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Harmonization of piece-by-piece measurement methods in all stages of roundwood manufacturing processes

Ziedonis Miklašēvičs
Rēzeknes augstskola. Address:Atbrīvošanas aleja 90, Rēzekne, LV-4601, Latvia

Abstract. **In the sawmill industry in Latvia the roundwood represents about 70 % of the total production cost. The quantity measurements of the round wood are required throughout the logic chain of wood from forest to the sawmills but inspite of a large proportion of the total cost the term "true volume" of roundwood is equally actual for supplies and processors of wood. The roundwood volume results differ measured the same load by measuring the diameters of log in short intervals using harvester measurement systems and in sawmills by measuring the diameters of log in short intervals using electronic 3D systems or measured manually using the most accurate method according to the requirements of standard LVS 82:2003 by measuring top and butt diameter. This means that it is a great interest in industry to develop the measurement methods and systems to have a lower cost and more efficient algorithm to determine the wood volume.**

The purpose of this study is to compare the wood volume calculation results made by the most accurate manual and automatic measurement methods and give the recommendations for minimizing difference between them.

The research is a continuation to the work done in the project „Harmonisation of piece-by-piece measurement methods of roundwood approved by Standard LVS 82:2003 „Apaļo kokmateriālu uzmērīšana" (Miklasevics, Z., 2013).

Keywords: **roundwood; piece-by-piece measurement methods; volume.**

I INTRODUCTION

Measurement operations where wood is the subject of business are sensitive to accuracy. Different calculation methods are used in wood harvesting, sale, purchase and wood processing using manual or automatical measurements. According to technical possibilities of measurement equipment methods of wood volume calculation and approach to problems, more procedures have been proposed to determine the "true volume". Due to results in the determination of volume electronic procedures are not consistent with manual methods or with each other and their results do not correspondent to "true volume" of measured assortiments (Janak, K., 2005, Janak, K., 2007, Miklasevics, Z., 2013.)

The analyse of the measurement results obtained in Latvia sawmills where the most accurate piece-by-piece manual measurement method (2) (Fig.7.) based on the top and butt diameter measurements is being used, have shown that the volume values especially of spruce logs from neiloid zone usually are overestimated comparing to results obtained by measurement methods based on measuring diameter in short intervals using harvester measurement systems and by measuring diameter in short intervals using electronic 3D systems (Patterson, D.W.). It is explainable because of irregular form of roundwood, the volumes of logs are determined through simplified approach and the different algorithm of volume calculationare being used.

The main characteristics of each measurement method used in the investigation are sequential:

1. *according to the top and butt diameter measurements by standard LVS 82:2003 (2) (Fig.8.)* For calculating the log volume the neiloid-shape profile of the log assume to be a conus in zone among the top and 0.5 m from the butt. Butt zone 0-0.5 m of the log assume to be a cilinder. The algorithm of the volume *(3.2.) (Fig.7.)*calculation formula partly ignore the natural shape of the log. Therefore the volume values possibly are overerestimated.
2. *by measuring diameter in short intervals using harvester measurement systems.*

There are couple of different formulas for calculating the log volume by harvester bucking computer (Circular VMR 1-99). In Finland only cylinder formula is used in practice. Other possible volume calculation formulas are truncated cone, Nilson (Estonian), Huber and Smalian (Räsänen, T., 2007, Reg 918/66/97). The corresponding variables related to the investigation are defined below:

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DBH ($d_{1,3}$) - diameter at 1.3 m from felling cut (cm)

Spp-file - stem prediction parameters

StanFordstandard- Standard for Forestry Data and Communication

Ktr-file - harvester calibration and control measurement file. Sent from digital callipers to (on-board) merchandishing (bucking) computer, and from merchandishing computer to the office computer

Prd-file - production of the harvester (measurement certificate)

Pri-file - production-individual. Data of each log made from the site.

The volume calculation (V1) of the first 1.3 meter part (3.2.) (Fig.7.) of the butt log is calculated a bit differently from the other logs. Calculation based on extrapolated butt diameter. Diameter of butt end on butt logs (0.0-1.3 m) is estimated on the height of 1.3m from felling cut based on measured diameter DBH($d_{1,3}$). Calculation carried out based on either functions or tables (Černy, M., 1995., EN 1309-2. 2006., Wood,G.B. and Wiant, H.V. 1995). Volume of 0.0-1.3 m section (starting from butt-end of first log) is usually calculated in 1 to 10 cm steps. Diameters for those points are estimated as a function of DBH($d_{1,3}$) or actually diameter at 1.3 m distance from cutting point (Fig. 1.).Tables and functions give the extrapolation coefficient of a certain point as a result of measured diameter at DBH($d_{1,3}$) and distance (height) of the extrapolation point from the point of the felling cut.The measured diameter at reference height multiplied with the given coefficient will give the extrapolated diameter. Volume of butt end using these estimated diameters is to be done in the same way as the upper part of the log. Harvesters could use either tables or functions depending on their present method or processing capacity. The coefficients given in tables are based on specific taper curve and stump height models for pine, spruce and birtch separately and have been developed by Metsäteho ("Spp-file in StanForD" (Räsänen, 2007.)). In Finland it is a legal requirement to use the function. In Latvia it is possible to use the function in all major harvester systems but it depends on the market whether it is activated in harvester and computer caliper although it is known that there might be some deviations in the stem profiles for certain areas.

Distance from felling cut, m

$d_{1,3}$, cm	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1	1,1	1,2	1,3
8	1386	1302	1241	1197	1164	1138	1116	1098	1081	1064	1048	1032	1016	1000
9	1381	1297	1237	1192	1159	1133	1112	1094	1077	1061	1046	1031	1015	1000
10	1375	1293	1233	1188	1155	1129	1108	1090	1074	1059	1044	1029	1015	1000
11	1370	1289	1229	1184	1151	1125	1104	1087	1071	1056	1042	1028	1014	1000
12	1364	1285	1225	1181	1147	1121	1101	1084	1068	1054	1040	1027	1013	1000
13	1358	1281	1222	1178	1144	1119	1098	1081	1066	1052	1039	1026	1013	1000
14	1353	1277	1219	1175	1142	1116	1095	1078	1064	1050	1037	1025	1012	1000
15	1347	1273	1216	1173	1140	1114	1093	1076	1062	1049	1036	1024	1012	1000
16	1342	1270	1214	1171	1138	1112	1091	1075	1060	1047	1035	1023	1012	1000
17	1337	1267	1212	1169	1136	1110	1090	1073	1059	1046	1034	1023	1011	1000
18	1332	1264	1210	1168	1135	1109	1089	1072	1057	1045	1033	1022	1011	1000
19	1327	1261	1208	1167	1134	1108	1088	1071	1056	1044	1032	1021	1011	1000
20	1323	1259	1207	1166	1133	1107	1087	1070	1056	1043	1032	1021	1010	1000
21	1319	1256	1206	1165	1133	1107	1086	1069	1055	1043	1031	1021	1010	1000

Fig. 1. The example of extrapolation coefficient table for pine using 130 cm as reference height (coefficients for butt end profile, %) (Räsänen, T., Poikela, A., Arlinger, J. 2007.)

The analyse of the measurement results obtained in Latvia sawmills where measurement methods are based on measuring diameter in short intervals using electronic 3D systems have shown that especially neiloid-shape profile of the logs butt end is not predicted well enough by using harvester measuring systems. The main reasons which cause these differences in harvester measurement systems are sequent.

Different calculation methods are used in harvesters for extrapolating butt end diameter values from the first measured values:

1. Different harvester head models start diameter measuring at different heights.
2. Falsely extrapolated diameter values lead to incorrect volumes of the butt end.
3. Incorrect volume values are the sequence of incorrectly estimated volumes of the butt end diameter.

Harvester measurerement system algorithm used in investigation based on functions defined in Spp file (Räsänen, 2007.).

3. by measuring diameter in short intervals using electronic 3D systems (3.1.) (Fig.8.).

There are no legislative norm that would determine the requirements for methods of processing the measured data and methods of calculating the logs volume in Latvia sawmills. The algorithm of the volume calculation using 3D scanner Mikropuu Oy (FIN) by measuring diameter in short intervals is given (3.1.) (Fig.8.).

according to the top and butt diameter measurements by model of volume calculation developed for Swedish roundwood systems (3.1.) (Fig.8.) (Anon 2000).

In Sweden as the most accurate piece-by-piece measurement method based on the algorithm model of the formula were developed for roundwood of Scots pine (Pinus silvestris) and Norway spruce (Picea abies) (Anon 2000). The formula were obtained from 10 751 logs from middle and southern Sweden measured in sections and at the small (10 cm from top) and large end (50 cm from large end for butt logs and 10 cm from large end for other logs).

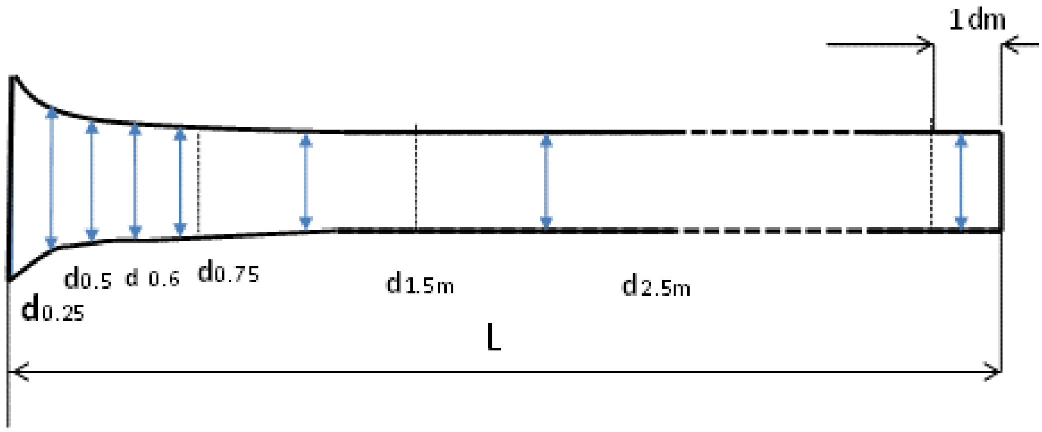

Fig.2. Control measuring points for developing of the volume calculation algorithm

The data needed for developing the volume calculation algorithm was prepared according to the measurement scheme (Fig.2.). The first diameter measurement taken at 25 cm from the log butt means that the most but not all buttress volume is included in the volume.

The calculation algorithm bases on „α" constant which redistributes the weight of those two diameters so that the small end diameter gets a larger influence on the diameter that represents the log in the formula. According to investigations made in Sweden (Anon 2000, Nylinder, M., 2010) predict the volume of roundwood obtained by measuring sections by using the small and large end diameter and lenght of the log will give more accurate volume results comparing to other manual measuring methods. The algorithm of the volume calculation formula is based on the natural shape of the log. Therefore measurement method is being chosen as the reference formula in this investigation.

The purpose of this study is to assess the wood volume calculation results made by the proposed manual, harvester and electronic measurement:

1. according to the top and butt diameter measurements by model of volume calculation developed for Swedish roundwood (Anon 2000),
2. according to the top and butt diameter measurements (LVS 82:2003),
3. by measuring diameter in short intervals using harvester measurement systems,
4. by measuring diameter in short intervals using electronic 3D systems and by analyzing the reasons of difference of the results to find and to prove that the industrial implementation of the most appropriate manual measurement method which provide the least roundwood volume deviation comparing to the results given by harvester and electronic measurement is feasible.

II MATERIALS AND METHODS

The study was carried out in March 2014 in the region Kurzeme in Latvia. Large buttress of the first log of the stem causes the wide dispersions of the measurement results. The wood felling area (Fig. 3.) was chosen (As)-Myrtillosa mel.*(Woodlands on drained mineral)* because of the shape of spruce stems with large buttress. The wood falling time was chosen because of the minimal risk of debarking in the process of harvesting.

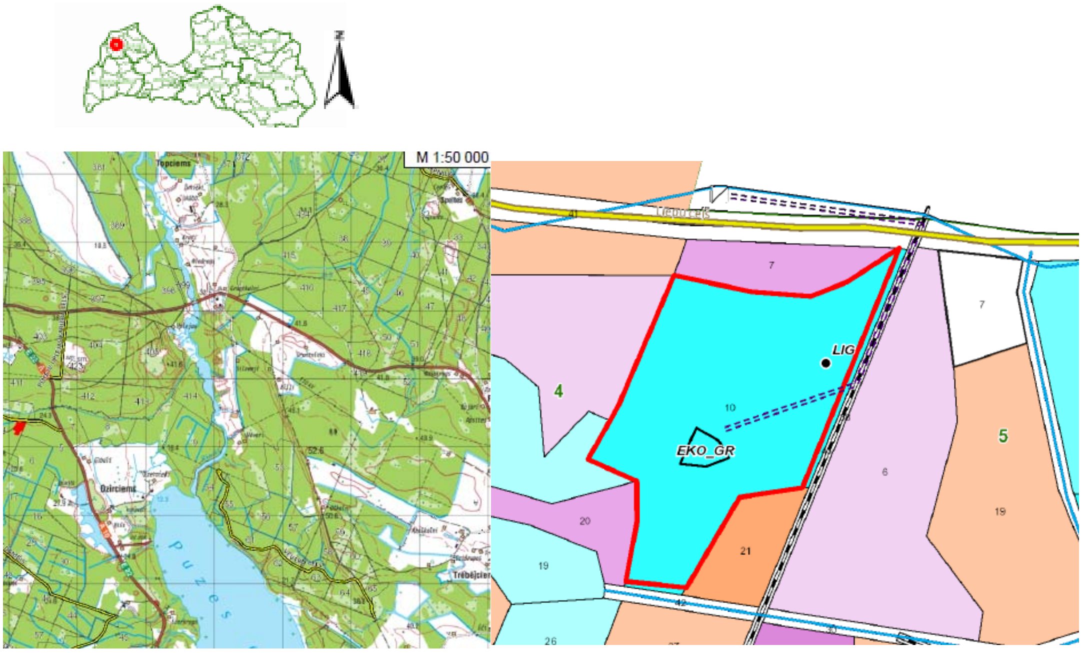

Fig. 3. Wood felling area and the technological scheme of harvesting

The typical shape of spruce stem in wood felling area is shown (Fig.4.)

After harvesting each log was manually measured with a caliper and a ruler for its diameter and lenght. The sequent log parameters were measured: D butt. max. sob. (mm); D butt. average sob. (mm); D 0.5 sob. (mm); D1.0 sob. (mm); D top. sob. (mm); butt swelling (cm/m); taper (mm). All logs were numbered to facilate the identification. After this measurement all 55 logs were measured once more to determinē the accuracy and repeatability of the manual measurement. This action was made by other scaller. The diameters were measured on bark but the volumes of roundwood assortiments measured on bark were estimated without bark by using the formula (1) (Fig.9.).

For spruce roundwood assortiments the double bark thickness at the point of measuring were determined:

$$B=3{,}08+0{,}0404xD \qquad (1)$$

where: D – diameter of roundwood assortiment, mm.

The following procedures were used to achieve the required objective:

1. To control the measurement accuracy of manual, automatic measuring (caliper, girthing tape to measure circumference, log measuring ruler, automatic device etc.)according to requirements of standard LVS 82:2003, to requirements of model of volume calculation developed for Swedish roundwood (Anon 2000) and technical requirements for automatic and harvester measuring systems (Ktr-file).

Fig. 4. The typical shape of spruce stem in wood felling area (As)-Myrtillosa mel.

2. To identify the spruce stems before harvesting and to measure the parameters of identified stems according to scheme (Fig. 5.)
3. To identify the first logs after harvesting and to measure the dimension parameters according to the scheme (Fig. 5.)
4. To collect and to analyse the harvester mesurement Prd- file and Pri-file data in connection with manually measured parameters of logs.

5. To measure the identified logs in sawmill by measuring diameter in short intervals using electronic 3D systems.
6. To calculate the volume of logs according to the top and butt diameter measurements methods according to requirements of standard LVS 82:2003 and by model of volume calculation developed for Swedish roundwood (Anon 2000) (Fig.5.)
7. To analyse the measurement deviations.
8. To control the algorithm of the volume calculation in each technological stage of roundwood processing.
9. To determine the dependences between the volume of logs determined by automatic devices and results of manual comparative measurement methods.
10. To give the recommendations for the most appropriate manual measurement method which provide the least wood volume deviation comparing to the results given by harvester and electronic measurement.

All calibrated measuring devices ensured measuring accuracy appropriate to requirements of standard LVS 82:2003 and the technical requirements for automatical and harvester measuring systems (Fig.6.; Table 1.).The length was determined with an accuracy 1cm for manual and automatical measurement devices and 3 cm for harvester measuring devices; the diameter was determined with an accuracy 1 mm for manual and automatical measurement devices and 3 mm for harvester measuring devices.

Harvester measurement accuracy were assessed through comparison with manual log measurements and volume calculation where volume standard deviation was 0.06% (Fig.6.)

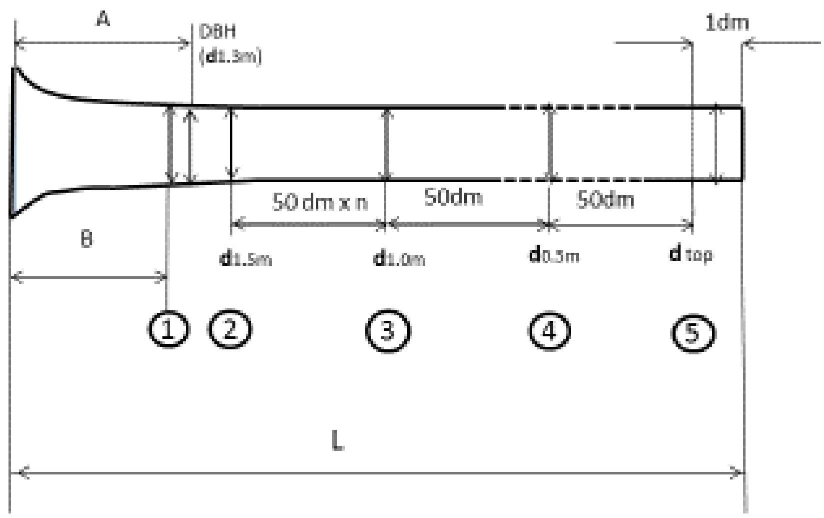

Fig.5. The scheme of the measuring points of the roundwood assortiment based on manual control (operator) measurements with caliper, where: A - the first measuring point DBH ($_{d1.3m}$) done by harvester measuring system for butt diameter prediction (A=130 dm), B - the first manual measuring point to control the harvester accuracy for the first log of stem : John Deer (B=120dm); Ponse (B=50 or 120dm); TimberJack (B=120dm)

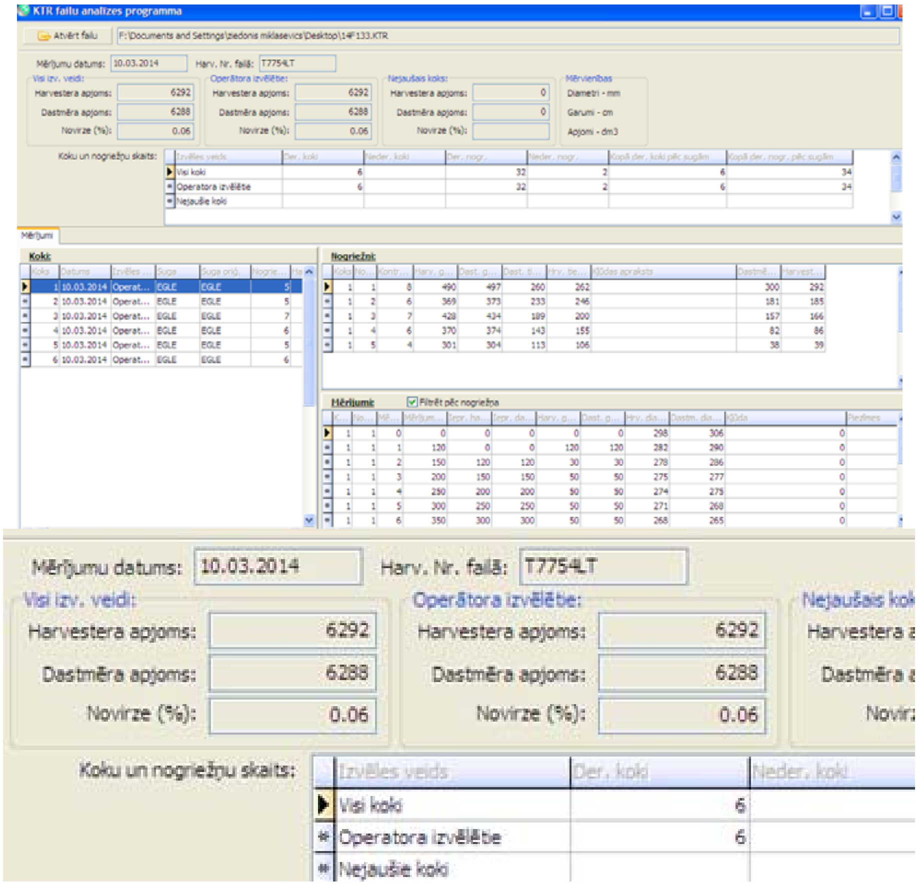

Fig.6. The result of control of harvester measuring system,where 6 control stems, 34 round wood assortiments, 96 diameter were measured. Standard deviation is 0.06%

For volume estimation the sequent measuring methods were applied (Fig. 8) by using manual measuring equipment, harvester measuring system (harvester John Deer 1270; harvester head HD 758; measuring equipment TimbermaticH 300; caliper version: SKALMAN 5.16) and automatical measuring system (3D scanner Mikropuu Oy (FIN) OPMES 604/614

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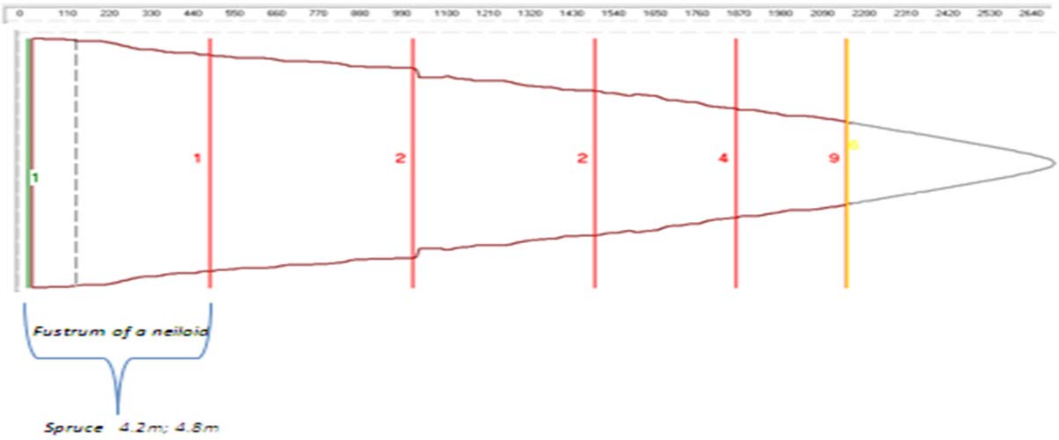


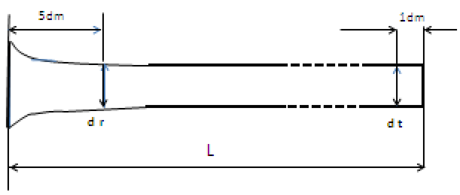
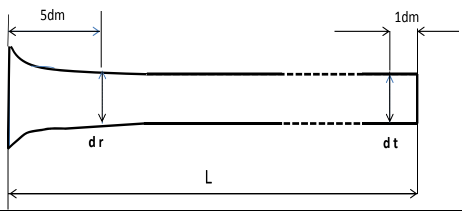
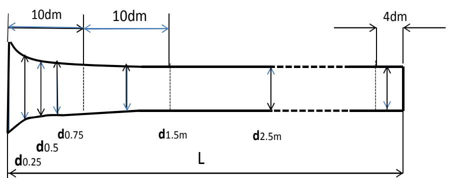
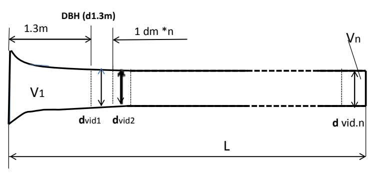
<table>
<tr><th>Method</th><th>Determination of the Volume</th><th>The formula</th><th>Measurement method for logs from neiloid zone of stem</th></tr>
<tr><td>1</td><td>According to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon 2000)</td><td>$$v = \frac{1}{100000} \times \frac{\pi}{4} \times l \times \left[\alpha \times Dr^2 + (1-\alpha) \times Dt^2\right]$$
For the constant α in the formula, the values presented in the following table should be applied:
<table><tr><td rowspan="2">Top diameter (cm)</td><td colspan="3">Length class (cm)</td></tr><tr><td>-349</td><td>350-449</td><td>450+</td></tr><tr><td>-14</td><td>0.485</td><td>0.485</td><td>0.485</td></tr><tr><td>15-24</td><td>0.465</td><td>0.460</td><td>0.455</td></tr><tr><td>25-</td><td>0.440</td><td>0.430</td><td>0.420</td></tr></table></td><td></td></tr>
<tr><td>2</td><td>According to the Top and Butt Diameter Measurements by LVS 82:2003</td><td>$$V_{tr} = \frac{\pi \times (d_t^2 + d_r^2) \times l}{4 \times 2 \times 10000}$$</td><td></td></tr>
<tr><td>3.1.</td><td>By Measuring Diameter in Short Intervals using electronic 3D systems</td><td>$$V_s = \frac{\pi \times (d_t \times d_t + d_t \times d_r + d_r \times d_r) \times l}{120000}$$</td><td></td></tr>
<tr><td>3.2.</td><td>By Measuring Diameter in Short Intervals using harvester measurement systems</td><td>$$V = V1 + \left(\frac{\pi \times d_{v1}^2 \times 1}{4 \times 10000}\right) + \left(\frac{\pi \times d_{v2}^2 \times 1}{4 \times 10000}\right) + Vn$$</td><td></td></tr>
</table>

Fig.7. Measuring methods applied in investigation for roundwood assortiments from neiloid zone of stem, where L=4.2m; 4.8m

TABLE 1

The control results of the 3D scanner Mikropuu Oy (FIN) OPMES 604/614

Etalon Nr.	**51011630**	**51011730**	**51011830**	
Etalon diameter, mm	110,3	200,7	315,5	
Average, mm	0.6	-0.5	-0.8	Accepted, mm
Standard deviation, mm	0.1	0.18	0.21	±1
Maximal positive, mm	1.0	-0.3	-0.5	+2
Maximal negative, mm	0.2	-0.8	-1.3	-2

III RESULTS AND DISCUSSION

The characteristics of the roundwood assortiments according to the manual piece-by-piece measurement are given in the Table 2.

The volume values of spruce roundwood assortiments from neiloid zone of stems were calculated according to the measuring methods applied in investigation for logs from neiloid zone of stem (Fig. 7.) by using manual measuring equipment, harvester measuring system (harvester T1386LH; measuring equipment TimbermaticH 1.13.14.; caliper version: SKALMAN 5.16) and automatical measuring system (3D scanner SAWCO POS A181). The results were compared with the volume values calculated according to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon 2000). The measurement and volume results are given (Fig. 9; 10; 11).

TABLE 2

The characteristics of the roundwood assortiments

Variable	**Parameters**
Number of roundwood assortiments	55
Amount of butt assortiments (%)	100
Top diameter (mm)	
Average	235
Std	2
Butt diameter (mm)	
Average	337
Std	3
D 1.0 (mm)	
Average	279
Std	2
D 0.5 (mm)	
Average	262
Std	4
Butt swelling (cm/m)	
Average	7
Std	0.1
Taper (cm/m)	
Average	0.7
Std	0.03

Fig. 8. The example of control of the harveaster measuring system, where:
the log Nº 3 participated one of the 34 round wood assortiments used in the process of control of harvester measuring system

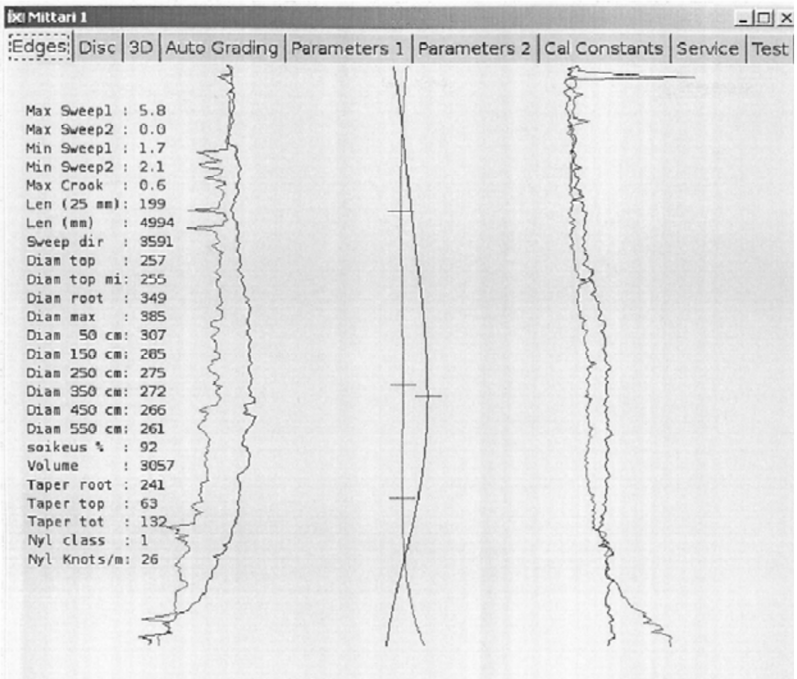


Fig.9. The measurement parameters of the sample Nº 3 (Fig.8.) by measuring diameter in short intervals using electronic 3D systems

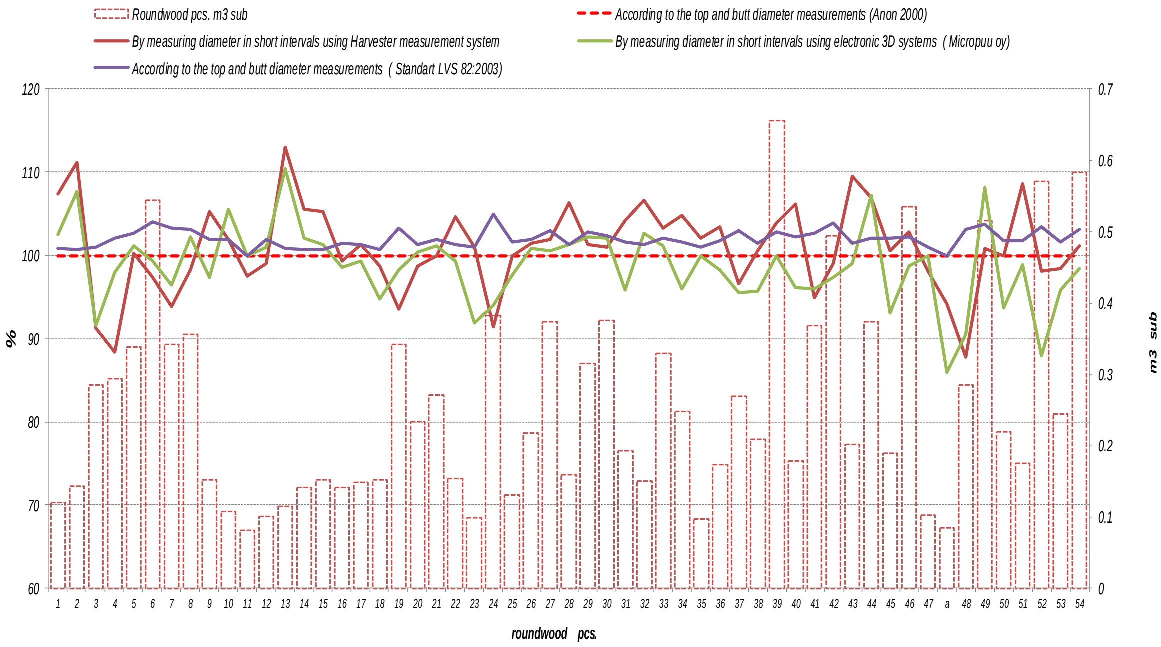


Fig.10 The volume results of spruce roundwood assortiments from neiloid zone of stems estimated according to measuring methods applied in investigation

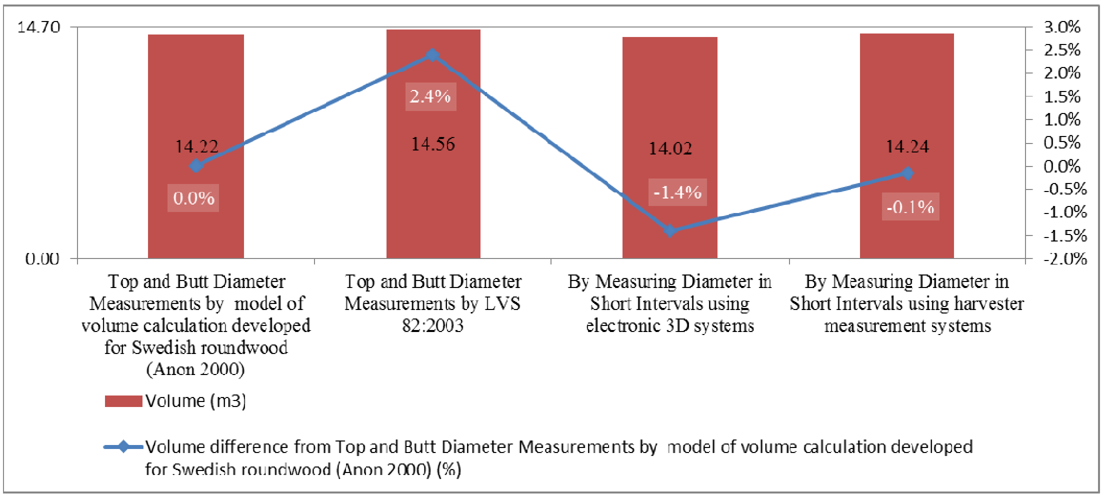


Fig.11. Roundwood load volume comparison using different measuring methods

a. The results of measuring are sequential:

The volume of roundwood assortiments determined according to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon) was 2.4% lower than the volume determined by the Top and Butt Diameter Measurement method (LVS 82:2003).

The volume of roundwood assortiments determined according to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon) was 1.4% lower than the volume determined by Measuring Diameter in Short Intervals using electronic 3D systems.

The volume of roundwood assortiments determined according to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon) was 0.1% lower than the volume determined by Measuring Diameter in Short Intervals using harvester measurement systems.

b. The results of of multiple regression analyse are sequential:

The results of multiple regression analyse between measurement diference (%)measured manually (according to requirements of standard LVS 82:2003 and to requirements of model of volume calculation developed for Swedish roundwood (Anon 2000)), butt swelling (cm/m) and taper (cm/m) are given in the Table 3.

TABLE 3

Multiple regression analyse

	Butt swelling (cm/m)	Measurement difference (%)	Taper (cm/m)
Butt swelling (cm/m)	1		
Measurement difference (%)	0.597656954	1	
Taper (cm/m)	0.349620121	0.565747656	1

The correlation between measurement difference (%)measured manually (according to requirements of standard LVS 82:2003 and to requirements of model of volume calculation developed for Swedish roundwood (Anon 2000)) and butt swelling (cm/m) is an average firm r=0.597656954.

The correlation between measurement difference (%)measured manually (according to requirements of standard LVS 82:2003 and to requirements of model of volume calculation developed for Swedish roundwood (Anon 2000)) and taper (cm/m) is an average firm r=0.565747656.

The correlation between butt swelling (cm/m) and taper (cm/m) is weak r=0.349620121.

The correlation between measurement diference (%) and taper (cm/m) is an average firm r=0.565747656. Standard error of the regression coefficient r=0.565747656 is s_r=0.1132

The actual value of the test t=4.9948; the critical value of the test $t_{\alpha v}=t_{0.05;53}$ indicating the number of degrees of freedom to characterize the distribution. The formula result is (-)1.67412. It shows that with a 95% confidence the multicollinearity is existing between features because of /t/=4.9948>$t_{0.05;53}$=(-)1.6741.

The correlation between measurement diference (%) and butt swelling (cm/m) is an average firm r=0.597656954. Standard error of the regression coefficient r=0.597656954 is s_r=0.1101. It shows that with a 95% confidence the multicollinearity is existing between features because of

/t/=5.4268> $t_{0.05;53}$ = (-)1.6741.

IV CONSLUSION

To increase the accuracy of volume values, to decline the commercial profability and to remove diferences originating among particular procedures of measurements it is proposed:

to base manual measuring on determination of the volume of spruce roundwood assortiments from neiloid zone of stem according to to the top and butt diameter measurement method according to requirements of volume calculation developed for Swedish roundwood (Anon 2000), to base harvester measuring system algorithm on functions defined in spp file (Räsänen, 2007.), in sawmils to determine the volume by measuring diameter in short intervāls using electronic 3D systems.

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