THE INFLUENCE OF THE HUMAN FACTOR ON THE MEASUREMENT RESULTS ACQUIRED BY USING THE RESISTANCE DRILLING DEVICE RINNTECH RESISTOGRAPH R650-EA

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Abstract
The diagnostics of wooden structures using the detection drill RINNTECH Resistograph R650-EA is one of the popular semi-destructive methods. This article deals with the issue of the influence of the human factor on the measurement results. The recommended testing direction is the radial direction, perpendicular to the grain. However, the desired direction is sometimes difficult to maintain. The experiment takes into account three different factors that may occur during the testing. The goal is to determine to what extent the human factor affects the measured results. Thanks to the conducted research, it was found that gradual tilting of the device during measurements influences the measurements most significantly.

Keywords
Wood diagnostics, resistance micro-drilling, resistograph, resistance characteristics, human factor influence

1 INTRODUCTION

Wood is, thanks to its properties, a very popular building material. Therefore, the development of new methods for diagnosing wooden structures is a current topic. New diagnostic methods include semi-destructive testing of wood using the RINNTECH Resistograph R650-EA resistance drilling machine. This article focuses on the impact of the human factor on measurement results acquired by this resistance drilling machine. In the experimental part, three different samples were measured, each demonstrating a different situation involving the human factor. Three possible influences were chosen, namely tilting the device sideways during drilling, gradual tilting to one side, and drilling at a specific angle. The measured values obtained in this way were compared with measurements that were not influenced by the human factor. The goal of this work was to verify whether any of the mentioned human factors affect the measured values. Furthermore, this work discusses which of these selected human influences distorts the measured values the most and whether this influence has any impact on the measured values [1], [2], [3].

2 METHODOLOGY

The RINNTECH Resistograph R650-EA is a specialized device which is primarily used for assessing the internal condition of trees. Arborists use this device to evaluate the safety of trees. The measured values are represented graphically, and through the curve's profile, any potential internal decay, cavities or other anomalies within the treecan be easily identified. These issues may weaken the strength of the wood and increase the risk of a tree falling. This method is a semi-destructive testing method, so the trace left after the measurement is negligible. This fact is very environmentally friendly. However, this test assesses the condition of the tested element only locally, not throughout the entire length of the sample. For more precise data, a larger number of drillings is required [2], [4], [5].

This method can be easily implemented from the tree condition assessment to the evaluation of the condition of wooden structures. The testing principle is the same. This device is often used in the diagnosis of wooden structures or the assessment of the internal condition of various wooden elements. The test can be easily evaluated in situ, allowing for the localization of any decay or internal damage. However, sufficient workspace is required during measurement. The recommended drilling direction is perpendicular to the wood grain. Due to the limited

DOI 10.13164/juniorstav.2024.24023

accessibility certain parts of the tested element or moments of inattention or other unintended human factors, deviations from the recommended drilling direction can occur. To determine how much these factors can influence the results, the following experiment was conducted [3], [6], [7], [8].

Experiment description

The experimental part involved selection of 3 spruce wood samples, labeled A, B, and C. Each sample underwent 10 drillings with maximum elimination of the human factor. This was achieved by securing the device in a vertical position perpendicular to the grain of the test sample to eliminate any external interference. The test locations were numbered 1 to 10 and were set 7 cm apart. The different grips of the instrument during measurement are shown in Fig. 1.

a) b)

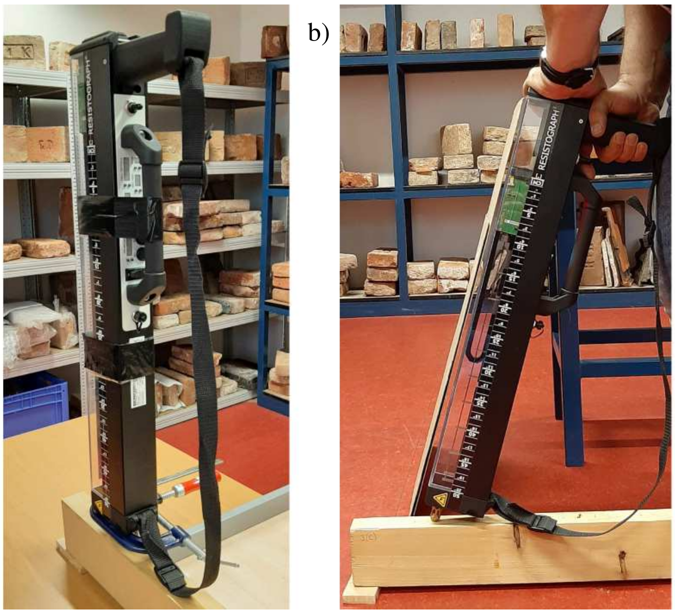

Fig. 1 Device a) attached to the stand, b) held in tester's hands during measurements.

Subsequently, three different factors that could occur during the measurements and potentially affect the recorded results were chosen. Each sample was assigned one of the following possible scenarios. Sample A underwent measurements where the device was tilted about 10° to one side and then to the other side. During a single drilling, there were 8-9 deviations from the axis. Sample B was subjected to drillings where there was a gradual deviation from the vertical axis. The third selected method tested on sample C involved drilling at an angle of approximately 16°. These human factors were demonstrated during the testing. Each sample contained test locations labeled 1' to 10'. The locations were set 7 cm apart from each other. There was a 2 cm distance between the test locations with the elimination of the human factor and those affected by the human factor. These two drillings were compared for the purpose of this experiment. Fig. 2 schematically depicts the selected test locations on a randomly chosen sample.

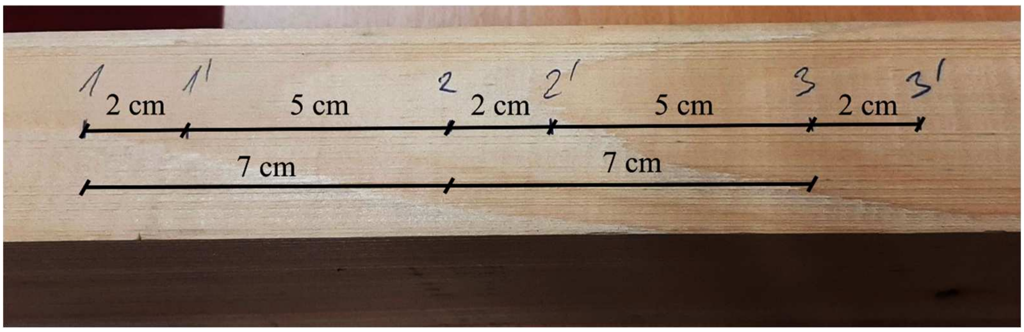

Fig. 2 Layout of test locations.

Resistance characteristic

To compare the results, the resistance characteristic RM was chosen. The resistance characteristic allows the drilling results to be compared with various wood properties, such as its density. Records define the condition of the wood only locally at the drilling site. When drilling a sample multiple times, the method provides an overview of the overall extent of damage. This characteristic can be easily determined using the following formula:

$$RM = S/h \tag{1}$$

where S is the area under the curve of the graph, and h is the length of the measured section [8], [9].

3 RESULTS

The measured values were compared in two ways. The first method involved selecting a graphical comparison of the respective dendrograms. The second method was a comparison based on the established resistance characteristic.

Graphical comparison

During the measurements, the graphical output was printed on a paper strip and simultaneously saved electronically. This allowed for data manipulation in various software programs. The values from all the test drillings were plotted in Python, and afterwards, the corresponding dendrograms were compared. For graphical comparison, these curves were plotted on a single graph. A representative graph was selected from each set.

In Fig. 3, a selected graph from set A is displayed. The red curve represents the measured resistance along the drilling length without human influence. The trace along the blue curve corresponds to measurements with human factors. The device was tilted to the sides at an angle of approximately 10° during the measurements, resulting in 8–9 deviations during drilling. Individual test locations were set 2 cm apart from each other. From the resulting graph, it is apparent that the curves have a very similar profile. The curve influenced by the human factor almost matches the curve measured without this influence. Towards the end of the graph, there is a slight deviation, which was likely caused by the internal structure of the wood. This probably occurred due to the curvature of growth rings along the sample's length.

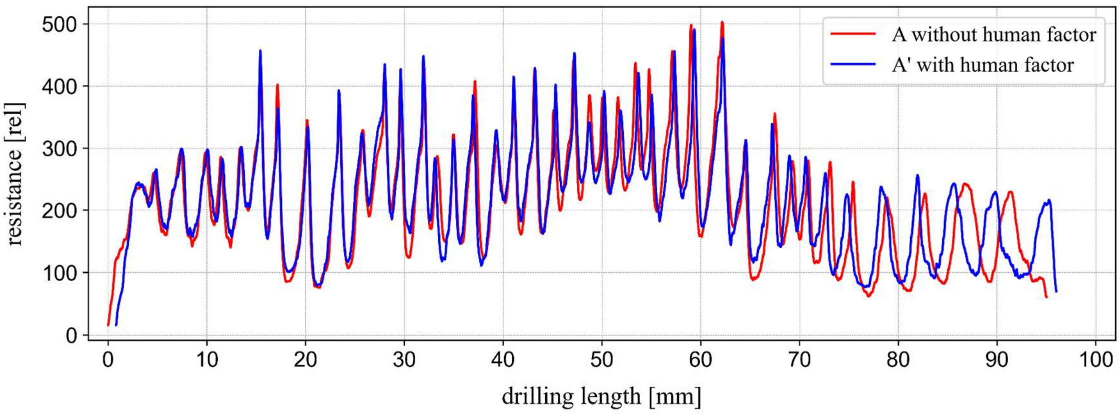

Fig. 3 Comparison of curves on a selected pair of drillings from set A.

In Fig. 4, a selected graph from sample set B is plotted. Like in the case of the previous set, the red curve represents the trace of measurements without human influence, and the blue curve shows the recorded measurements with human influence. The device was slowly tilted away from the vertical axis during the test. Based on the resulting graph, it can be concluded that the curves have a similar profile, differing only in resistance values. At the beginning, the curves nearly overlap, but as the device was gradually tilted, there was an increase in the recorded resistance.

DOI 10.13164/juniorstav.2024.24023

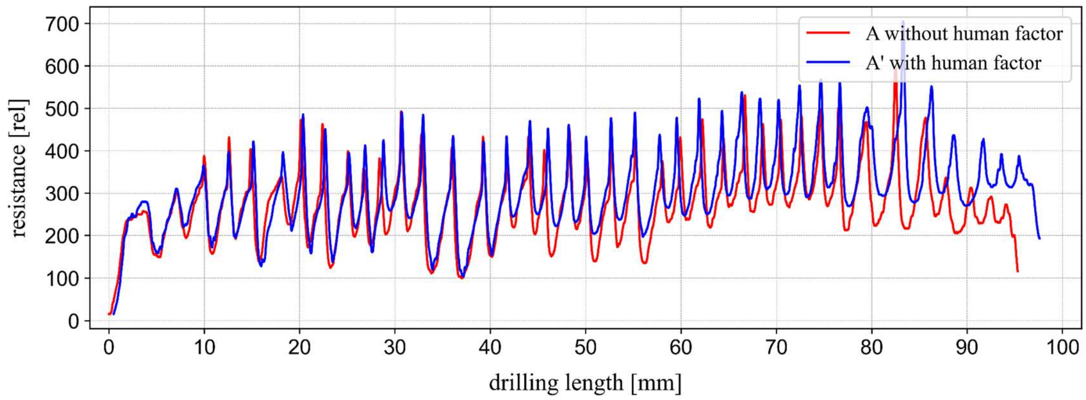

Fig. 4 Comparison of curves on a selected pair of drillings from set B.

Fig. 5 below represents a sample graph from set C. Similarly to the previous two sets, the red curve illustrates the measurement sequence without the inclusion of the human factor, while the blue curve represents the development of measurements with the presence of human influence. Based on the graphical representation, it can be inferred that the individual curves have relatively different profiles. During the testing of elements in set C, drilling was performed at an angle of approximately 16°, which meant that the growth rings were not crossed as rapidly. The drill passed through a single growth ring for a longer period, which is evident in the graphical representation where the blue curve is shifted relative to the red curve.

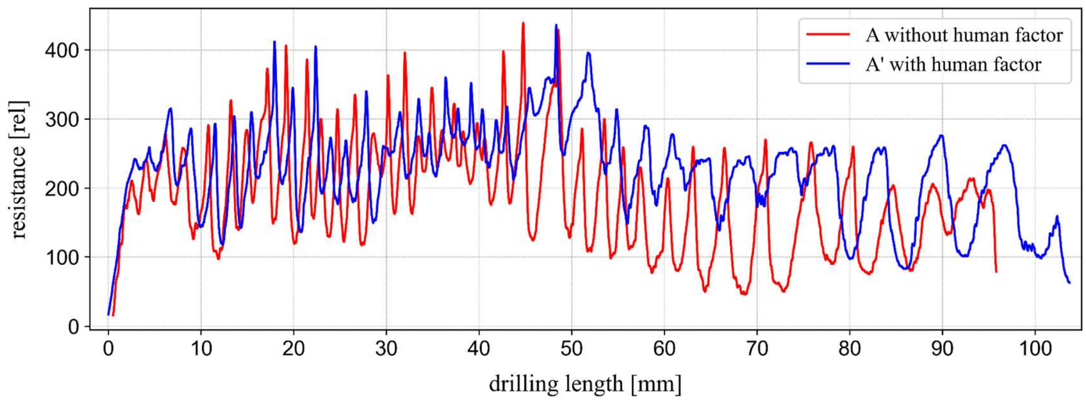

Fig. 5 Comparison of curves on a selected pair of drillings from set C.

Comparison based on *RM* characteristic

As a second method for comparing the measured values, a comparison based on the resistance characteristic and the percentage deviation due to the human factor was chosen. The *RM* characteristic, calculated according to relation (1), was determined for each test location separately. Subsequently, these values were averaged for the individual sets and measurement types. These values are shown in Tab. 1.

Tab. 1 Evaluation of *RM* characteristics.

	***RM* characteristic without human factor [mm]**	***RM* characteristic with human factor [mm]**	**Difference [mm]**	**Deviation caused by human factor [%]**
Sample A	*203.796*	*219.657*	*15.861*	*7.78*
Sample B	*253.337*	*293.958*	*40.621*	*16.03*
Sample C	*200.621*	*228.242*	*27.621*	*13.77*

4 DISCUSSION

Based on the graphical representation, it was found that the compared curves have a very similar profile at first glance. In set A, the curves were nearly identical. In set B, the curve influenced by the human factor had a similar profile to the curve without human influence; however in the second part, it had a higher recorded resistance. This could have been caused by internal friction. Even though the drill is designed with special geometry to eliminate internal friction, tilting the device to one side may still have led to distorted results. At first glance, the resulting graph from the curves in the measurements of set C showed the most significantdissimilarity. This is due to the drilling angle. In drilling without the human factor, the test was performed perpendicularly to the grain, leading to more frequent changes when transitioning between growth rings. In drilling with the human factor, drilling was done at an angle of 16 ° which is why there were fewer transitions between spring and summer wood. The resulting resistance is probably increased due to the drilling angles.

Based on the established values shown in Tab. 1, it is apparent that the human factor used in testing set A had the smallest impact on the measurements. The influence of the human factor on the recorded values was quantified to 7.78%. This factor can be considered negligible, considering the structure of the wooden elements. For set B, the difference in the established values is the largest. In this case, it is not a factor caused solely by the structure of the wooden element. The gradual tilting of the device during measurements has a 16.03% influence on the results. The percentage factor for set C was 13.77%. In this case, the human factor used was drilling at an angle of approximately 16°. The drill bit did not pass perpendicularly to the grain, so, as mentioned before, there were no rapid transitions between spring and summer growth rings. The resulting *RM* characteristic is lower than that of set B; thus it can be concluded that inclined drilling has smaller impact on the recorded results than gradual tilting to one side.

5 CONCLUSION

Wood has a highly specific internal structure which undoubtedly affects recorded values. Sometimes it is very challenging to compare the results because resistograph measurements test the element only locally. Having conducted the experiment, it was determined that all three selected factors influenced the recorded results. Testing included tilting the device to the sides during measurement, gradual tilting to one side, and drilling at the 16° angle. The results were compared both graphically and mathematically. For comparison purposes, values of the resistance characteristic were computed. The influence of the human element was quantified as a percentage. A surprising finding was that tilting the device to the sides had lesser impact on the results than drilling at a certain angle or drilling with gradual tilting to one side. This fact was supported by the determined *RM* characteristic value. Based on these findings, it can be concluded that the drill bit is quite flexible and resistant to tilting to the sides during measurement. The human factor is an influence that is very difficult to eliminate during resistograph testing. Therefore, it is necessary to consider the human factor as an integral part of the measurement and it is advisable to minimize it as much as possible. Since the only way to interpret the recorded values is through the evaluation based on the dendrogram, it is important that the measurement is conducted by a sufficiently experienced person. It is possible to compare the established resistance characteristicbut it can often be distorted by various factors. Unfortunately, there is currently no established relationship for expressing strength. This article can potentially be considered as a partial indicator for the subsequent evaluation of the recorded results.

Acknowledgement

The results presented in the article were obtained as part of the project 2112 – Institutional Support for the Development of a Research Organization, ID 22738.

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