key time delay for calibration Δt=b. The standard deviation and standard error were also calculated, which enabled a better comparison of the cutting a wooden beam method of calibration with the standard one.

RESULTS AND DISCUSSION

The results of the measurements of three species of wood (Scots pine, sycamore, Norway spruce) are presented in figures 3-5. In all cases there is a perfect linear correlation confirmed by the value of determination coefficient close to unity.



a)



b)

Figure 3. Dependence of signal registration time on the length in samples cutting beam: a) Norway spruce wood, b) sycamore wood

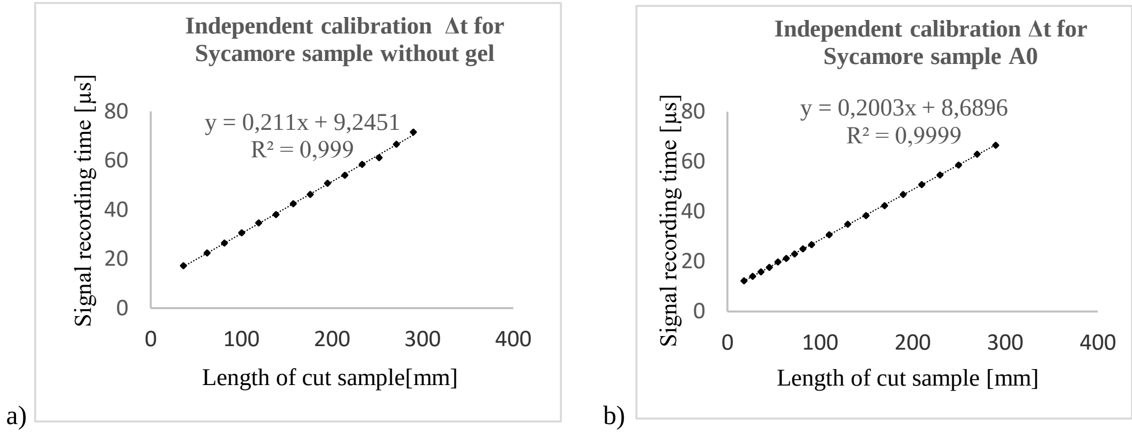


Figure 4. Dependence of signal registration time on the length in the sycamore (cutting beam): a) with using polyacrilic gel, b) without using polyacrilic gel

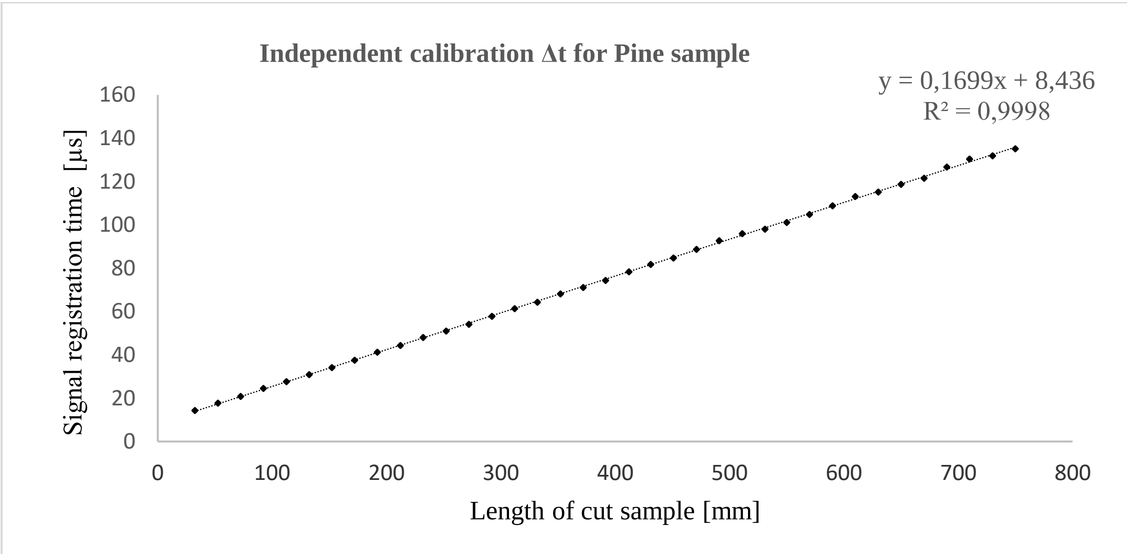


Figure 5. Dependence of signal registration time on the length in the Scots pine samples (cutting beam)

The last chart Fig. 5 shows dependence of signal recording time on the length of Pine samples beam with an initial length of over 750 mm.

The ideal straightness of the graph shows the homogeneity of the wood material used, as well as the constant value of the measured ultrasound pulse velocity. In view of significantly different phase and group velocity values presented in the literature [Bocur 2019, Saadatnia et al. 2011, Spycher 2008], the constant value of the ultrasonic pulse velocity is not so obvious. As a result of dispersion, the waveform pulse is blurred with different component velocities. However, no changes in the total pulse velocity are visible on the chart.

The essential results for the article of the calibration delay times are shown in Table 1.

Table 1. Delay times calibration results for measured wood species

Samples spices	Delay time – absolute term $\Delta t = b$ [µs]	Determination factor R^2
Scots pine	8,436	0,9998
Sycamore A0	8,6896	0,9999
Sycamore A1	8,4325	0,9999
Sycamore without using gel	9,2451	0,999
Norway spruce	8,8676	0,9999
Average	**8,73**	Conclusion: Compatibility of both calibrations (even after rejecting the advantageously high measurement without gel)
Standard deviation	0,34	
Standard error	0,15	
Calibration Δt Standard to 2µs	**8,78**	

Table 2 shows the calculated ultrasonic wave velocities by three methods based on: the time correction determined by the standard, according to the slope of a straight line and the time correction of absolute term from the charts. The velocity values in samples of given wood species are similar for these three calculation methods. A noticeable difference in velocities was observed only between the tested samples with and without using gel in sycamore wood.

Table 2. Comparison of the ultrasonic velocity in the tested wood species determined by three methods

Samples spieces	Velocity and standard deviation (based on standard calibration) [m/s]	Velocity from chart „1/a" (based on slope of a straight line) [m/s]	Velicity from chart „b" (based on absolute term) [m/s]	Density [kg/m³]	Moisture content [%]
Scots pine	5926±43	5886	5870±76	615	11,4
Sycamore A0	4997±44	4993	4993±45	569	12,8
Sycamore A1	4954±44	4907	4900±40	575	
Sycamore no gel	4644±111	4739	4607±193	556	
Norway spruce	6478±27	6439	6429±53	515	11,1

Table 3 shows the literature data of the three wood species concerning the velocity of ultrasonic waves and also the velocity results obtained during tester calibration. These data allow concluding that the problem of testing the velocity of acoustic waves in wood is quite complex and requires deeper analysis. Suffice it to say that modern researchers [e.g. Moliński and Fabisiak 2001, Kurowska et al. 2016, Hadinata nad Kozakiewicz 2020] usually follow a different methodology distinguishing types of velocity (group and phase) than earlier researchers such as Kollmann (1951), Krzysik (1978) and Dzbeński (1984).

Table 3. Comparison of measured ultrasonic wave velocities with source data

Spieces of wood sample	Velocity from the tests [m/s]	Velocity from Kollmann [m/s]	Velocity according to other sources [m/s]		
	[m/s]	[m/s]	[m/s]		
	Impuls	Impuls	Group	Phase	Impuls
Scots pine	5926	4760 [5][6]		5026 [4] 5000 [1]	
Sycamore	4970	3826 [5][6]		3700 [1]	4180 [12]
Norway spruce	6478	4790 [5][6]	1855 [11]	4085 [11] 5600 [1]	5388 [12]

[n] - number in square brackets at the value refers to the source

In future, it is worth checking the tester with an independent method, e.g. with an oscilloscope, which should make it possible to distinguish between group and phase velocity.

CONCLUSIONS

Ultrasonic tests with the pass-through method with the use of the UMT1 material tester with software UMTLink allowed to draw the following conclusions:

1. The method of calibration by shortening the wooden beam proved to be compatible with the method of calibration with a metal standard. The confirmation is therefore of a qualitative nature (independence from wood or metal material) and of a quantitative nature (independence from sample length).

2. The measured orthotropic material, i.e. wood, has shown high repeatability within a single beam (determination factor R2 is at least 0,999).

3. The very high ultrasonic velocity, relative to the source data, can be explained by the low moisture content of the wood. In any case, it is known that it is not due to an incorrect value of the time delay which has been confirmed.

4. The applied delay time calibration method is not a complete calibration method.

REFERENCES

1. BEKHTA P., CHOPYK Y., KOZAKIEWICZ P. 2001: Determination of wood moisture content by ultrasound method. Annals of Warsaw Agricultural University. Forestry and Wood Technology No 52:13-18.
2. BOCUR V., 2019: The Acoustics of Wood (1995), CRS Press Taylor & Francis Group.
3. DYBEŁ P., JASKOWSKA-LEMAŃSKA J., WAŁACH D., 2015: The impact of moisture content of wood on the results of non-destructive tests. Annals of Warsaw University of Life Sciences - SGGW Forestry and Wood Technology No 92: 448-454.
4. DZBEŃSKI W., 1984: Nieniszczące badania mechanicznych właściwości iglastej tarcicy konstrukcyjnej wybranymi metodami statycznymi i dynamicznymi. Rozprawy Naukowe i Monografie, 43. Wydawnictwo SGGW, Warszawa.
5. EN 13556:2003 Round and sawn timber – Nomenclature of timbers used in Europe.

6. GŁÓWNY URZĄD MIAR, 2015: Międzynarodowy Słownik Terminów Metrologii Prawnej, Wydawnictwa Główny Urząd Miar, Warszawa, s. 17
7. HADINATA M.E., KOZAKIEWICZ P., 2020: An investigation of selected properties of teak wood from 9-year-old plantation forest in Indonesia. Annals of Warsaw University of Life Sciences – SGGW No. 110, 2020:61-72 DOI: 10.5604/01.3001.0014.3929
8. HASSAN KTS., HORÁČEK P., TIPPNER J. (2013): Evaluation of stiffness and strength of Scots pine wood using resonance frequency and ultrasonic techniques, BioResources, ojs.cnr.ncsu.edu
9. KOLLMANN F., 1951: Technologie des Holzes und der Holzwerkstoffe, vol 1, 2nd edn. Springer, Berlin.
10. KOTARBIŃSKI M., 1970: Zagadnienia ultradźwiękowych metod badania drewna. Przemysł Drzewny 1: 12-15.
11. KOZAKIEWICZ P., 2002: Badanie właściwości mechanicznych tarcicy konstrukcyjnej charakteryzujących kohezję poprzeczną drewna sękatego. Praca doktorska wykonana na Wydziale Technologii Drewna w Szkole Głównej Gospodarstwa Wiejskiego w Warszawie.
12. KRZYSIK F., 1978: Nauka o Drewnie, PWN
13. KUROWSKA A., KOZAKIEWICZ P., GŁADZIKOWSKI T., 2016: Ultrasonic waves propagation velocity and dynamic modulus of elasticity of European oak, European aspen, American cherry and wenge wood. Annals of Warsaw Agricultural University. Forestry and Wood Technology No 93:83-88.
14. MACKIEWICZ S., KOPIŃSKI J. 2001: Doświadczenia z zastosowań ultradźwiękowej techniki TOFD, Materiały VII Seminarium „Nieniszczące Badania Materiałów”. Zakopane 14-16 marca 2001.
15. MATAUSCHEK J.,1961: Technika ultradźwięków. WNT Warszawa.
16. MOLIŃSKI W., FABISIAK E., 2001: Velocity of ultrasound propagation in the beech (*Fagus sylvatica* L.) tension wood. Folia Forestalia Polonica. Seria B – Drzewnictwo No 32:75-81.
17. ONOSZKO K., 2012: Metody stosowane w badaniach nieniszczących. Politechnika Poznańska, Wydział Elektryczny IAPGOŚ 4a/2012:11.
18. PUCHAŁA A., CZARNECKI M., 2012: Wzorcowanie, jako forma nadzoru metrologicznego nad wyposażeniem pomiarowym; Mechanizacja i Automatyzacja Górnictwa, Instytut Technik Innowacyjnych EMAG R. 50, nr 4:38.
19. RUNKIEWICZ L., 2018: Historia metod nieniszczących stosowanych w budownictwie polskim. Badania nieniszczące i diagnostyka. Nondestructive testing and diagnostics. Instytut Techniki Budowlanej. Politechnika Warszawska.
20. SAADATNIA M., BRANCHERIAU L., GALLET P., ENAYATI A., KAMBIZ POURTAHMAI K., HONARVAR F., 2011: Ultrasonic wave parameter changes during propagation through poplar and spruce reaction wood. Bioresources 6(2):1172-1185.
21. SPYCHER M., SCHWARZE F. W. M. R., STEIGE R., 2008: Assessment of resonance wood quality by comparing its physical and histological properties. Springer-Verlag, Wood Science and Technology 42:325–342.
22. ŚLIWIŃSKI A.,2000: Ultradźwięki i ich zastosowania. Wyd. 2. Wydawnictwa Naukowo-Techniczne. Warszawa.

Streszczenie: *Kalibracja ultradźwiękowego testera materiałów przy pomocy przycinanej belki drewnianej.* Celem badań było sprawdzenie kalibracji ultradźwiękowego testera materiałów UMT 01 bez użycia wzorca fabrycznego. Sprawdzenie to polegało na pomiarach całkowitych czasów przebiegu sygnału w skracanych próbkach. Skracanie próbek odbywało się naprzemiennie i równomierne odcinanie jej końców. Badania przeprowadzono z użyciem ultradźwięków przy zastosowaniu impulsowego trybu pracy testera. Kalibracja została przeprowadzona na trzech gatunkach drewna: sosny zwyczajnej, świerka pospolitego i klonu jaworu.
Wyniki pomiarów poddano analizie. Ustalono, iż proponowana niezależna metoda kalibracji jest zgodna i równie dokładna jak kalibracja wzorcem dedykowanym. Równocześnie badania te potwierdziły, iż używanie poliakrylowego żelu ultrasonograficznego podczas badań istotnie zwiększa precyzję pomiarów. Na mocy porównania wyników badań z danymi źródłowymi oraz dokładnego przeglądu literatury, można stwierdzić, iż w zagadnieniu ultrasonografii drewna zdarza się słabe doprecyzowanie rodzaju prędkości mierzonych fal (grupowej, fazowej, impulsowej). Uporządkowanie i rozstrzygnięcie rodzaju prędkości mierzonych, znacznie ułatwiłoby interpretację i metaanalizę danych z różnych prac.

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