

Manual and Automatic Volume Measuring Methods for Industrial Timber

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Abstract. Given the great importance of timber measurement, various methods for industrial timber dimensional control have been established in the practice over the last decades. They allow generating the relevant results for calculation of the prices at different locations, independently of the measurement time. These methods range from simple manual measurements of the stack using a tape to photo-optical measurement systems. Also other measurement methods like water immersion are currently used in practice. The paper presents the individual manual and automatic measurement methods for industrial timber and their working principles. Furthermore, the advantages and disadvantages concerning the requirements and accuracy of the individual procedures will be explained and their practical use will be discussed.

1. Introduction

The measurement of round wood is probably the most important element of the chain connections between the forestry and the timber industry. In addition to the timber quality, timber volume is the most important parameter for the fixing of prices.

The majority of sawmilling companies have state-of-the-art round wood measurement systems. The round wood is measured either electronically in the factory, or manually and the volume determined on an individual log basis is used for the billing of the timber. Therefore, the one by one measurement of logs plays a special role when it comes to determining the prices.

In contrast to the sawmilling, pulp, paper and wood-based panel industries process round wood assortments of lower diameter and quality referred to as industrial or stacked timber. The ratio of stacked wood versus logs can be quite high, especially in case of broadleaved species. This ratio depends on more factors such as wood species, soil quality, the climate conditions and age of the stand stock. Due to the requests or qualities of the industrial wood, their low value compared to roundwood, and the absence of technical facilities, electronic measurement of these assortments on an individual log basis is not possible. Therefore, other measurement methods must be used, which are capable of representing the volume as accurately and efficiently as possible. For this reason different integrated methods were developed which try to estimate the overall volume of the piled or stacked industrial wood. The volume measurements of stacked wood last back for centuries and different solutions were developed. The methods were continuously developed according to the technical possibilities of the time. The last decade seems to be a technical revolution in the field of industrial wood volume



determination. More and more innovative solutions appear on the international markets which compete with each other. Expectedly, within some years the automatic measurement methods will dominate the industrial log markets. Although the present standards and scaling manuals give instructions for manual measurements, however in some cases they mention the possibilities of use photo-optical techniques.

Present paper intends to give a short overview of the manual and automatic measurement systems for industrial logs.

1.1. Requirements and characteristics of the measurement methods

The various measurement methods for industrial timber must meet specific requirements. In general, the measurement method must be characterised by a high degree of rationalisation and at the same time should provide the highest possible level of accuracy. The measurement values must be understandable and verifiable by all persons involved in the processing and sale of timber. In addition, the sequence of the phases timber harvesting, skidding and transport must not be disturbed by the data acquisition and the cost has to be kept as low as possible.

1.2. Historical overview

Already in 1875, as the Würzburg Decisions became effective, the states of the German Empire agreed on the introduction of the units "Festmeter" (solid cubic meter) and "Raummeter" (volumetric cubic meter) as common calculation units for the sale of timber and timber acceptance [1]. An uniform regulation regarding the grading and measurement for sawmill logs and industrial timber was not established until 1936 with the "Reichsholzmessanweisung" [2] in Germany.

One of the first methods to measure the stacked wood filing factor was published by Schnur [3] who measured the tree solid volume and piled the cut parts segmented diameter classes. He compared the filing factors of the diameter classes. To determine the converting factor of mixed oak cordwood Barrett et al. [4] used planimeter, which was the first photo optical solution. However, Barrett *et al.* determined only the filing factor for manual measurements and not the solid content of every pile. The picture was taken from the end of the stack, calibrated by means of scale and put to the edge of the stack. Keepers [5] used a diagrammatic top-plan view of wood measuring device. The picture taken from the stack butt end was analyzed and calculated the ratio of wood. These studies and results prove that the photo analytical solutions offered evident and pragmatic way.

Scientific examinations however revealed that the specified measurement instructions and conversion factors resulted in variation and volume errors between - 12% and + 7% [6].

The provisions of the "Gesetzliche Handelsklassensortierung für Rohholz" [7], which entered into force in Germany in 1969 and were valid until 2009, provided a new regulatory framework for the round wood trade and measurement of industrial timber. In this context, the conversion factors were reviewed in order to calculate the timber volume as accurately as possible.

The new standard "Rahmenvereinbarung für den Rohholzhandel in Deutschland" [8], valid in Germany since 2015, suggests new conversion and reduction factors while using existing measurement methods. This suggests that a representation of the exact wood amount for industrial timber has still not been achieved and thus depends on numerous factors and sources of error.

2. Manual Measurement Methods

In the frame of this article the authors have not the possibility to use or study full overview of manual and automatic measurement methods, that is why the stream line methods are presented which are used widely in the practice or in case of automatic measurements can be a popular solution in the near future.

2.1. Sectional volumetric measuring method

The sectional volumetric method is widely used to measure industrial stacked timber also in Europe and in North and South America and also in other parts of the Earth. The method can be used for different size of the stack in width, length and height. The most common length of stacked logs is 1.0; 2.0 and 3.0 m in Europe and 2.44 m (8 ft.) in North America. The measurement method is applied to the completed stack and the determined volume is used as a measure for sale.

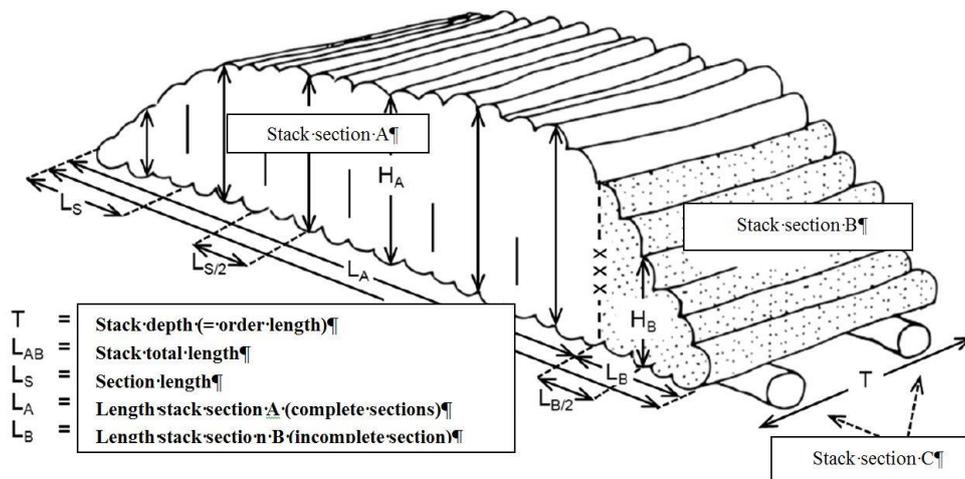


Figure 1. Measurement using the sectional volumetric method (RVR, 2015).

The length, height, and depth of the stack (corresponds to the order length of the assortment) measures are used to determine the gross volume in the unit cubic metres. Usually the measurement values are determined using a measuring tape for the length and a yard stick for the height figure 1. Depending on the overall length of the stack (L_{AB}), the stack is divided in defined sections of equal length (L_S) (see table 1) for the length measurement. The section size can be different according the regulations in different countries. After division and marking of the respective sections, an incomplete section is obtained at the end of the stack (stack section B) with the length L_B . This is measured separately and the volume is added to the determined stack volume from L_A .

Table 1. Division of section lengths according RVR, 2015.

Total stack length (L_{AB})	Section length (L_S)
up to 10 m	1 m
10 to 20 m	2 m
20 to 40 m	4 m
40 to 60 m	6 m
60 to 80 m	8 m
80 to 100 m	10 m

The respective section centres ($L_S/2$) are relevant for the subsequent height measurement and are therefore marked using colour spray.

The section heights are determined vertically to the stack and on both sides. The measuring points at the bottom and topside of the stack must always be determined where the vertical marking leaves the end face of the last log. Height compensation within the respective sections in case of irregular placement of the logs at the top of the stack is not allowed. There are regulations that determine a recommended or maximum height [9]. There are regulations to determine height or other dimension corrections in special cases [10] [8].

The gross volume resulting from the measurement values determined (length and height of the stack) and the order length are reduced according to a fixed measure allowance of 4% and additional reduction factors depending on the wood species and the assortment length (see table 2). The resulting net volumetric measure without bark valid for the timber sale is thus calculated according to the following formula.

$$net\ volumetric\ measure\ (m^3ub) = (H \times L \times T) \times reduction\ factor\ (\%)$$

Table 2. Reduction factors depending on the timber length and type according RVR 2015.

Wood species	Assortment length	
	2m	3m
spruce/fir/Douglas fir	0.96 – 0.94	0.94 – 0.92
pine/larch	0.94 – 0.925	0.92 – 0.905

The Swedish SDC 2014 gives a similar solution a little more sophisticated way by calculating the individual section overall volume instead of average value of stack height.

2.2. Conversion factors

The calculated overall volume comply the solid wood content and the air space between the logs. The conversion factor is the relationship between staked measure and solid contents. The ratio between these two components of the pile can be different within a range of 0.50 to 0.80. The higher number means the higher solid wood content in a stacked cubic meter. Some prescription defines this ratio in percentage and do not make any diversification within an assortment [11]. Laar and Akça [12] determine the conversation factor 0.80 for pulpwood under bark and in the case of firewood, which is recovered from wood not meeting the quality standards for sawlogs, a conversion factor of 0.70 over bark. There are other official regulations make a fine diversification of converting factors for different assortments and wood species [13]. Scientific investigation was done for the more accurate determination of conversion factor function of different conditions of stacked piles [14]. The optimal cost of estimation stacked wood solid content was investigated by Smith [15].

Meyen and O'Connell [16] show a special method on how to determine the actual conversion factor using a 0.7 by 0.7 m grid and counting the numbers and diameters of the logs.

2.3. Xylometry

The difficulty of log volume measurements derives from the irregular shape of the trees and branches. The stems have bends and twist and irregular surface shapes which inhibit to develop a perfect mathematical model for calculate the real surface and volume. A measurement method which could regenerate the surface unevenness would be perfect. The log immersion to water approximates this method the closest or appropriate way. Özçelik *et al.* [17] investigated the xylometry method and compared to others. Despite of the difficulties of measurement execution the results shows very good correlation to the real volume of the stack.

2.4 Automatic Measurement Methods

The automatic measurement systems use technical background and informatics for analysis of data. By the time more and more innovative solutions come to the light and become available on the market. The electro-mechanical harvesting technology is one of the earliest ways to determine the solid contents of stacked wood. Despite of disadvantageous of measurement accuracy the advantage is that the measurement happens in the same time as the harvesting. No additional activity and time are requested for measurement.

Photo optical solutions strengthened in the last years and such application can be run also in smart phones. The more sophisticated technologies use other additional equipment for taking pictures and for analysing the of images.

2.5. Harvester measurement

In Germany, half of the timber harvest is already carried out fully mechanically today, which is why measurement by means of harvester is gaining increasing importance [18]. The measurement equipment contained in the harvester unit automatically captures the data of the respective processed log.

The length measurement of the sections is generally carried out by means of toothed feed rollers equipped with sensors. These rollers are pressed mechanically or hydraulically to the surface of the logs located in the processing unit and move along during processing.

With diameter measurement data acquisition is either effected by determining the distance of the feed rollers to each other or indirectly by determining the opening angle of the delimiting knife during log processing figure 2 [19].



Figure 2. Harvester unit [29].

In addition to the individual log volume determination based on the measured lengths and diameters, the quantity is required for the calculation of the total volume of a stack. This is determined fully automatically with each log cut with the chain saw and stored in the system.

Continuous calibration of the measurement systems and changes of the parameter settings according to the respective timber condition are a basic requirement for obtaining correct data [20].

2.6. Photo-optical systems

Photo-optical measurement has gained increasing importance over the past years. Currently, different systems exist on the market allowing an automatic mobile capture of individual stacks by means of image analysis [21].

A differentiation is made between two technologies with distinct principles of operation [22]. There is a largely automated measurement of stacks where the measurement is carried out by a camera system on the roof of the car with simultaneous calculation by means of special software. Other photo-optical systems are based on manual capture using digital cameras and automatic external evaluation of the photo material.

The full automated measurement technology of wood stacks allows data collecting at different viewing angles, distances, and speeds. The measurements are carried out using a stereo camera system with two cameras positioned in a certain angle to each other figure 3.

Individual images are recorded in a fixed and known scale without requiring additional reference points. The camera generates several images per second and a stereo film of the stack front. Based on this film, a 3D model with all parameters relevant for the timber volume, such as cubic measure, solid measure, quantity, diameter distribution, is calculated [23]. Once recorded, the measurement data is immediately transmitted to the server and can be imported and corrected where necessary using a monitor installed in the car [24].



Figure 3. Camera log measurement system by the company Dralle [25].

Photo-optical measurement of the timber is also possible by using a digital camera. Several frontal individual images (i.e. of the end face) of a stack are recorded. In each of these individual images, a scale (e.g. a yardstick) must be used as a reference during image analysis.

The evaluation of the image data cannot be performed on site. Instead, the obtained data sets of the individual images are sent to a central web server in an automated manner. This web server assembles the images of the individual stack sections to a total image of the stack, similar to a panoramic photo figure 4.

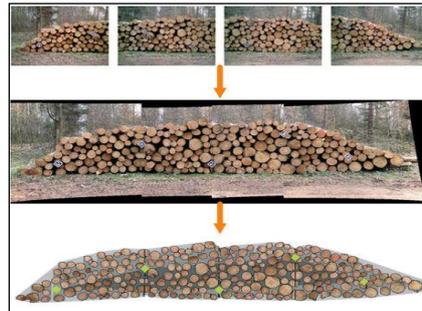


Figure 4. Individual steps of photo-optical stack measurement [28].

The recorded images are used to determine the log quantity, end face diameter, and the storage density of the stack. Based on these values and the uniform log lengths, the total volume of the stack in cubic metres, the average mid-diameter and the size class distribution are calculated first. By application of conversion factors it is later also possible to calculate the total volume in solid cubic metres [26].

3. Discussion

The manual and automatic measurement methods listed and explained will now be discussed with respect to their requirements, accuracy, and rationality.

3.1. Requirements and accuracy

To ensure that the determined volumetric measure is correct, certain conditions and minimum requirements must be fulfilled [8]. If these are not fulfilled, the sectional volumetric measurement method cannot be used for determination of the sales measure. Hence, it could only be used for determination of a control measure.

- Minimum stack size of 20 m³
- Stack height as uniform as possible and max. 2.50 metres
- Stacks separated according to wood species
- Stack placed in a dense and flush way
- One order length per stack of wood
- Building of stacks without inclusion of branches and foreign material (snow, dirt, etc.)
- Free access to front and rear of the stack

Even though the aggregates and the board computers are constantly further developed by the manufacturers, the harvester measurement process and the problems connected to this have not changed according to the present state of knowledge. By permanent calibration of the measurement system and changes of the parameter settings according to the respective timber condition, certain measurement accuracy can be reached, but this does not reflect the exact timber volume.

The main reason for this is the different condition during the harvesting of the timber. For example, if the logs are processed while they are producing sap, major bark portions are removed during delimiting. As a consequence, log portions with and without bark alternate during measurement making diameter determination more difficult. With length determination there is often the problem that with very knotty or bumpy logs the hydraulically pressed measurement wheels temporarily come off the log and that jamming of the length measurement wheel due to, for example, peeled of bark

pieces, leads to incorrect results. In addition, external influences such as time of the year, weather, and mechanical factors affect the measurement by harvester.

In practice, errors often occur when determining the quantity, caused by incorrect operation of the systems or software errors.

Due to these error sources the harvester measure is only used as a control measure and for logistic purposes. For calibration reasons it cannot be used as a sales measure relevant for the calculation of prices [20].

In Denmark, approximately 300.000 m³ of roundwood has been photo-optical measured by the Federal Agency for Nature Conservation every year since 2009 [27]. It is claimed that regular calibration of the measurement equipment ensures that the specified error tolerances can be met. The accuracy ranges of these tolerances are not specified and mentioned.

The manufacturers of photo-optical equipment advertise with good and precise measurement results of their products without specifying exact tolerance ranges. According to the current state of knowledge, individual scientific studies have been conducted on the comparability of the results of photo-optical measurement and assessments on an individual log basis of sawmill timber. Tests regarding the measurement of industrial timber have not been performed yet.

In general, it can be said that the accuracy of the measurement results largely depends on the respective system, the stack quality and the operation. There are detailed regulations on the distance and the angle to the stack front in which the recording camera is to be positioned. Small changes already lead to inaccuracies and incorrect results. In addition, external influences, such as the incidence of light, affect the correctness of the measurement data as due to shadows or minor darkness individual end faces may not be detected and measured. Similar problems are caused by dark or dirty end faces. While it is possible to subsequently process these logs with a special software, this is connected with significant extra time and efforts.

3.2. Rationality

If all conditions and requirements are met, the volumetric measurement method is characterised by a high degree of rationalisation. This is mainly beneficial in case of large stacks. Consequently, it is one of the fastest and most cost efficient manual methods [1]. In addition, the method can be reproduced by all persons involved in the wood sale at any time and the measurement result is transparent for all parties.

The harvester measurement allows an early determination of measures and therefore a quickly available measure for logistical processes. The data can be made digitally available by means of modern software and interconnected with other database systems via radio.

As explained, the photo-optical measurement methods offer the possibility of early determination of measures. In practice, the method is characterised in particular by its uncomplicated and easy way of data provision and the comprehensive documentation of the measurement. This allows for rationalisation of the complete business process of the timber sale and its transparent representation for all persons involved.

4. Conclusion

In summary, it can be concluded that although the automatic measurement methods for roundwood developed over the past years (harvester, photo-optical methods) have significantly improved with respect to the rationalisation of the timber measurement compared to the manual methods, the measurement accuracy required for the sale of timber can be achieved. It remains to be seen whether these systems can be improved further with respect to the measurement accuracy and can thus become easy and quick to calibrate.

Therefore, at present, the only alternatives available for determination of a sales measure for industrial timber are the manual measurement methods as used for several decades. The problems regarding the requirements and accuracy mentioned often give rise to disputes and arguments between the forestry and timber industry. Depending on the situation of the timber market, each try to impose the measurement method which is the best, i.e. most beneficial for the respective party.

Looking to the future, it would be necessary and desirable in the interest of the overall forestry and timber industry to generate a measurement system for industrial timber which complies with the required dimensional tolerances while ensuring a rational procedure at the same time. With today's technical possibilities and the experience from several decades in the sale of industrial timber this should be possible.

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