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# MODEL OF ROUND WOOD VOLUMES BASED ON TOP DIAMETER AND LENGTH OF LOGS

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*In the analysis of traditional and advanced methods for round wood volumes estimation some disadvantages of existing in Ukraine log rules have been specified. As a result, a new model of round timber volume estimation based on top diameter and length of logs has been developed.*

***Round wood, top diameter, length, form factor, volume, model.***

Over a prolonged historic time of forest mensuration theory and practice a variety of methods for round wood volumes estimation have been developed that are distinguished primarily on the principles of measurement. Provisionally, these principles can be divided into two groups: contact and non-contact. Among contact methods, geometrical methods of round wood measurement, including simple formula of mid-point cross-section (Huber's formula) and log rules based on top diameter and length of logs, received more practical application. However, these methods are highly labour-intensive and not suitable for automation of the measurement process. The determining factor in this case is the human factor that often leads to technical errors. More promising nowadays are contactless methods like optical, ultrasonic and photometric. They provide registration of reflected radiation from the object of measurement and computerised analysis of the results and, therefore, are characterized by high efficiency, objectivity and accuracy. The main disadvantages of modern electronic systems, especially in the difficult economic situation of Ukraine, are their high cost and need for more qualified personnel.

Modern electronic scanning systems improve significantly the technology of round wood measurement. They are among the elements of sawmill enterprises in

developed countries of Europe and are installed in harvester heads. Such systems offer the possibility for automated sorting and volume estimation of timbers right in the process of logging. Currently, there are two common types of electronic measuring systems: 2D-scanners, which provide measurements of diameters in two perpendicular directions, and 3D-scanners that create almost a full three-dimensional model of the timber.

The measurement of timbers by means of 2D-scanner is conducted simultaneously in two directions – vertical and horizontal or at 45-degree angle. The latter option is used for logs with elliptical form of cross-section, although the position of the sensor does not make a significant impact on the accuracy of volume estimation [7]. 3D-scanners allow making a much bigger number of measurements of diameters assortment at one point (16–36 measurements) with an error not exceeding ± 2 mm. According to K. Janak [6] volumes of round timbers estimated using electronic measurement systems are consistent with the Huber's formula results. At the same time three-dimensional scanning have no significant advantages over the two-dimensional one.

In the Belarusian State Technological Institute, a method for accurate estimation of actual size of assortments has been developed which allows considering their specific features in volume calculation [5]. This method is based on constructing geometric models of the round timber using spline functions. Volume is calculated by integrating the equation of log profile. The simulation results showed that the errors in volume determination of round timbers based only on a form of two cross-sections (top and bottom) do not exceed 1.5 %. In case of measuring parameters of 3–11 cross-sections by means of the above described electronic measuring systems, errors practically disappear (0.5 %). Application of such models is proposed for optimization of production sawn timber. In forest mensuration they have had so far only theoretical significance.

In forestry of Ukraine there are two log rules: State Standards 2708–75 [2] and 4020–2–2001 [3].

Coming into force of the State Standard 4020–2–2001, co-authored by scientists of the Department of Forest Mensuration and Forest Inventory at the National University of Life and Environmental Sciences of Ukraine, was prompted by the need for unification of measurement techniques of round wood in Ukraine and corresponding approaches abroad. In most countries Huber's formula is used for these purposes while in Ukraine most methods are based on top diameter and log length according to State Standard 2708–75.

Application of Huber's formula as a mathematical model in log rules of State Standard 4020–2–2001 not only removes above mentioned discrepancies in measurements, but also helps to take into account a taper of timbers during calculation of their volumes. It is believed that this factor leads to significant errors in round wood measurements according to log rules of State Standard 2708–75, which in some cases reach values of ± 30 % [1].

The current log rules of State Standard 2708–75 are based on unprecedented in terms of the amount of study material collected in the early 20$^{th}$ century under the supervision by A. Kriudener and converted into metric system by G. Turskiy [1]. Graph-analytical evaluation of volumes of spruce timbers led to unified log rules that were applied for all tree species 2–9 meters long. Log rules for timbers shorter than 2 meters were developed by M. Kosharnovskiy using elementary analytic extrapolation. Volume tables for logs longer than 9 meters are based on graphical extrapolation of data measurement of shorter timber. Besides, State Standard 2708–75 includes also volume tables for of timber from top part of tree stems. Taking into account technological complexity of detection to which part of stem a particular log belongs and the accuracy of such tables, their practical application is hardly recommended.

Thus, a significant methodological drawback of State Standard 2708–75 as well as its predecessor State Standard 2708–44 is the lack of a unified approach for modeling of volumes of round wood with different dimensions. In addition, detailed analysis of selected log rules allows us to identify following disadvantages. Common violation is principle of Krylov-Bradis concerning rules of approximate calculations

(significant digits i.e.). In some cases there are a lot of technical errors, for example, volume of logs which has length 1.8 m and diameter 6 cm is 10 times overestimated.

**Objective of the research –** analysis of log rules of State Standard 2708–75 and eliminating of typical for them technical as well as illogical errors that are likely to appear as a result of uncontrolled graphic and analytical mistakes.

**Materials, methods and results of the research**

Detailed analysis of log rules of the State Standard 2708–75 was carried out using well known [1] in the forest mensuration relative quotient named "form factor" of logs, which is the ratio between the volumes of round wood and cylinder whose parameters match the top diameter and length of timber. The results of this analysis showed the presence of bad methodological mistakes during development of this standard, including volume tables for logs which have length less than 2 m. So, for 0.5 m round timber form factors are less than one (Fig. 1), i.e. the volume of logs are less than volume of the cylinder or, in another words, the top diameters of the logs are bigger than bottom. In addition, the need to improve existing log rules can be proved by step nature of the change of form factors almost for all dimensions of logs.

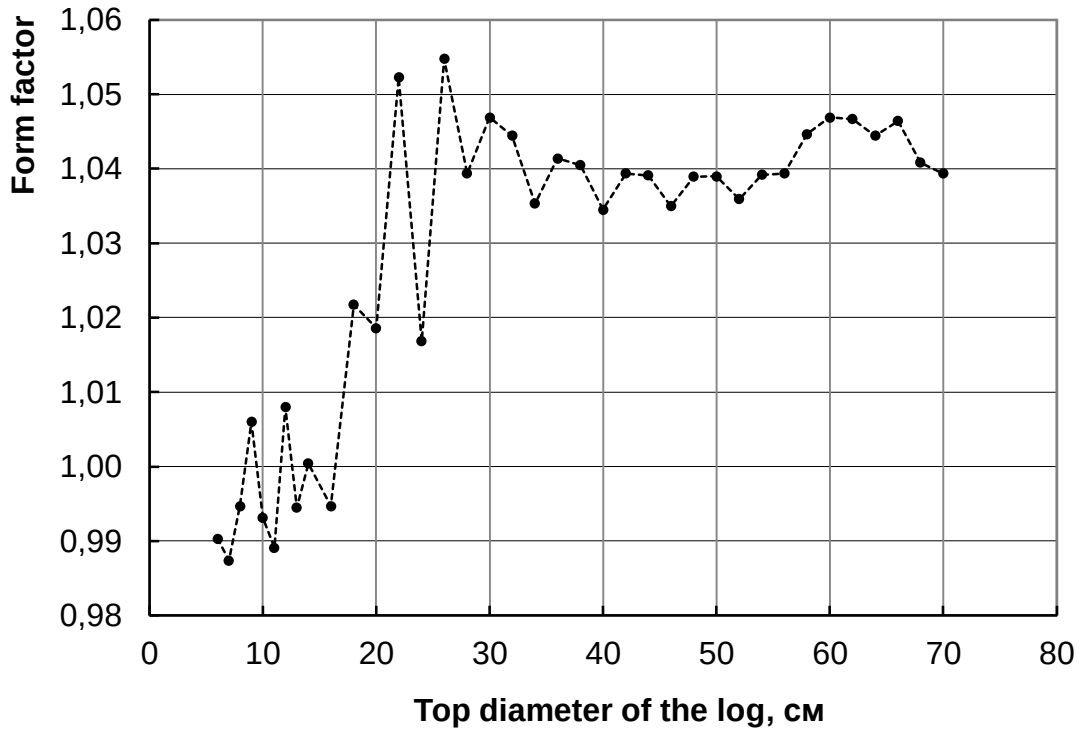


**Fig. 1. Form factors of logs with a length**

Based on the common in mathematical modeling principle that relative indices are not as variable as their absolute analogues, form factors of logs ($f$) were used for developing of the model of round wood volume. The mathematical model of this index based on length ($L$) and top diameter of logs ($d_в$) is as follows:

$$f = \begin{cases} 1{,}1535 - 0{,}57156 \cdot L / d_{вв} + 5{,}7730 \cdot L / d_{вв}^2 + 0{,}11870 \cdot L^2 / d_{вв} - \\ -0{,}50937 \cdot (L / d_{вв})^2 + 2{,}4701 \cdot 10^{-4} \cdot d_{вв} \cdot \ln L - 0{,}99443 / L / d_{вв}, & L \geq 2 \text{ м} \\ 1 + 0{,}5l \cdot \left(\sqrt{3 f_{L=2м} - 0{,}75} - 1{,}5\right) + 0{,}25l^2 \cdot \left(f_{L=2м} - \sqrt{3 f_{L=2м} - 0{,}75} + 0{,}5\right), & L < 2 \text{ м} \end{cases} \quad (1)$$

where $l$ – log length shorter than 2 meters, m;

$f_{L=2м}$ – form factor of logs with a length of 2 m.

Parameters of the mathematical model of logs which have length 2 m and more was established by regression analysis based on the standards of Tourskiy-Kosharnovskiy-Boyarskiy and eventually – State Standard 2708–75. Graphical form of this model is displayed on Fig. 2.

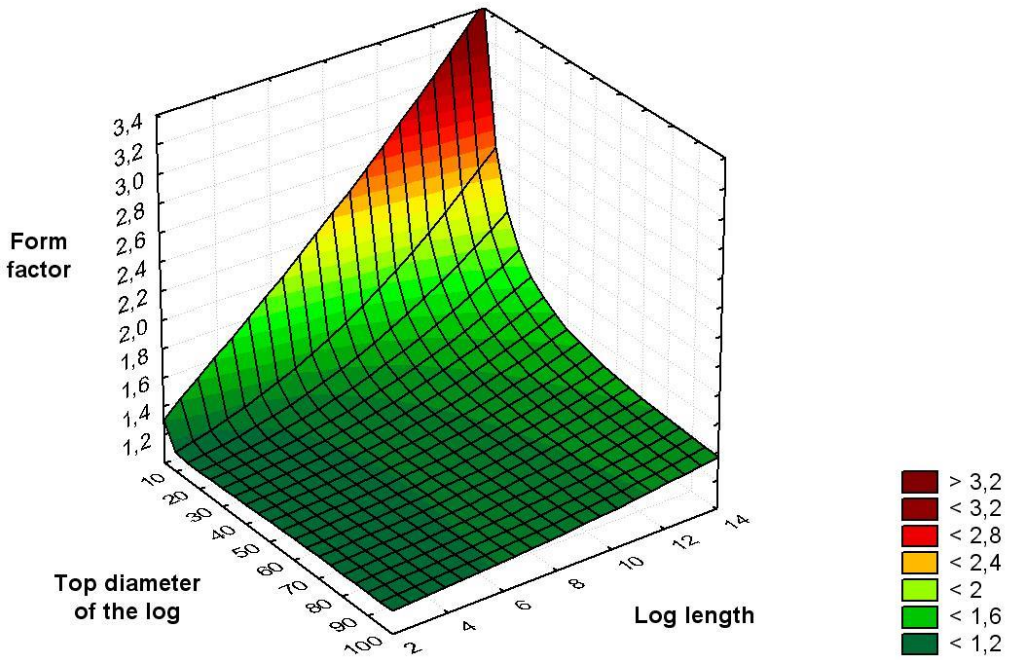


**Fig. 2. Dependence of form factors of logs on length and top diameter of round wood**

The model of form factors of logs shorter than 2 m was developed as follows. Let $F$ denote form factors found by regression analysis for log length of $L$ (in this case, two or more meters) and $f$ – form factor to be found for part of the same log

which has length *l* (Fig. 3). Considering the log as a truncated cone from definition of a form factor can be obtained:

$$F = \frac{\frac{\pi}{4} \cdot (D^2 + D \cdot d_{вв} + d_{вв}^2) \cdot \frac{L}{3}}{\frac{\pi}{4} \cdot d_{вв}^2 \cdot L} = \frac{D^2 + D \cdot d_{вв} + d_{вв}^2}{3d_{вв}^2}, \quad (2)$$

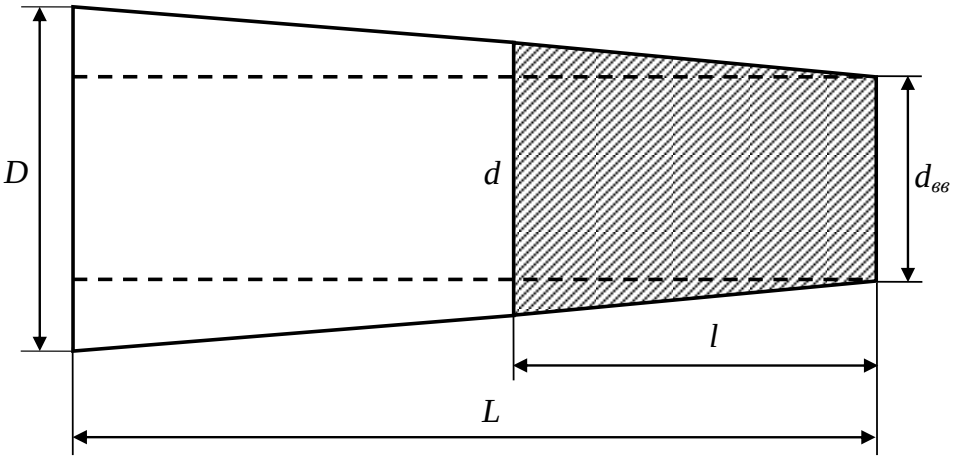


**Fig. 3. Scheme of log with required for calculation of their volume parameters**

After transformation of the formula (2) was obtained:

$$D = d_{вв} \cdot \left(\sqrt{3F - 0{,}75} - 0{,}5\right) \quad (3)$$

According to linear interpolation

$$d = d_{вв} + \frac{D - d_{вв}}{L} \cdot l = d_{вв} + \frac{d_{вв} \cdot \left(\sqrt{3F - 0{,}75} - 0{,}5\right) - d_{вв}}{L} \cdot l = d_{вв} \cdot \left(1 + \frac{\sqrt{3F - 0{,}75} - 1{,}5}{L} \cdot l\right) \quad (4)$$

Thus form factor of logs shorter than 2 m can be calculated using following expression:

$$f = \frac{d^2 + d \cdot d_{вв} + d_{вв}^2}{3d_{вв}^2} = 1 + \frac{l}{L} \cdot \left(\sqrt{3F - 0{,}75} - 1{,}5\right) + \left(\frac{l}{L}\right)^2 \cdot \left(F - \sqrt{3F - 0{,}75} + 0{,}5\right) \quad (5)$$

The final formula (5) takes the form:

$$f = 1 + 0{,}5l \cdot \left(\sqrt{3f_{L=2м} - 0{,}75} - 1{,}5\right) + 0{,}25l^2 \cdot \left(f_{L=2м} - \sqrt{3f_{L=2м} - 0{,}75} + 0{,}5\right) \quad (6)$$

Using the developed model of form factors of logs new log rules based on top diameter and length of round wood were constructed. These standards were approved by the State Agency of Forest Resources of Ukraine and published in new forest inventory book [4].

**Conclusions.** As a result of the research new standards for volume estimation of round timbers were developed and now they are recommended for practical use in forestry of Ukraine.

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