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EXPERIMENTAL VERIFICATION OF A NEW TOOL FOR WOOD MECHANICAL RESISTANCE MEASUREMENT

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ABSTRACT

Many non-destructive methods for the assessment of wood incorporated in buildings are based on indirect measurement of density, which is closely related to the mechanical properties of wood determining the static condition of the construction. As the best methods for the determination of density, various resistance methods have been proved, which react well to changes in the material structure in contrast to methods that are totally noninvasive (e.g. ultrasound methods). The paper presents a new diagnostic tool for "in-situ" assessment of timber based on the principle of mechanical resistance of wood against tool (pin) penetration. To verify the proper function of the tool, measurements were conducted using three basic species of softwoods. With the aim to discern the variability of properties caused by their distribution along the diameter and the length of trunk, always one complete trunk of spruce, fir and pine was used. After cutting into sections, the selected trunks were subjected to analysis of physical and mechanical properties. The results show a very good correlation of the average force necessary for pin pushing penetration into the wood with wood density and compression strength parallel to the grain.

KEYWORDS: NDT, pin, resistance, mean force, density, wood strength.

INTRODUCTION

A number of currently used diagnostic tools and methods are based on the measurement of resistance against a tool penetration into a wood to describe behavior and properties of wood (Kasal and Tannert 2010, Pellerin and Ross 2002). Mechanical resistance of timber is correlated with density of wood, which is basic physical property of any material. The most widespread resistance method is measurement of the depth of pin penetration in which the pin is shot into the material by a constant energy of a spring (indentor) – this can be considered a semi-destructive method (Ross et al. 1999). The most frequently used tool Pilodyn 6J Forest is a simple mechanical device with pin of diameter 2.5 mm, driven into the wood by calibrated spring at a constant work of 6 J. However, the maximum depth of pin indentation is limited and only superficial parts of specimens can be evaluated (Feio 2005, Görlacher 1987, Kasal and Anthony 2004, Smith and Morrell 1986, Turrini and Piazza 1983, Watt et al. 1996).

Another penetration test is based on repeated pin hammering into the wood by means of a hammer with a constant energy. This penetration test based on gradual measuring of one layer after another makes us able to distinguish different degrees of decay expressed by the number of hits per 1 cm of pin penetration (Ronca and Gubana 1998).

Other resistance methods for wood diagnostics are resistance microdrilling (Kasal 2003, Kasal and Antony 2004, Feio 2005) and the screw-withdrawal resistance method (Divos et al. 2011, Cai et al. 2002, Yamaguchi et al. 2011). Instrumented microdrilling, by the fact of gradual penetration through the material one can gain an overview of specimen's internal structure. For example, measuring by a tool Resistograph, based on this principle, measures the resistance of material against penetration of a small bit with the diameter 1.5 – 3.0 mm where the output is the profile of energy consumption or the relative resistance (where the energy needed to pass the internal friction in deeper layers is deducted). The peaks in the graphical record correspond to higher resistance of wood (and so higher wood density), whereas lower points are related to a lower relative wood resistance (Machado and Cruz 1997, Emerson et al. 1998). The shift of the bit is constant and the revolutions are unchangeable (Rinn 1994, Rinn et al. 1996).

The screw-withdrawal test uses a simple manual tool for withdrawing a standard screw with 4 mm in diameter driven into a depth of 18 mm (Divos et al. 2011). The outputs of screw-withdrawal methods (e.g. screw withdrawal resistance) are used for indirect determination of wood density (Cai et al. 2002), it can be also combined with outputs of other non-destructive methods (e.g. stress wave velocity) with the purpose to derive wood basic mechanical properties such as the modulus of rupture (Divos et al. 2011).

Despite of wide spectrum of used methods and tools there is still lack of a solution which would combine a continuous record of resistance against gradual tool penetration into a material to depths corresponding to common dimensions of wooden constructional elements. Therefore an alternative tool had been developed and it is a semi-destructive penetration test based on continuous monitoring and recording of a force applied to a gradual pin penetretion into a material in relation to the measured distance of pin displacement (Kloiber et al. 2011). The device used for this test is autonomous and portable, yet it is able to evaluate properties in the entire cross section of a wooden element thanks to the sufficient length of pin while it still retains the character of the indentation test. The output is a graph of the force applied to drive pin into the specimen. The various parameters derived from the graph can be used to describe the mechanical resistance of the material.

The aim of this paper is to present this newly designed device and experiments conducted to verify the proper function and usability of the device. The objective of the research was to design a tool which could be used for indirect establishment of wood density and mechanical properties, and even to give precision to the indirect establishment of dynamic modulus of elasticity obtained through acoustic methods.

MATERIAL AND METHODS

Device Construction

The device (Fig. 1) consists of the movable part of the body, to which a tool base is connected perpendicularly in its lower part and a gear casing in the upper part. Inside the movable part is a toothed rack driven through a pinion located in the gear casing. The force to the pinion through a crank. The toothed rack is connected to a 5 kN load cell, the load cell is connected to a pin indentor, with diameter 2.5 mm, length 120 mm and rounded tip; the pin is fabricated from spring steel. The pin indentor has a semi-round tip. Parallel to the direction of the toothed rack movement there is a movable pin guideway connected to the body movable part. The guideway is a landing and protects the load cell against damage. The pin indentor passes through the tool base in bronze grommets which reduce friction of the pin movement. They are fixed in the tool base by a thin nut (Fig. 2). The device is equipped with a displacement sensor, which consists of a displacement gauge fixed to the movable part and a coded strip fixed in a groove in the rear wall of the toothed rack. In the rear of the movable part there is a wireless data transmitter that is electronically connected with the displacement gauge; there is also a wireless connection between the wireless data transmitter and a USB receiver of the recording PC with specially developed software SigVis for recording and analysis of measuring.

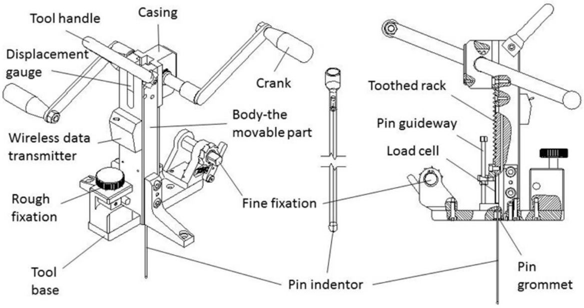


Fig. 1: Axonometric and side view of the device with the pushing pin.

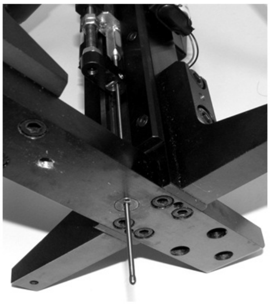


Fig. 2: Detail of pin passage through the tool base.

The body of the device can be fixed to the tested object (usually a constructional element of right-angled cross section) by means of a fabric strap (Fig. 3). The strap is roughly adjusted to the required length and fixed to one side of the tool base by a fixation knob with a pressure board; on the other side it is tightened by a winch with a ratchet. The device can also be fixed to the tested element by a roller chain using a similar method (Fig. 3). In contrast to the fabric strap fixation, the alternative way is more demanding for manipulation and fixation. The fabric strap allows gentle fixation, e.g. if the tested timber is a part of a historic building. On the other hand, the roller chain is sturdier and stretches less. Another alternative mounting method is using of screws (Fig. 3) where the entire circumference of the element is not accessible. Fixation by screws is more invasive and thus undesirable in historic and heritage buildings.

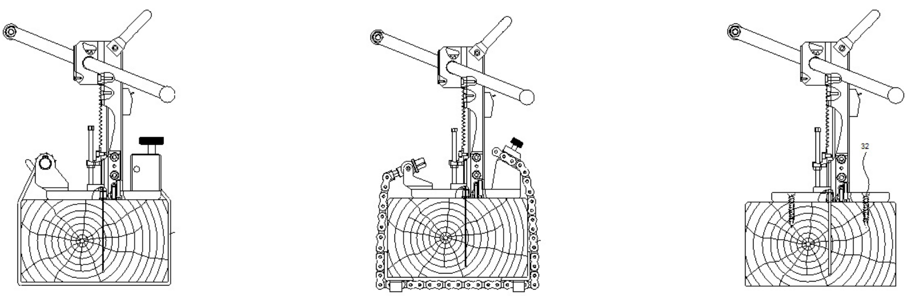
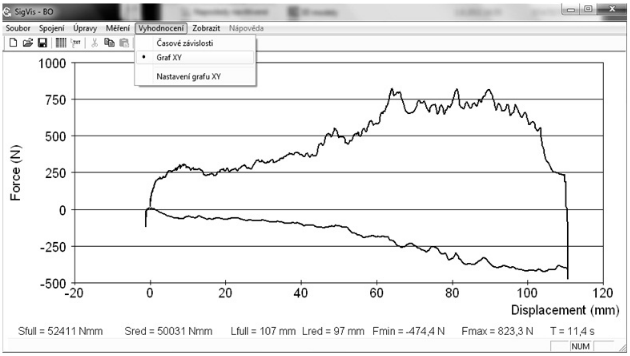


Fig. 3: Fixation by fabric strap, roller chain and mounting screws.

As the device is fixed to the object, a pin starts to be gradually pushed into the timber perpendicularly to the surface. Its movement is ensured by rack and pinion gear driven by two opposite manual cranks for both hands. The device is equipped with a linear magnetic position sensor and tensometric force sensor, which allow to measure the progress of the force and the displacement of the pin. The outputs of the sensors are transferred to a microprocessor with sampling frequency of 100 Hz and are saved in the memory of the device. Simultaneously, the measured values of both quantities are transferred wireless via the USB receiver to the PC where their progress is visualized. The record is assessed in the form of a graph which shows the measured force during the process of pin pushing. On the axis x represents the depth into which the pin was driven; the axis y represents the force (Fig. 4).



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Sfull = 52411 Nmm     Sred = 50031 Nmm     Lfull = 107 mm  Lred = 97 mm  Fmin = -474,4 N     Fmax = 823,3 N     T = 11,4 s
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Fig. 4: Record of the progress of force and displacement for pine wood.

Basic parameters are calculated from the record using software SigVis, namely work S (N.mm) – as the area under the curve of the diagram, length or the depth of pin penetration L (mm), time of pin movement t (s), the maximum force achieved F_{max} (N) and the minimum force achieved F_{min} (N). After the pin is drew out of the timber, the user stops the recording by switching off the transfer. Subsequently, the measured file is saved in a text format on the PC disk. The peaks in the graph correspond to the higher force, i.e. the higher resistance of wood, whereas the lower values of force are related to the lower resistance of wood. Reduced quality of timber caused e.g. by wood-destroying insects is manifested by a relative drop of the measured force, thus we can identify in which part of the profile of the tested element the degradation is located.

Versatility of the device is improved by constructional possibility to replace the pin with a hook for withdrawal of screws or other fixings (Fig. 8) to provide the screw withdrawal test. The ability of timber to hold mechanical fixings also depends on its species, density, moisture content and quality. With a higher density the resistance of timber against withdrawal increases. We can estimate wood density indirectly by the measured screw withdrawal force and the defined length of the screw-timber connection at defined moisture content.

Measured data are transmitted to the PC through a wireless data transmitter and USB transducer. The transducer is supplied from USB port and the data transmission is implemented via virtual serial port. Any computer or notebook with a USB port and OS Windows XP (Vista) 7 can be used. Software SigVis collects and processes the data from the wireless receiver, visualizes them in real time and saves them (the applied force at the moment on time scale or in mode x-y together with pin displacement), until new measuring is launched in the interface. During measuring the software evaluates the basic properties. Dividing the work S by the depth of penetration L the mean force F_{AVG} (N) for pin penetration is calculated. This parameter is of key significance for practical assessment of the timber mechanical resistance. Other derived criteria (based on ratios of output quantities) were tested as well, however, these have not been found practicable.

The pin with several alternatives of shank and edge was tested separately using a special fixture on the testing device (Kloiber et al. 2009). To verify the proper function of the resulting new device, mainly regarding the variability of wood properties, and thus to verify the range of its usability for the estimation of properties of constructional timber used in trusses in the area of the Czech Republic, we carried out measurements on three basic types of softwood. As we wanted to take notice of the distribution of properties along the diameter and the trunk length, one entire trunk of each species was taken. Norway Spruce (*Picea abies* (L.) Karst.), Silver Fir (*Abies alba* Mill.) and Scots Pine (*Pinus sylvestris* L.) were chosen for tests. This selection corresponds to the most frequently used material composition of historic trusses in the Czech Republic. The sample trees were carefully chosen from only one closed stand in Zubří in area called Czech Canada, approximately at 15° E and 48° N at an altitude of 680 m a.s.l. The trees grew at a site with typical ecological conditions without negative anemo-orographic influences or a negative impact of the social position of the individual within the stand. The selected trees were individually felled down, trunks were sawed to 3 m logs and quarter-sawn so that each of their sides corresponded to their respective cardinal directions as the trunk grew (Fig. 5). The logs were then cut so that only a radial plank from their centre with a thickness of 60 mm was created (Fig. 6). A total of 24 planks for each species were used for measuring.

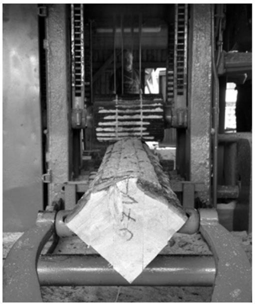

Fig. 5: Processing of quarter logs into radial planks of 60 mm.

Fig. 6: Storing of radial planks in the sawmill.

After slow drying of the radial planks and conditioning to moisture content of 12 %, the pin penetration test using the new device was conducted (Fig. 7). Pin pushing was carried out in purely radial direction, into a depth of 110 mm, every one meter of the plank length, from 1 m to 18 m of the trunk height, for each cardinal direction separately. In total, we had 72 positions for each species. To fix the device we used the alternative with a fabric strap, as can be seen in Fig. 8. The mean force was established at pushing in a velocity of about 10 mm.s^{-1}. At the spot adjacent to pin penetration the measurements via Pilodyn 6J Forest, resistance microdrill Resistograph 2450p and screw-withdrawal method, were also conducted to compare them with the new device results. During pin penetration, acoustic emissions in wood were measured also. Before these semi-destructive tests, also non-destructive measuring by acoustic methods (6 devices in total) was performed. Complex processing of the results will be object of further research because of enormous data content however, the first of the conclusions is that the output of the new method (the average force F_{AVG}) correlates significantly with the outputs of resistance methods.

To verify the proper function of the new device, we have used experiments based on comparison of quantities measured during pin pushing and destructive testing of standard specimens using universal testing machine Zwick Z050 with test control and result evaluation by software TestXpert v 11.02.

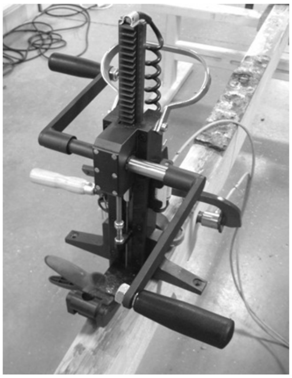

Fig. 7: Pin pushing with the new device.

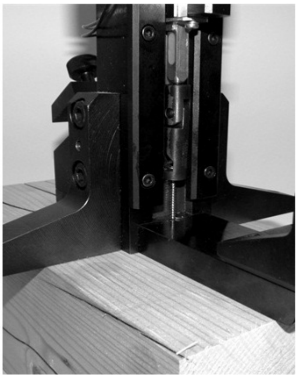

Fig. 8: Screw withdrawal.

The basic parameters included in analysis for device verification were: the height of the position in the trunk (Tree Height), wood density (Density), wood strength in compression parallel to the grain (MOR_L), proportional limit in the radial direction (PL_R), modulus of elasticity in compression parallel to the grain (MOE_L) and perpendicular to the grain (MOE_R) and also hardness according to Janka in longitudinal (H_L), radial (H_R) and tangential (H_T) directions. The tests were performed in compliance with standard European regulations using 20x20x30 mm (or 50x50x50 mm in the case of hardness tests) samples taken at the individual positions adjacent to the spots of pin pushing. The specimens were closely adjacent so that we could analyze the distribution of properties along trunk radius. The number of specimens depended on the width of the plank as this changed with the height adequate to the trunk diameter, usually 7 or 8 adjacent specimens for compression parallel to the grain and 2 to 3 adjacent specimens for radial compression. The data was further processed in the Statistica 9.0 software (survey analysis of data, verification of distribution normality, independence of elements of the selection, correlation analysis, linear and non-linear regression).

RESULTS AND DISCUSSION

Average force, hardness in radial direction, density and strength in compression parallel to the grain of the three wood species are presented in Fig. 9. The results of analyses prove significant difference between the species. In other words, the fact that during the usage of the device it is necessary to respect the tree species. Fig. 9 also shows that the values of the average force for pin pushing into pine wood are disproportionately lower. This phenomenon is caused by the inclusion of soft sapwood in the pin pushing, when nearly a half of the depth of pushing was conducted in the sapwood (by contrast, the average values of density, MOR_L and MOE_L have been established from a larger part of trunk radius containing heartwood). The relatively higher resistance of fir wood corresponds to more onerous workability of fir wood (especially when compared with workability of pine wood) and the ability to hold fixings better. This phenomenon corresponds with the ascertained higher friction during pin pushing and pin withdrawal and mainly with the results of screw withdrawal tests, in which the resistance of fir was about 15 % higher than resistance of pine sapwood (a more detailed analysis will be subject of future papers).

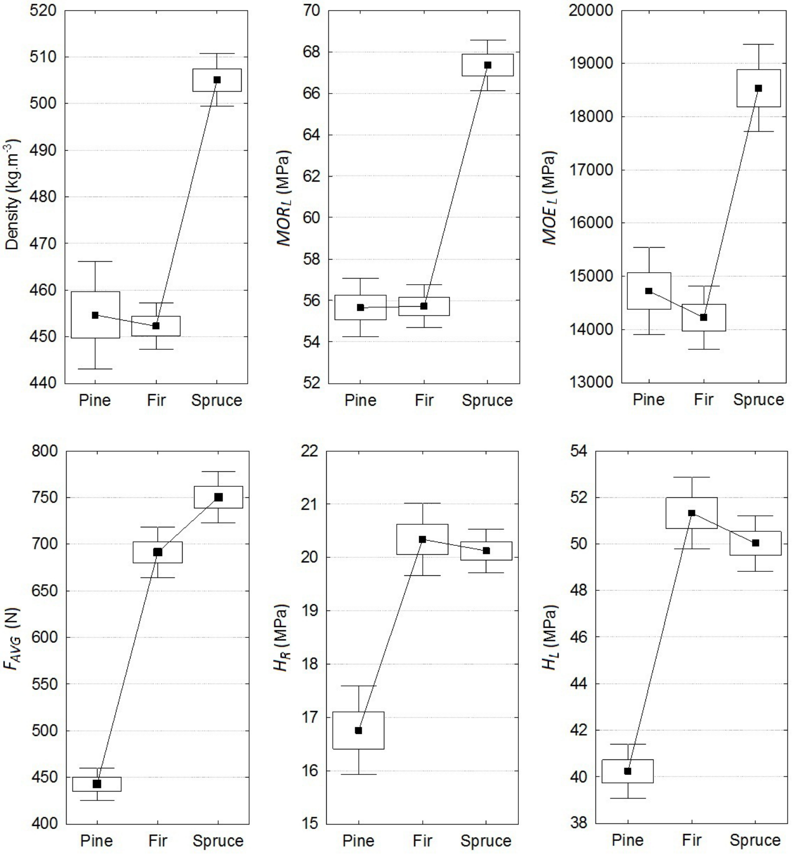

Fig. 9: Boxplots – data for average force (F_{AVG}), hardnesses (H_R, H_L), density (ρ) and compressive strength parallel to grain (MOR_L), modulus of elasticity parallel to grain (MOE_L).

The distribution of density and MOR_L along the trunk and according to cardinal directions is illustrated in Fig. 10 and Fig. 11. The differences of properties founded for individual sides of the trunk are not statistically significant (Duncan's test) and can be neglected. The distribution along the trunk height cannot be neglected, as will be discussed further. As the wood originated from a closed canopy stand, the influence of orientation is less probable and can be rejected. That has practical reasons because the original orientation of the tree in cardinal directions can hardly be established in incorporated timber.

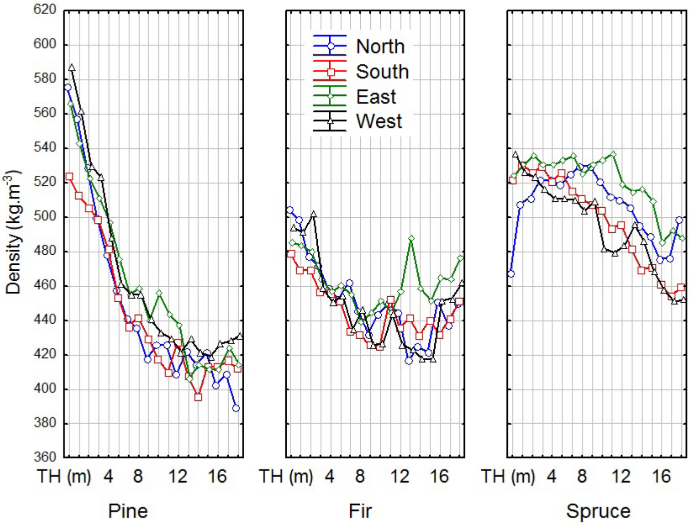

Fig. 10: Distribution of density along trunk and according to cardinal directions.

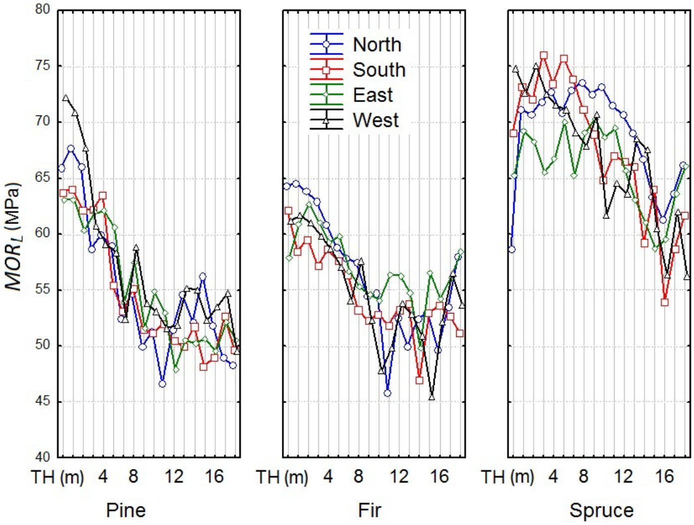

Fig. 11: Distribution of MOR_L along trunk and according to cardinal directions.

The radial distribution of properties is important for evaluation of two basic outputs measurement by the new device – the record of force and the calculated mean force. The continuous record of the force related to the pin displacement is able to describe the changes in properties along the depth of pin penetration – these changes can be caused by natural distribution of properties, as documented in Fig. 12 in comparison with Fig. 13. The x axis in Fig. 12 and Fig. 13 marks the position of the specimen with a cross section of 20 x 20 mm along the diameter. Position 1 thus corresponds to pin penetration depth 0–20 mm; position 2 corresponds to pin penetration depth 23–43 mm, position 3 - 46–66 mm, etc. (3 mm needs to be add to each position due to sawed out wood during processing. Comparing the trend of measured properties in Fig. 12 and the trend of force progress fitted through all graphs for specific timber exported from SigVis (Fig. 14), we find both the similarity in progress along the diameter and the differences between the three species. The device appropriately reveals the changes of wood properties during pin indentation and it is highly probable that it identifies wood defects very well; however, if the integral parameter – average force – is used, the significance of property distribution is then absorbed in that parameter. Due to the deep penetration of the pin into the trunk the probable effect of distribution along the trunk diameter on the average force is incorporated and can be neglected. Thus, when the average force is used to estimate wood average density or strength along the pin penetration depth, the cross distribution of properties can be neglected.

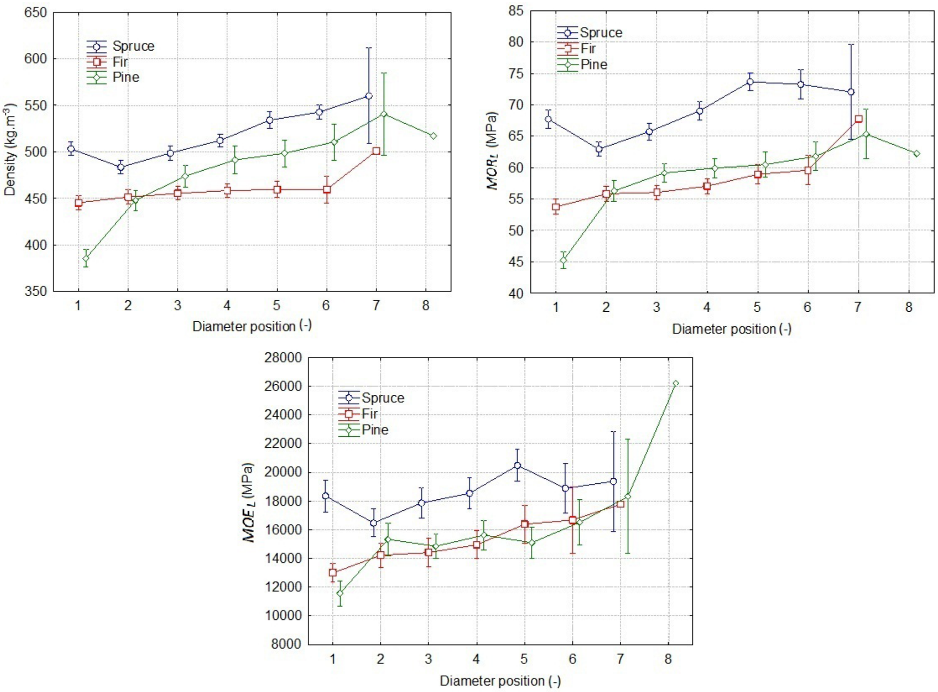

Fig. 12: Distribution of density, MOR$_L$, MOE$_L$ along trunk diameter for individual species (the positions along diameter correspond to positions of samples for the test by compression parallel to the grain).

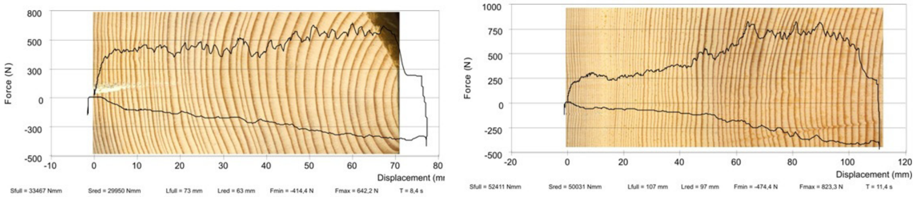

Fig. 13: Record of the progress of force and displacement for spruce wood and for pine wood.

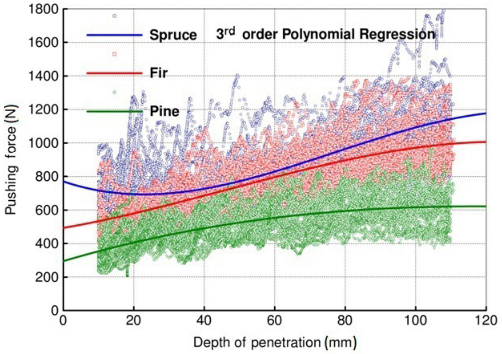

Fig. 14: Trends of force progress during pin pushing into individual species (polynom of 3^{rd} grade fitted through all graphs of wood measurement records).

The differences in properties along a trunk were statistically confirmed and they can be used to determine original vertical position of the measured specimen in the trunk. It is recommendable to respect the effect of the longitudinal distribution and to create alternatives which respect and neglect this effect.

Tab. 1 shows the correlations between the monitored parameters and the average force. Especially the relation with density and hardness can be considered strong for all species. The character of pin penetration is closest to the character of damage caused during hardness tests, which is proved by the closest dependence. The relations are weakened mainly by the variability of wood properties in the vicinity of knots; stronger relations found in pine are caused by its branching systems and thus the more frequent measuring in wood unaffected by presence of knots.

Tab. 1: Correlations between the indentation average force (F_{AVG}) and other estimated variables for three wood species. Bold marked correlations are significant at $p < 0.050$.

	Tree height	MOR_L	PL_R	MOE_L	MOE_R	**Density**	H_R	H_T	H_L
Spruce	-0.47	0.37	0.03	0.13	0.29	0.60	0.41	0.56	0.54
Fir	-0.37	0.41	0.07	0.11	0.10	0.65	0.58	0.52	0.40
Pine	-0.78	0.83	0.49	0.56	0.39	0.88	0.75	0.81	0.67

The correlation coefficients of all monitored properties (density, strength, hardness, moduli of elasticity) show existing relations; in most cases the Duncan's test confirmed a significant difference of properties along the trunk height. The correlation coefficient for the average force F_{AVG} and the height is -0.47 for spruce, -0.87 for pine, and -0.37 for fir. Fig. 15 is an example of a 3D model describing the dependence of spruce density on the measured average force (F_{AVG}) and the known height position (left) and the dependence of spruce strength on F_{AVG} and height. The other models are presented in Tab. 2.

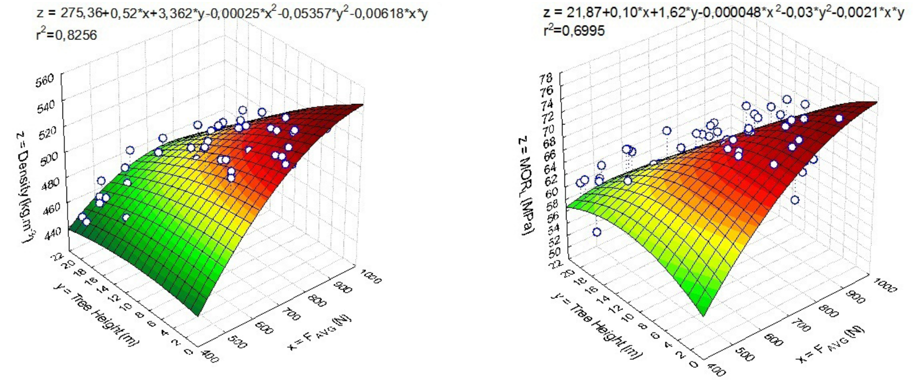

Fig. 15: – 3D models deriving density and strength from the average force and height position in the trunk.

Tab. 2: Non-linear 3D models deriving density or strength or hardness from the average force and height position in the trunk.

z = Density (kg.m^{-3}), x= F_{AVG} (N), y = Tree height (m)		
Spruce	$z=275.364+0.522305x+3.36196y-0.00025x^2-0.05357y^2-0.00618xy$	$R^2=0.8256$
Fir	$z=462.242+0,03533x-12.925y+0.0000126x^2+0.416954y^2+0.005628xy$	$R^2=0.8265$
Pine	$z=457.121+0,046248x-7.589y+0.000282x2+0.418984y^2-0.01451xy$	$R^2=0.9496$

z = MOR_L (kg.m^{-3}), x= F_{AVG} (N), y = Tree height (m)		
Spruce	$z=21.8785+0.101931x+1.6233y-0,000048x2-0.03134y^2-0.00214xy$	$R^2=0.6995$
Fir	$z=52.5924+0,047978x-3.1266y-0.000039x2+0.092857y^2+0.001288xy$	$R^2=0.6590$
Pine	$z=23.5623+0.12592x+0.245726y-0.00008x2+0.035746y^2-0.0036xy$	$R^2=0.8285$

z = H_R (MPa), x= F_{AVG} (N), y = Tree height (m)		
Spruce	$z=15.6498+0.004896x-0.13085y+0.0000041x2+0.016161y^2-0.00032xy$	$R^2=0.3180$
Fir	$z=-8.7916+0.06248x+0.607658y-0.000026x2+0.024124y^2-0.00161xy$	$R^2=0.4633$
Pine	$z=24.8364-0.03072x-0.5051y+0.0000519x2+0.025047y^2-0.00078xy$	$R^2=0.7061$

z = H_T (MPa), x= F_{AVG} (N), y = Tree height (m)		
Spruce	$z=-15.689+0.093921x+0.644164y-0.000053x2-0.00738y^2-0.001xy$	$R^2=0.6395$
Fir	$z=25.6859-0.00146x-1.5238y+0.00000238x2+0.042413y^2+0.000804xy$	$R^2=0.5305$
Pine	$z=6.34283+0.051376x-0.15882y-0.000026x2+0.022766y^2-0.00144xy$	$R^2=0.7732$

z = H_L (MPa), x= F_{AVG} (N), y = Tree height (m)		
Spruce	$z=15.1724+0.065007x+0.096497y-0.000023x2+0.00402y^2-0.00029xy$	$R^2=0.4863$
Fir	$z=110.272-0.1197x-4.8544y+0.000072x2+0.094192y^2+0.003839xy$	$R^2=0.4929$
Pine	$z=-38.726+0.252636x+3.19466y-0.00017x2-0.00865y^2-0.007xy$	$R^2=0.5248$

If the height position of measurement in the trunk is unknown or negligible, we can use the available relations deriving density and strength from the average force with significant precision. Relations between the average force and selected quantities were described more closely by means of linear regression, as is shown in Fig. 16. A summary of the models is shown in Tab. 3, where R^2 coefficients also confirm the closeness of dependences. In this case, also more complicated non-linear polynomial models were tested; however, their contribution to precision is not considerable.

Usually, a closer relationship was found for one species only (often for pine). For the estimation of hardness in all directions, the coefficients of determination indicate slightly close relations, which was more significant for hardness measured in the tangential direction. The relations are the weakest for the direction of pushing (radial). Although due to the character of wood damage the pin penetration test seems to be the closest to hardness test in the same direction, the damage during penetration is more complicated. Probably, the existence of lateral compression during pin penetration, small breaks of ring layers, etc., make the influence of other properties more pronounced.

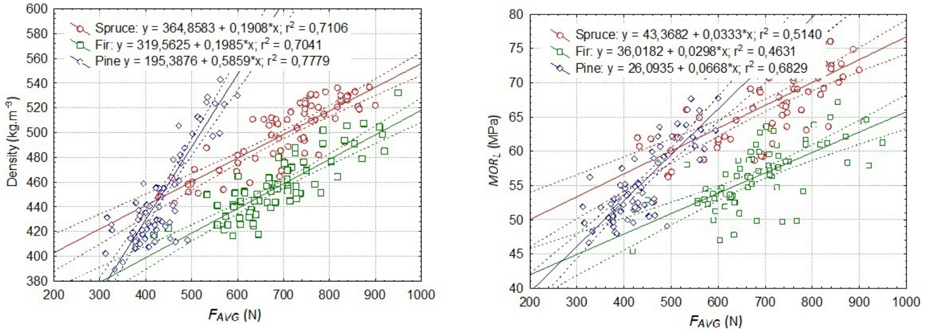

Fig. 16: Dependence of density and average force, dependence MOR_L parallel to the grain and average force.

Tab. 3: Linear 2D models deriving density or strength from the average force.

y = MOR_L (MPa), x= F_{AVG} (N)		
Spruce	y=43.3682+0.0333x	R^2=0.5140
Fir	y=36.0182+0.0298x	R^2=0.4631
Pine	y = 26.0935+0.0668x	R^2=0.6829

y = Density (kg.m^{-3}), x= F_{AVG} (N)		
Spruce	y=364.8583+0.1908x	R^2=0.7106
Fir	y=319.5625+0.1985x	R^2=0.7041
Pine	y=195.3876+0.5859x	R^2=0.7779

Regression equations, including coefficients of determination R^2, which serve for as a derivate of density or strength MOR_L (z) based on average force F_{AVG} (x) and height position in the trunk (y) are summarized in Tab. 2. R^2 values indicate strong up to very strong significance of dependences. No close relations were found for the longitudinal and radial modulus of elasticity as well as the proportional limit in the radial direction (R^2 always below 0.5). The explanation is predominantly the high variability of data caused by minor knots – for this reason, R^2 is always slightly higher for pine, where more pronounced knots and thus larger places without their influence are found.

CONCLUSIONS

The aim of this study was to test the new device on basic softwoods and in common variability of properties – that is why entire trunks were used. We can conclude that the device is usable for estimation of a wide range of properties of healthy wood of spruce, pine and fir. The research has also proved that the device is sufficiently sensitive to natural differences among species and to natural changes of properties (distribution along the diameter and length of trunk, defects). For this reason, it is now appropriate to make experiments with sets with a lower variability and a higher number of repetitions (e.g. healthy spruce wood with a narrower span of density values, etc.).

Based on measuring conducted at 72 positions, the relationships among quantities measured by the newly designed device and wood properties ascertained by standard tests were explored. Strong relations were mainly found among the average force F_{AVG}, wood density and wood strength. These were described more closely by practically usable simple models. The average force F_{AVG} more or less correlates with other monitored parameters of wood as well and the future experiments could identify and explain other practically usable relations. Moreover, the distribution of properties across the trunk was evaluated, which nicely corresponds to the continuous force record provided by the new method and which is at the same time negligible if an integral output – the average force – is used. The differences in wood properties in the various sides of trunk were not recorded and can thus be neglected for practical usage. By contrast, the distribution along the trunk is significant for the new method and its inclusion as another parameter of the models makes the estimate of wood density and strength more precise. The described differences in properties along the trunk diameter also prove that superficial properties, measured locally by means of current methods, cannot be extrapolated to the entire element, as was confirmed in previous research (Drdácký et al. 2006, Kotlínová 2008). The obtained knowledge should facilitate further research and development of new diagnostic resistance techniques, as the pin pushing and hardness establishment, which correlates with density, seems to be prospective for the future as well as little invasive (Kloiber et al. 2009). The described derivation of densities based on pin pushing can also be used for the derivation of the dynamic modulus of elasticity based on measuring of stress wave propagation velocity, in which wood density is a basic input parameter.

The diagnostic device for “in-situ” measuring of mechanical resistance against tool (pin) penetration is a very gentle semi-destructive method. It can be used for derivation of density and strength as well as other mechanical parameters of wood, up to a depth of 110 mm of constructional element profile. In comparison with the commonly used indentor method, this method provides information on a larger part of the explored element; the sufficient length of the pin and thus the depth to which it can be pushed into an object allow us to identify internal defects hidden in wood. The progress of pushing enables us to gain quantities gradually in the steps corresponding to the varying depth of pin penetration. Beside the resistance microdrilling method, which is different in principle, this is another semi-destructive method for direct assessment of wood mechanical resistance. The advantage of the solution is the universal character of the device; the affecting force can be measured both during pin pushing and screw withdrawal. Finally, the method was successfully tested during several “in-situ” surveys of historic wooden constructions (trusses and ceiling constructions). It was proved that thanks to the gradual recording of the pushing force the method is able to identify disintegrated timber and presence of natural defects which are invisible from outside. Also the estimate of wood density based on the average force needed for pushing conducted by regression relations was successful. On the basis of the above mentioned relations, the outputs of pin pushing can be successfully used to derive basic properties used for assessment of incorporated timber.

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