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RESISTOGRAPHIC VISUALIZATION OF TREE-RING DENSITY VARIATIONS

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ABSTRACT

The RESISTOGRAPH drill drives a fine needle into wood at a constant feed rate (drilling hole diameter 3 mm). The power consumption of the motor is recorded as a measure for the mechanical drill resistance. The mean level of the obtained charts correlates with the density of the penetrated wood. Variations in density caused by decay, compartimentalization zones, compression wood and different tree-ring zones are revealed. RESISTOGRAPH systems are applied to study wood anatomy, to assess wood quality, to calculate timber-construction stability, to evaluate growth rates of forest trees and traffic safety of standing trees.

KEYWORDS: *Resistograph, drill resistance, wood-density variations, tree-ring structures*

INTRODUCTION

Radial wood density profiles and derived time series of tree-ring density parameters characterize wood quality aspects, tree growth and growth-influencing factors, such as site conditions and climate (Schweingruber 1986). The corresponding measurements are commonly done by X-ray densitometry.

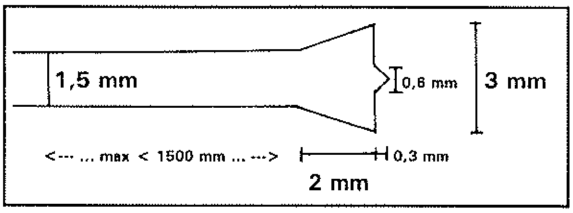

Figure 1 The RESISTOGRAPH needle is made of a special steel. The needle's tip is treated during the production process and gets a special grinding. The brad point guarantees a linear motion of the needle. The flat front ensures the measurement of the density perpendicular to the penetration direction allowing to correlate the measured value to the actual position of the needle's tip.

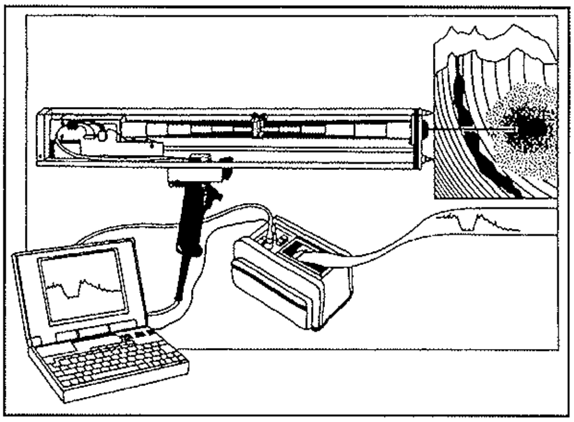

Figure 2 RESISTOGRAPH equipment: drill, rechargeable battery pack with control panels, printer, inbuilt computer memory or RS232 interface. The drill contains two motors, one responsible for the constant feed and one for the rotation of the needle. The needle shaft is stabilized quasi-continuously inside the drilling device by means of a special telescope. Maximum drilling depth 1000 mm, maximum feed rate 700 mm/min.

In 1985 two German engineers invented a method for measuring drill resistance of a needle to find decay in utility poles (Kamm und Voß 1985). Further developments, carried out in Heidelberg by the author, led to several different prototypes of drilling devices, originally named DENSITOMAT, in 1993 renamed to RESISTOGRAPH (Rinn 1988, Brandt und Rinn 1989; Rinn 1989a-c; 1993). Accuracy and reproductivity have been increased up to a linear resolution of 100 measurement points per mm which makes tree ring density structures visible in the obtained drill resistance profiles (Rinn et. al 1990, 1992). This paper tries to figure out the variety of tree ring structures visible in the RESISTOGRAPH profiles of dry wood: visualization of radial wood density profiles. Consequently, graphics dominate the following text.

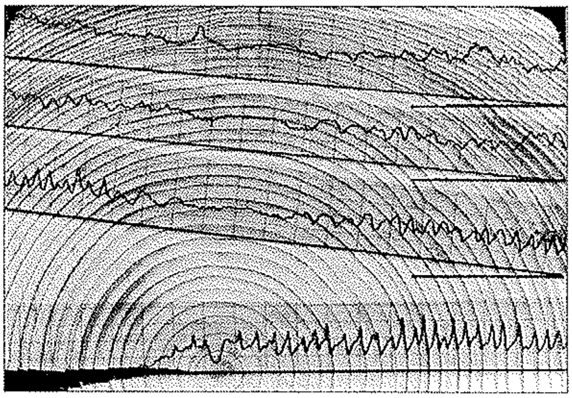

Figure 3 Drillings in a beam of *Picea abies*, carried out from right to left with a feed rate of 280 mm/min. and different piercing angles. The profiles visualize the dependency of the tree-ring resolution from the piercing angle. If the needle penetrates the tree-ring border perpendicular (90°, profile below) the rings appear clearly and distinctly. With a decreasing angle, the visibility of tree-ring structures gets worse, as indicated in the profiles above.

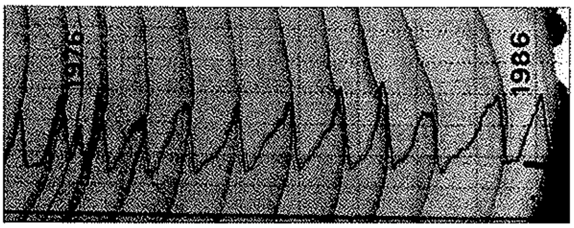

Figure 4 Tree ring density structures in fast growing spruce (*Picea abies*) stem disk. The dry summer of 1976 is indicated by a narrow ring with much less latewood than contained in the surrounding rings. The following year, 1977, consequently contains less earlywood. The tree recovered relatively fast from this bad growth condition. The drilling was carried out with 280 mm/min feed rate from right to left. The vertical dotted lines equal 10 mm steps.

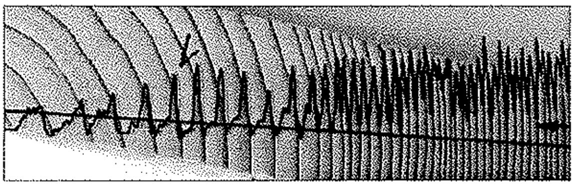

Figure 5 Wood surface and RESISTOGRAPH profile of *Abies alba* with broad and narrow tree rings (drilling path along black line, total length ~ 100 mm). The drill resistance profile increases in the area of narrow rings (right) due to the relatively higher amount of latewood, therefore revealing the radial density trend, often correlated to the age trend.

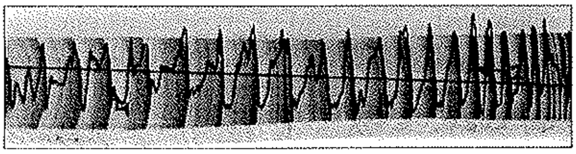

Figure 6 This drill resistance profile reveals compression wood zones in *Abies alba* (drilling path along black line from right to left, total length ~ 150 mm).

DESCRIPTION OF THE RESISTOGRAPH-METHOD

The RESISTOGRAPH tool drives a fine needle into the wood and measures the drill resistance as it rotates continuously with ca. 1500 rpm (Fig. 1, 2). The drill resistance is concentrated at the tip of the needle because its width is double the width of the shaft (Rinn et al. 1990 and 1992). An electronic regulation of the motor guarantees a constant feed rate of the needle adapted individually to the wood density: 50 mm/min for extremely dens wood *Lophira alata*, 700 mm/min for very soft wood like *Populus nigra*. Maximum drilling depth of the shortest RESISTOGRAPH-version for timber inspections is 280 mm, the standard-version for tree inspection provides 410 mm and the longest version allows to drill 950 mm deep. The ordinate of the RESISTOGRAPH-charts represents a relative measure for the power consumption. Electronic resolution is 12 Bit, the ordinate values therefore differ from 0 to 4095, representing a relative scale of drill resistance.

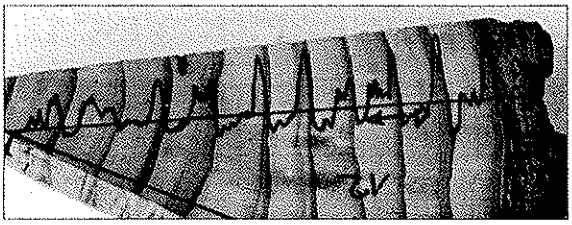

Figure 7 Wood surface and RESISTOGRAPH profile of *Larix decidua*. The black line under the profile indicates the drilling path from right to left (total length ~ 80 mm). The intra-annual variations of the drill resistance in the third tree ring from the bark, for example, show that the visual impression of the latewood area can lead to wrong measurements of late wood width. The latewood is broader than indicated by the dark area visible on the surface. In the corresponding tangential cut the intra-annual variations in density have been visible more clearly, confirming the drill resistance profile.

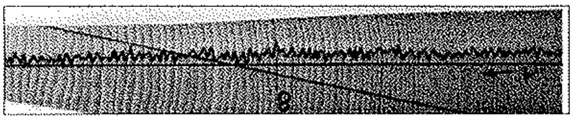

Figure 8 Wood surface and RESISTOGRAPH profile of *Pinus cembra*. Compared to the previous samples the earlywood-to-latewood variations in density are very small, revealed by the relatively smooth drill resistance profile.

More than 30,000 experimental measurements, carried out by the author since 1986, and several other scientific institutions have proved the method's suitability for different fields of scientific and practical application (Rinn 1989b, 1992, 1993, 1994; Ehlbeck und Görlacher 1990; Eckstein und Saß 1994; Büchele 1995; Winnistorfer et. al. 1995). The bore chips remain in the 3 mm drilling hole after measurement. As compared to core sampling with bore-hole diameters of 10 to 40 mm the resistographic drillings are much less destructive.

USES OF THE RESISTOGRAPH-METHOD

For dry wood, the drill resistance correlates to the gross density ($r^2 \sim 0.8$; Görlacher und Hättich 1990; Büchele 1995; Winnistorfer et al. 1995). For calibration of drillings in standing trees, the influence of the moisture content has to be taken into account (Eckstein und Saß 1994). However, in most of the practical applications relative evaluations of the charts (intact-decay or earlywood-latewood) are sufficient. For wood quality evaluation, grading according high, middle or low mean level of density seems to be sufficient.

Tree-ring density variations

The RESISTOGRAPH-charts reveal variations in density of earlywood and latewood areas (Fig. 3 - 13).

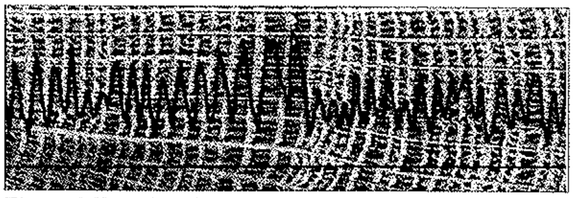

Figure 9 Tree rings in RESISTOGRAPH profile of *Quercus robur* (feed rate 280 mm/min, right to left). Tree rings containing as much latewood as early wood are revealed clearly. Narrower rings without recognizable latewood do not contain radial density variations and consequently cannot be identified from a drill resistance profile. The mean level of the profile represents a measure for the local density along the needle's path (the profile decreases in the area of narrower rings, which have lower density).

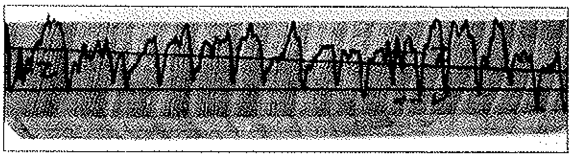

Figure 10 Tree rings of *Ulmus campestris* as revealed by RESISTOGRAPH drill resistance measurements (drilling along the top black line, total length ~ 120mm).

Identification of tree rings is limited mainly by wood anatomical properties, the piercing angle and the needle geometry (Fig. 1). In general, the drill resistance reflects the local relation between earlywood and latewood. Narrow coniferous rings with a higher amount of latewood and density lead to a higher drill resistance. Narrow rings in ring- and diffuse porous wood are dominated by earlywood with less density and lead to decreased level of the drill resistance profile. In palms, the drill resistance reveals the radial density profile, too (Fig. 16).

Decay detection

Decomposed wood causes reduced mechanical drill resistance and is visible in the RESISTOGRAPH charts (Fig. 14 and 15). Different stages of decomposition can be inferred from the drops of the curves. Extremely high values of drill resistance were detected around decayed areas in standing trees (Rinn 1989a). These peaks have been found to be correlated with the presence of compartimentalization zones around fungal decay areas (Fig. 14-15, Eckstein und Saß 1994).

Comparative evaluations of different drill resistance profiles have been published (Rinn 1993) showing that the charts clearly reveal

- fungal decay (depressions in the profile, formally differentiated in three stages)
- insect damage (deep local depressions mostly in the outer part of the profile)
- cracks, splits, ring checks, voids (deep local depressions mostly in the inner part of the profile)

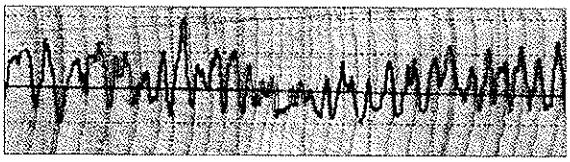

Figure 11 RESISTOGRAPH-profile of *Fagus sylvatica* (feed rate = 280 mm/min, right to left, vertical dotted lines = 10 mm steps). Narrow rings dominated by earlywood lead to decreasing profile level, revealing the radial density trend.

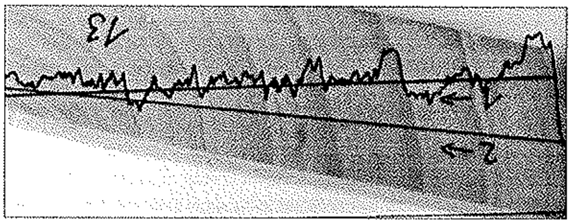

Figure 12 Tree rings in *Populus nigra L.*, containing inter- and intra-annual density variations as revealed by the RESISTOGRAPH drill resistance plot (drilling along the top black line, total length ~ 120mm).

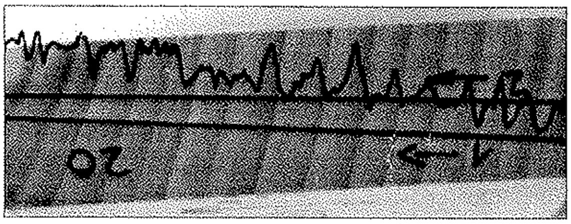

Figure 13 RESISTOGRAPH profile of *Tilia cordata* revealing inter- and intra-annual density variations of the tree-ring structures (drilling along the top black line, total length ~ 60mm). Resolution of the tree ring structure in this case is limited because of the non-perpendicular piercing angle.

- density levels (mean level of the profile).

Providing fast and nearly non-destructive decay detection, the RESISTOGRAPH method is used for several different practical applications, for example

- traffic safety inspection of road and park trees (Mattheck and Bethge 1993)
- wood quality assessment of veneer logs
- evaluation of the stability of historic and recently built timber constructions parts (Ehlbeck und Görlacher 1990; Görlacher und Hättich 1990; Rinn 1989a, 1992, 1993, 1994b).
- maintenance check of utility poles (Rinn 1994a).

In addition, RESISTOGRAPH analyses are used in scientific areas, such as forestry and wood science (Eckstein und Saß 1994; Rinn et al. 1995; Winnistorfer et al. 1995).

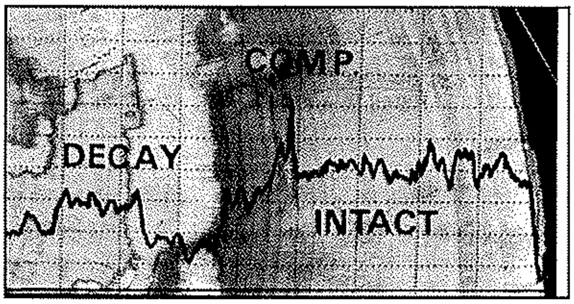

Figure 14 Decay in plane (*Platanus acerifolia*). The white area (left) was decomposed by fungal decay. The drill resistance consequently drops down, compared to the intact zone (right). The profile visualizes different stages of decomposition (feed rate 280 mm/min, dotted lines = 10 mm steps). Before the profile drops down into the decomposed area, a peak arises indicating the existence of a compartimentalization zone (Shigo 1986; Eckstein und Saß 1994). This peak is interpreted as a sign that the tree is still vital enough to try to defend itself against the fungus.

PROSPECTS

So far, RESISTOGRAPH analyses have been limited to the detection and evaluation of relative changes in the drill resistance, providing sufficient information for decay detection and growth rate assessment. The influence of the wood moisture content on drill resistance values is currently being studied in order to assess absolute values of wood density of standing trees.

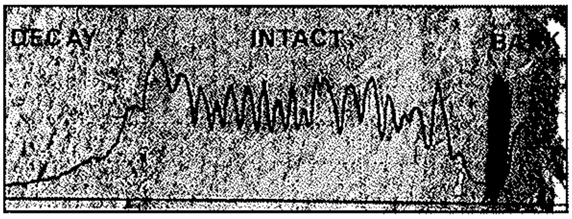

Figure 15 Intact-decay transition in *Sophora*. This picture shows the steady declining RESISTOGRAPH profile coming from the bark and the intact zone (right) into the central area, decomposed by fungal decay (left). The thickness (t) of the intact outside wooden wall of a tree's trunk is important to evaluate the traffic safety: if the ratio of t over the radius is less than 1/3 and the tree is fully crowned, the probability for stem breakage by wind force increases significantly (Mattheck and Bethge 1993).

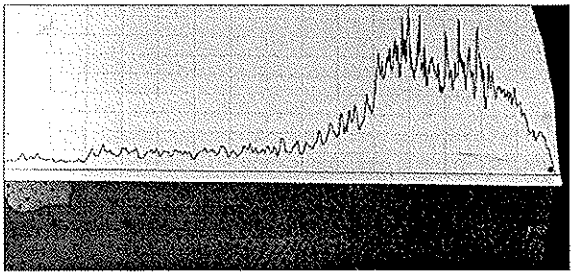

Figure 16 RESISTOGRAPH-profile of a palm. The profile visualizes the radial density variation of a palm stem (feed rate = 280 mm/min, right to left, vertical dotted lines = 10 mm steps). The area of high density in this case was found to be approximately 35% of the radius, which is probably correlated with the biomechanical 1/3-rule of breakage of fully crowned but hollow or rotten trees (Mattheck and Bethge 1993).

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