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HARVESTER MEASURING SYSTEM FOR TRUNK VOLUME DETERMINATION: COMPARISON WITH THE REAL TRUNK VOLUME AND APPLICABILITY IN THE FOREST INDUSTRY

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Abstract: *In Germany, the determination of log volumes for commercial transactions are performed in accordance with established German legal requirements by the manual measurement method (callipers) and by the use of opto-electronic systems. In the timber industry, log volumes determined by the harvester measuring system are not considered to be reliable. In this investigation, the manual measuring method and the harvester measuring system were compared with the real (reference) trunk volume determined using the water immersion technique based on the well-known Archimedes principle (water displacement method). Results show that the volume determined using the harvester measuring system was on the average -0.45% compared to the water immersion technique. Interestingly, the difference between the recommended rules of the raw timber trade framework agreement (RVR) using Huber's formula and the water immersion technique was -7.53%.*

Key words: *harvester technology, harvester measuring system, water immersion technique, manual (calliper) method, principle of Archimedes.*

1. Introduction

There are many different ways of single-log measurement of round timber in the forest industry. In German forestry, only opto-electronic measuring devices installed at the infeed of sawmills are currently valid for commercial transactions. The measurement technology incorporated in harvester measuring systems is only used to provide reference dimensions. While this technology is quite advanced, it is not considered to be trustworthy in Germany and other European countries such as, for example, the Czech Republic [3]. In particular, legal requirements do not allow

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harvester measuring systems to be used for billing purposes. This state of affairs is the underlying motivation of this paper: to investigate harvester-processed timber and compare the "real" trunk volume with values obtained by other measuring methods used in forestry. In fact, harvester technology itself provides quite a few log dimensions, like log diameter or log volume at the very beginning of the forest logistic chain, which can be suitable for all subsequent processing steps. Several projects such as, for example, the NAVKE-project [4], aimed to determine the accuracy of harvesting units. The reasons for these investigations are in the continuous discussion of harvester measuring accuracy and the question of calibration (conformity).

A measuring system used in commercial trading to determine log volume has to successfully comply with the conformity or type approval process. The legal basis in Germany, with effect from 1 January 2015, is the measuring and calibration law [7] and the measuring and calibration ordinance [8]. One legal issue hindering the approval of harvester measuring systems is the fact, that such systems are not "closed"; they allow interventions, such as the readjustment of measuring components (type of wood or environmental conditions). While such readjustment is essential in order to adapt the measuring system to changing conditions, legal requirements stipulate that to prevent tampering, any kind of intervention in a measuring system for commercial trade is prohibited.

At present, there is a general agreement between the sectors involved in Germany (forestry and timber industry) for raw wood trade [9]. In addition, a framework agreement is available for the wood processing industry [6]. However, for harvester measuring systems, the stakeholders have not yet been able to agree on binding rules. One document [2] ("Lastenheft Harvestervermessung") describes the basic requirements applied to a harvester measuring system. These requirements, with regard to measuring accuracy, are based on the error limits of wood processing systems [6].

In the past, electronic devices installed at the infeed of saw mills, were investigated with the aim of establishing the accuracy of volume measurement during the measurement of wood sections. Thomas and Bennett [1] as well as Staudenmaier [5] studied the accuracy of determining log volumes of saw logs by using high-resolution laser scan data. Thomas and Bennett [1] compared the log volume estimates using Smalian's and Huber's formulas to the log volume from scan data. Volumes, determined using Huber's formula were found to be closer to the observed scan volumes [1]. In addition, Staudenmaier [5] compared the relative volume differences of existing and potentially possible measuring methods with the reference of laser scan data. In both cases, the reference volume was determined by the laser log scanning system, which is not completely accurate.

Dvorak [3] carried out a comparison of harvester measuring system with the "Recommended Rules for the Measurement and Grading of Timber in the Czech Republic". These rules are comparable to the German raw timber trade framework agreement (Rahmenvereinbarung für den Rohholzhandel - RVR) [9]. For example, the volume calculation of a log is defined on the basis of the mid-diameter of the given assortment and nominal log length (e.q. Huber's formula). At the same time, the real trunk geometry is simplified to a cylinder model. A study on volume measurement accuracy of harvester measuring system, in which data from the harvester is compared to real volume, has not yet been carried out.

Before discussing any legal issues pertaining to harvester measurements, it is essential to first establish the accuracy of the harvester measurement system as well as the manual-method using callipers for determining the trunk volume.

2. Objectives of Investigation

The focus of this study is to provide a reference (real) trunk volume obtained by the highly accurate though cumbersome water immersion technique based on the Archimedes Principle. Then, to compare this value with the volume outputs obtained from the harvester measuring system and the manual measurement method using callipers. The questions addressed in this study are:

- What volume differences occur between the volume measured directly by the harvester and the volume measured by the water immersion technique?
- What is the volume difference between the volume determined manually and calculated by Huber's formula and the volume determined by the water immersion method?
- How do volume differences vary due to changes in roller pressure?

3. Material and Methods

The experimental measurements were carried out in the Harz region in northern Germany over a period of several days in April 2016. Timber harvesting was performed using a Ponsse Ergo 8W harvester equipped with a Ponsse H6 unit and Ponsse Opti Win 4.710 measuring system. Detailed technical specifications can be found in Ref [10]. Spruce was used as the sole material of examination for this study. The sample size consisted of 282 logs. The 41 trees were classified in 5m, 3m and 2,4m logs. The 5m- logs were passed through the complete measuring sequence once again after debarking. In this manner, the accuracy of bark thickness, listed in published tables, could be assessed. The concept of this study is that the machine harvested and then measured the logs. Moreover, an electronically self-sufficient parallel measuring system captures the sensor raw data at the harvester head. Furthermore, the roller pressure is adjusted in defined-steps. Normally, while reprocessing, the correct roller pressure is regulated either manually or automatically by the operator. Since this parameter could influence the volume calculation, three fixed pressure steps (120 bar, 130 bar, 140 bar) were used. After timber harvesting, the logs were manually-measured using callipers. The data from manual measurements provides the mid-diameter, the total length and the diameters of 40 cm length-sections, into which log is subdivided. Two diametrically opposite diameters are obtained for each diameter measurement. The measurement sequence is sketched in Figure 1.

The real volumes of arbitrary shaped bodies can be readily ascertained with the help of the Archimedes Principle. This Principle states that the static lifting force of a body in a medium is just as great as the weight of the fluid volume displaced by the body. In this study, the reference volume is calculated by measuring the lifting force. Two measurements per log were made. Firstly, the weight of the log was measured with force sensors. Secondly, the log was immersed into a water-filled container (20 m³) and the lifting force determined. In order to measure a tension-force each time and to prevent floatation of the wood, loading was carried out. From the calculated differential force, water density and acceleration due to gravity, the volume of each individual log can be calculated according to Formula (1).

$$V = \frac{F_{G1HTB} - F_{G2HTB} - (F_{G1TB} - F_{G2TB})}{\rho_{water} * g}, \quad (1)$$

where:

F_{G1HTB} is weight of trunk, measuring device (incl. traverse), load [N];
F_{G2HTB} – lifting force [N];
F_{G1TB} – weight of measuring device and load [N];
F_{G2TB} – lifting force of measuring device and load [N];
ρ_{water} – density of water [kg/m^3];
g – acceleration due to gravity [m/s^2].

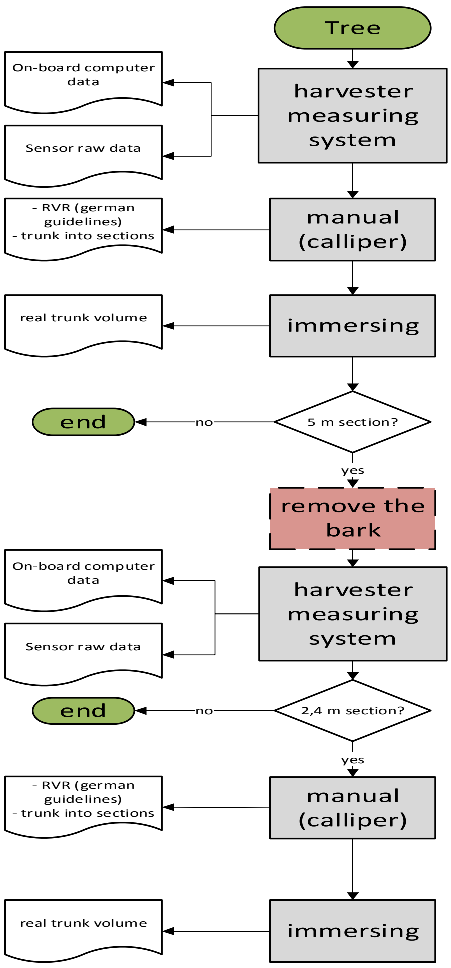

Fig. 1. *Measurement sequence of comparative measurements*

The forces F_{G1HTB} and F_{G2HTB} were, thus, determined for each log. In order to be able to take into account the offset of the measuring device and load, the weight of device and load (F_{G1TB}) as well as the lifting force (F_{G2TB}) in the water was determined at the beginning of each measuring day.

The measuring device was equipped with a traverse, two accurate force sensors and two cylinders. This arrangement allows for easy immersion of the trunk into the water-filled container. In order to avoid any sudden changes in the force, which could negatively affect the sensors, hydraulic cylinders were used when lifting the trunks. The immersion process is shown in Figure 2. The logs as well as the load were firmly fastened to the traverse with tension belts.

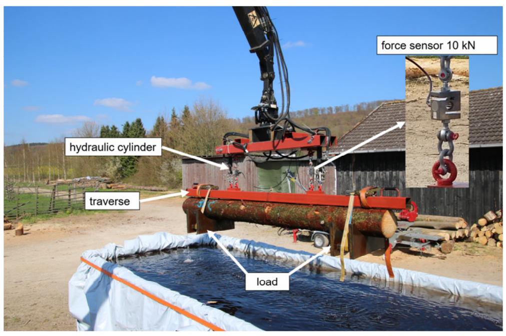

Fig. 2. *Image of water immersion process*

4. Results und Discussion

In order to assess the accuracy of the harvester measuring system, the raw data from the experiments were processed and analysed. The first aim of this work was to compare the volume measurements with the real trunk volume (reference measurement) based on the immersion technique. Figure 3 includes the relative differences of volume (in percent). Box-Plots are used to represent the data. In the box-plots, outlier values are not displayed. Within the boxes are 50% of the basic population. The boxes are limited by the lower quartile (25% of the measured values) and the upper quartile (75% of the measured values). The spread and the distribution characteristics are made clear by the box-plots.

The left box-plot shows the relative volume differences of the harvester measuring system and the real volume (Fig. 3). On average, the volume measured by the harvester was 0.45% smaller than the real volume determined using the immersion technique. The upper and lower quartiles are 2.08% and -3.60%, respectively. The harvester production-recording software underestimates the real timber volume. Undoubtedly, the measuring conditions while timber harvesting occurs are challenging. Timber harvesting during processing, changing measuring conditions, the extreme working environment and the raw material wood impose enormous demands on the measurement system. However, it may be concluded that the harvester measuring system, which divides the whole-stem log in small sections and then calculates the volume, is sufficiently accurate.

Volume calculations based on the "RVR"-method [9] were accomplished using Huber's formula. The mid-diameter was measured in centimetres in the middle of the log length with the calliper. The volume is calculated, just like a cylinder, using the mid-diameter and length. The right box-plot (Fig. 3) shows the relative volume difference of this method. As a result of this simplification, an average volume loss of 7.53% was achieved. The upper and lower quartiles were -3.05% and -12.37%, respectively.

Due to the fact that only the mid-diameter was measured, there were high deviations from the real volume. In principle, it was noted that the volume deviation of the harvester production-recording software was significantly less than the manual measurement and calculation using Huber's formula. Obviously, the volume consisting of sections in which the whole log is divided is more accurate than a volume calculated by one mid-diameter. These test results reflect the tendency of Dvorak *et al.* (2016) [3]. They found that the difference between timber volume is 4.7% in favour of the harvester.

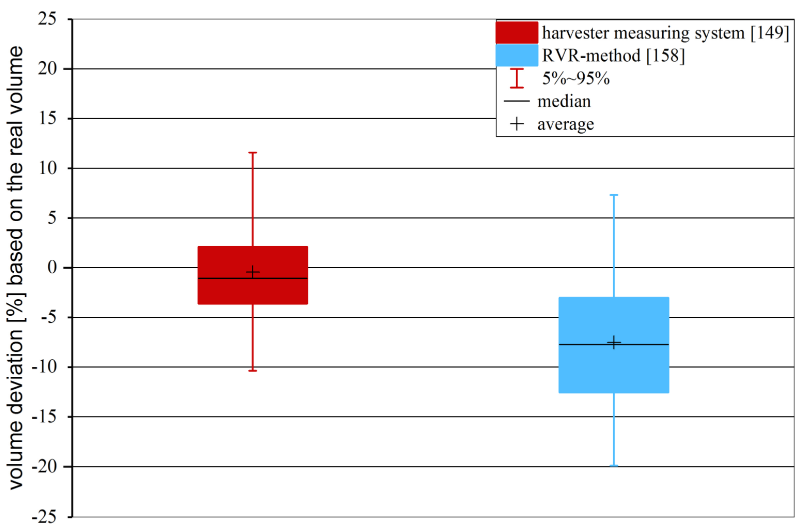

Fig. 3. *Volume deviation of harvester measuring system and manual method*

Another reason for the significant deviation may be the fact that the raw data from the harvester sensors is calculated in millimetres, while manual calculations involve rounding down to a whole number in centimetres.

In both cases, only the measurement methods were examined. Bark deductions were not conducted. The section-by-section survey results in a better representation of the real trunk geometry.

The second aim of this study was to investigate the deviation of volume determination due to the modification of the harvester roller pressure. The diameter data for harvesters can generally be collected in two different ways: either via position of the delimbing knives and the respective kinematics or the position of the rollers and the respective kinematics. In both cases, the diameter data are determined by contact. Figure 4 shows the volume difference as a function of the roller contact pressure. A trend can be inferred. As the contact pressure increases, the volume difference becomes larger. This means that the diameter measured by the harvester and used to calculate the volume of the log, is reduced. The rollers are pressed deeper into the surface of the log as a result of the increased contact pressure. There was a direct dependency between the diameter measurement and the height of the pressure. At this point, it must be noted, that an intervention in the measuring system and a manipulation (e.g. diameter change due to the modification of roller pressure) is not in conformity with legal requirements. The measuring system of the harvester clearly needs to work independently in order to successfully comply with the conformity process.

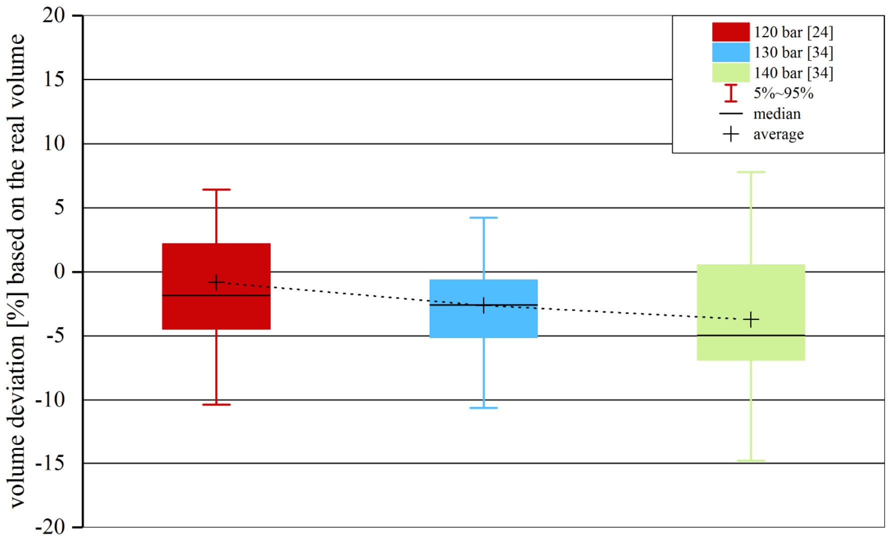

Fig. 4. *Volume deviation as a result of increasing roller pressure*

5. Conclusions

In this study, both the conventional manual method and the harvester measuring system were examined and the calculated volumes were compared with the real volume using the water immersion technique. The results indicate that the harvester measuring system determines the real trunk volume more accurately than the manual method of log calculation using callipers. It may be concluded, that the division of the whole log into sections is more accurate than the use of one diameter. Comparing the volume calculated by the harvester with the real volume, it can be noted that an average volumetric deviation of -0.45% was observed. Thus, concerns that the harvester measuring system is not trustworthy are not valid. While it is correct that this type of measuring system is not closed and, therefore, not tamper-proof, this study clearly demonstrates that the volume deviation is less than the legally accepted manual method using callipers based on the "RVR-method". Furthermore, the roller pressure significantly affects the diameter determination, as well as volume calculation. Volume calculations according to the "RVR-method" lead to greater deviations. The difference between the real volume determined by water immersion and the manual calculation according to recommended rules was observed on average to be -7.54%.

An examination of the calculated volumes of the opto-electronic measurement system compared with the real volume using the immersion technique is planned. Also planned are studies to analyse possibilities of developing independent measuring systems for harvesters and to define and specify requirements that are in accordance with established German legal guidelines.

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