Practical application of micro-resistance drilling for timber inspection

Frank Rinn

Resistance drilling is used to inspect trees and timber since 1987. However, several application areas provide specific requirements referring precision, resolution, and technical application properties of the machine. Meanwhile, nearly ten different resistance drills are available. Because they differ strongly in many properties, it is very important to know and understand the major practical aspects of the applications as described in this paper to be able to select the appropriate drill version for a specific task. And the user has to understand that not every resistance drill is a real Resistograph®, because this internationally registered trademark is exclusively allowed to be used for labeling high-resolution precision drills providing a high linear correlation to wood density – the sole base for reliable profile interpretation.

Keywords: Resistance drilling, timber inspection

Introduction

Since 1987, recording resistance drilling using thin needles is applied by experts for determining the condition of structural timber and joints by measuring density profiles of wood. Experienced users are able to identify decay, insect damage, and cracks in the profile. In addition, the method allows the expert to find invisible beams below floor and inspect hidden timber (*Rinn,* 1989a). The information obtained on internal condition of beams and joints helps engineers evaluating historic and modern timber structures (*Görlacher and Hättich,* 1990) and is the base for repair planning.

Meanwhile, nearly ten types and generations of resistance drilling machines are available, differing strongly in many ways. Some types are applicable for timber inspection. Unfortunately, many applications of this method do not lead to satisfactory results, because the selected machines are not appropriate for the given task and because of missing knowledge about how to apply and how to interpret the results. Thus, a basic understanding of the method and knowledge about technical properties of the machines is mandatory for being able to properly select the appropriate machine type and generation for any kind of application.

Machine type selection

Technical properties of the drilling machine and needle strongly influence the quality and reliability of the resulting profiles. In addition, the applicability on site is determined by size, design, handling and weight of the machine. The economic efficiency of the application is not only determined by the price of the equipment but furthermore by costs per drilling (for paper and needle), speed of drilling, time needed for paper and needle replacement, data management, and maintenance. The available drilling machine types are different in such an extent, that it is very important before purchasing, renting or using, to clearly analyze which tasks have to be fulfilled by the machine in order to be able to select the appropriate one.

For detecting voids in trees or hardwood timber, a simple machine with low resolution may be enough. If conifers (as full-size or laminated beams) or other softwood species shall be inspected for decay, high resolution and electronically measured profiles with a linear scaled ordinate (y-axis) are mandatory in order to enable the user to distinguish decay from intact but soft wood reliably (the same applies for quantitative wood density and tree-ring and analysis). This is because in soft but intact wood the resistance can be lower than in decayed parts of originally higher density and then only the change in the variations between earlywood-latewood-zones can be interpreted in terms of potential presence of decay. If the absolute level of the profile seems to be normal, only the shape of the tree-ring variations may help distinguishing between soft but intact and decayed parts. And this requires a high resolution of a linearly scaled profile. Although most resistance drilling machines currently used on the market do not fulfill this condition, the users commonly are not aware of this limitation and are thus very likely to misinterpret the results.

Fig. 1: This conifer ceiling beam (*Pinus sylvestris*) was inspected visually and with the help of an endoscope. No decay was found. Some weeks later the beam broke and two carpenters fell down one level, luckily not heavily injured. Later, a detailed analysis of the beam showed that there was a brown rot in an early stage in the center the cross-section. Obviously, strength was significantly lowered. On the sawn cross-section it was impossible to identify the decayed area. Surface sanding and microscopic analysis was required.

Abb. 1: Dieser Kiefer-Deckenbalken (Pinus sylvestris) war visuell und mittels eines Endoskops untersucht und für intakt befunden worden. Einige Wochen später brach der Balken durch und mit ihm fielen zwei Zimmerleute einen Stock tiefer, verletzten sich jedoch nicht schwer. Glücklicherweise war die kurz zuvor noch im unteren Raum befindliche Besichtigungsgruppe zu diesem Zeitpunkt schon wieder gegangen. Später zeigte sich, dass der Balken eine innere Braunfäule im frühen Stadium hatte, die zunächst nicht, aber nach Schleifen unter dem Mikroskop erkannt wurde.

Wilcox (1978) showed that brown rot fungi, for example, can lead to an 80 % loss of bending strength in early stages while density is only lowered by about 10-20 %. This means, that the profiles have to provide high resolution and a linear scaled curve, calibratable to wood density. Otherwise the profiles cannot be used to identify decay of early but dangerous stages. Reliable identification of decay requires knowledge about the typical shape of profiles and intra-annual fluctuations.
However, beside resolution and precision of the profile, there are many other aspects to be regarded before deciding what machine to take and how to apply. In historic timber structures, for example, it is critical that the drill is as thin as possible in order to be able to reach narrow areas. For this, in addition, the handle and main switches have to be at the end rather than at the front of the machine, otherwise it cannot be operated.

Machine length and drilling depth

In narrow historic roof structures, a thin and short machine is required in order to access many points of interest, such as the joint of rafter and ceiling beam. Most historic beams are less than 30 cm in diameter. Thus, a drilling depth of 30 cm is sufficient. The same applies to utility pole inspection: mostly, 30 cm drilling depth is enough. But, in some cases, 40 cm or even 45 cm are required because the pole is bigger in diameter or because the drilling has to reach deeper down below ground level. And, it is much more convenient if the machine is longer because drillings at the base of the pole can be done while standing. For this application, in addition, it is important that the handling switches are at the end of the drill and not at the front because this makes drilling much more convenient.
For inspecting invisible ceiling beams below floor, the penetration depth mostly has to be around 40 cm, if not more, in order to enable the machine to penetrate floor, support beams and then the ceiling beams completely. Inspecting glue-laminated beams often requires drillings much deeper than 30 cm because the dimensions of the beams can reach up to 1 m, or even more. Many modern structures are built in a way that inspection of the beams, especially in joints, is quite difficult. Because the beams cannot be accessed from all sides, a resistance drill with long drilling depth is required. But, especially due to the mostly unpredictable and changing orientation of the tree-ring borders within a glue-laminated beam, the needles often do not penetrate straight as soon as drilling depth exceeds 40 cm with the standard needles. This is a consequence of the stiffness of the steel commonly used for the 1.5 mm drill bits. If the tree-ring border is not penetrated perpendicular, the needle is deflected from the straight path due to the abrupt density change from earlywood to latewood. The same can happen when the needle hits a knot in an angle different from 90°.
In full size beams, the drilling orientation can be adapted to the expected tree-ring geometry in order to ensure a straight drilling. In laminated timber, the tree-ring orientation mostly changes from one lamella to the next. Consequently, deeper drillings more often penetrate tree-ring borders in a non-perpendicular angle. As soon the needle starts deflecting, this trend can even increase and lead to a needle coming out of the wood even perpendicular to the original drilling direction.

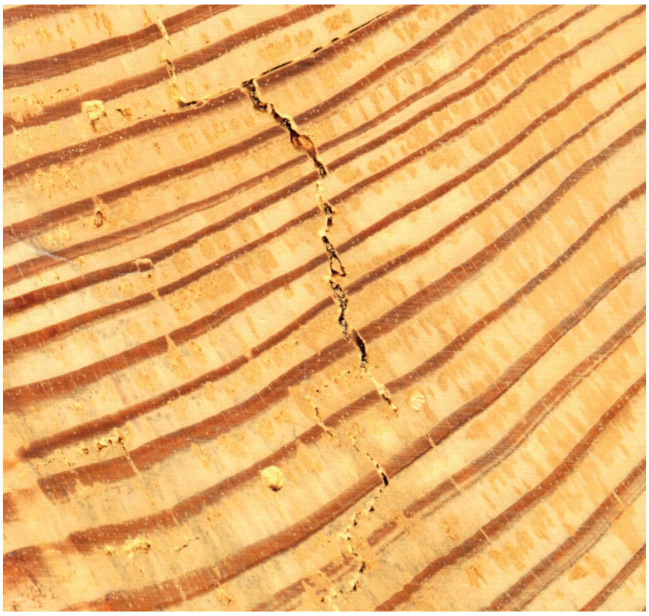

Fig. 2: This more detailed close-up of Fig. 1 shows the spotted areas of early brown rot decay of the broken Pinus ceiling beam. In this stage, obviously only early-wood is affected as can be seen by the location and size of the decayed areas. Resistance drills thus have to provide high resolution and linearly scaled, calibratable profiles in order to enable the experienced user to identify such decay in the curves. As in this example, although the decay is in an early stage, the consequences of bending strength loss can be severe.

Abb. 2: Dieses Detail aus Abb. 1 zeigt die verteilten Bereiche beginnender Braunfäule. In diesem Stadium wird, wie hier zu sehen, mitunter zunächst nur das Frühholz angegriffen. Dies wiederum kann nur mit Bohrwiderstandmessgeräte festgestellt werden, deren Kurven linear und zur Dichte korreliert werden können. Auch wenn die Fäule noch nicht viel Material abgebaut hat, kann, wie in diesem Beispiel, die Biegefestigkeit schon stark reduziert sein.

This will not directly destroy the needle, but the profile does not contain reasonable information about wood condition because shaft friction dominates. However, this can be prevented by observing the sound of the drilling: any severe bending of the needle can be identified by corresponding noise because of increased shaft friction. Then it is better to pull back and to start another drilling in another angle or at another spot.

Summarizing experiences from thousands of timber structure inspections, a drilling depth of 40-45 cm has been shown to be a good compromise as long as the machine length is less than 70 cm. With such a device, most tasks can be fulfilled in terms of machine size and drilling depth. If occasionally a much deeper drilling has to be done, machines of up to more than one meter drilling depths can be rented.

For achieving a straight drilling, especially for pole and glue-lam inspection and for drillings in an angle, needles with bigger shaft diameter can be used if the machine offers this feature. The disadvantage then is, that the damage to the sample is bigger because the tip of the needle should always be at least twice in diameter than the shaft in order to minimize the influence of shaft friction.

Taking into account all aspects of machine properties and the typical tasks in structural timber inspection, a few drill resistance machines types available on the market are suitable for timber inspection, others may be better for trees.

Two reasons clearly speak for a plastic casing of the resistance drill instead of metal: temperature and electric isolation. The needle can always touch an electric power cable. This may

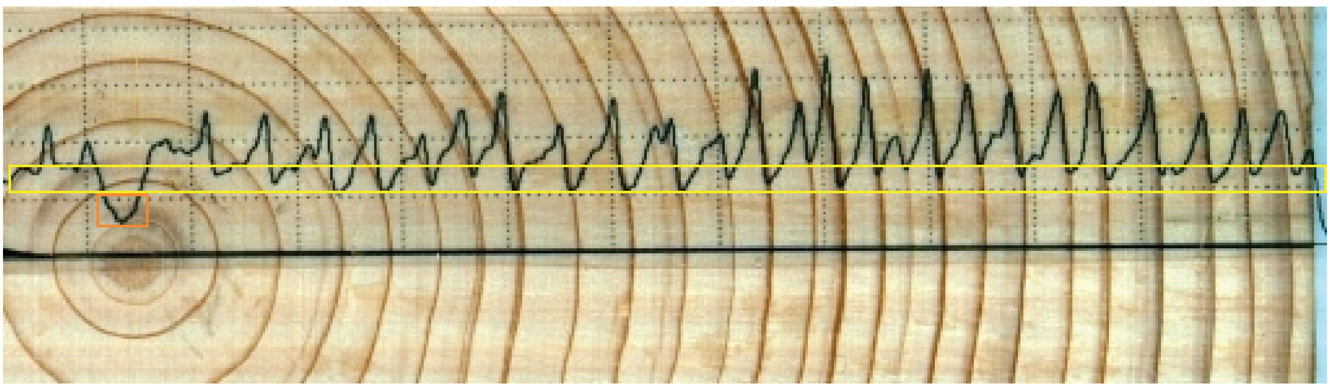

Fig. 3: The yellow lines indicate the typical levels of resistance in early-wood zones of this conifer ceiling beam (spruce, *Picea abies*). If the profile drops below this level, it either indicates decay, cracks, voids, or the soft pith as in this case (marked red). Such a profile drop can only be identified as an indicator of decay if the deviation from the normal tree-ring structure (earlywood-latewood transitions) and the drop in profile level is clearly revealed. This requires a high resolution (more than ten values per mm) and a strong linear correlation to density ($r^2 > 0.8$).

Abb. 3: Die gelbe Linie zeigt das in diesem Profil typische Niveau der Frühholzonen dieser Fichte (Picea abies). Wenn das Profil unter diese Grenze sinkt, dann zeigt dies in der Regel einen Schaden, z. B. Fäule, Hohlraum, eine Riss oder die Markröhre an. Solch ein Profilabfall kann nur dann zuverlässig erkannt und interpretiert werden, wenn die Profile ausreichend hohe Auflösung aufweisen (mindestens zehn Messwerte pro Millimeter) und direkt linear mit der Dichte des Holzes korrelieren ($r^2 > 0,8$).

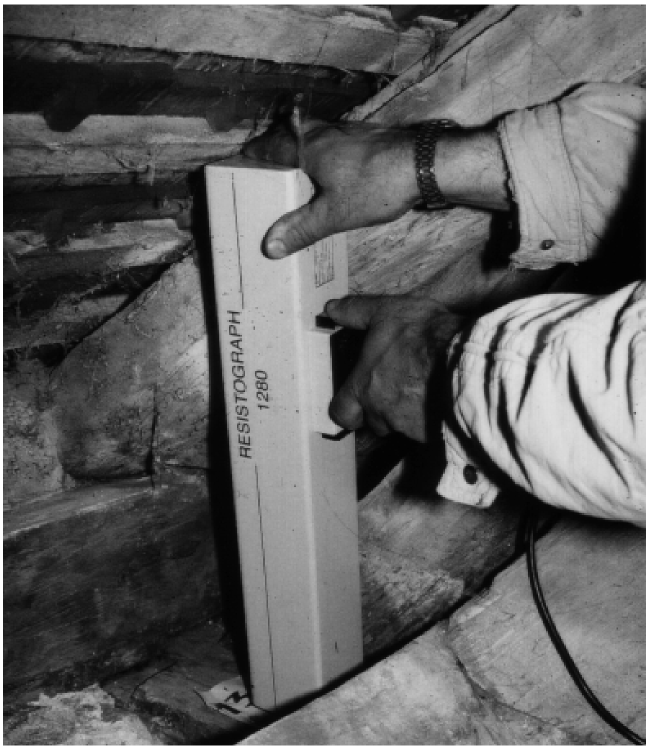

Fig. 4: Only short drilling machines can be applied in such narrow conditions at the base point of historic roofs in order to vertically drill through the head of the ceiling beam beside the finger joint connection with the rafter. The same applies for horizontal drillings between ceiling beams at this point to detect the finger within its hole in the ceiling beam.

Abb. 4: Nur kurze Bohrwiderstandsmessgeräte erlauben es, Hölzer auch in solch beengten Verhältnissen zu untersuchen: hier erfolgt beispielsweise eine Bohrung am Deckenbalkenkopf. Gleiches gilt für horizontale Messungen, um den Zapfen des Sparrens im Zapfloch des Deckenbalkens nachzuweisen.

happen at trees as well as in structures, especially if hidden timber is drilled. There is always the chance that an electric cable is attached to the back side of a beam that cannot be seen and checked before drilling. A plastic casing allows to reliably isolate the potentially electrified needle from the user. In addition, metal cases tend to become too cold in winter and too hot in summer for being hold by hand.

Machine handling

In some machines, the main switch to start the drilling is at the back end, some have a gun-like handle, others an attached ordinary drill at front. For drilling utility poles at the base and ceiling beams from below or top, switches at the back of the machine are preferable. Then the operator can still stand while starting, controlling, and stopping the machine.

For many applications, it is critical to be able to operate the machine with one hand while drilling because the other hand is needed to hold oneself on a ladder or scaffold. This requires the switches close to the handle and reachable with the hand that holds the machine with the help of the handle.

The force the machine pushes back itself from the wood mainly depends on the ratio between needle revolutions per minute and needle feet rate. With some machines it equals around 10 N, with others it can reach up to more than 100 N. This pressure has to be carried in addition to the machine its own weight (and vibration) when drilling overhead into ceiling beams, for example. If no tripod is available, the operator has to be strong enough to hold the machine still for the time of drilling (mostly in the order of one minute).

In many cases while inspecting timber, drilling has to be done in an angle of, for example, 45° to the surface. For these applications, the drill needs to provide a guiding adapter at the front. It is important that this adapter is long enough in order to guide the needle's tip at an angle into wood. Consequently, the front-adapter has to be longer than half of the longest side of the front cross section of the drilling machine.

During drilling, the noise of the machine is an important source of information. The variations of the resistance can be tracked by observing the motors noise. But, this is not possible with some machines being loud by construction and vibrating during drilling.

It is conveniant to directly see the profile while drilling, however, in many circumstances, the operator has no chances to watch it because he has to hold the device in a height or angle, that inhibits a direct observation of the profile shown in the machine. Because of that, some devices are offered with an external printer which can be put into a position that can be observed during drilling. If the printer is connected wireless, it is important that the connection is established automatically by the machine and that the machine is able to operate without printer, too. Although the machine should not be moved during drilling in order to prevent distortions of the reading, a tripod is usually not required if the operator hold the machine still.

Power supply

Some machines have an integrated battery and thus are heavier in weight. Other machines are lighter but require a cable connection to a battery pack. The external battery pack mostly provides more power and its weight is not of concern because it does not have to be carried while drilling.

Using drills with implemented rechargeable batteries, it is important to check if they are shock-proved and not dangerous if shaken. While climbing up a tree or a scaffold in a building for inspection, as well as in many other instances, it may happen that the drill (including the implemented battery) is shaken or even bumping against a structure. In such cases, the modern high-capacity lithium-ion batteries can be damaged, and even burn or explode. Because this happened already several times, strict requirements for transporting such rechargeable batteries have been established recently (www.iata.org). Thus, only battery types that cannot explode should be used for mobile

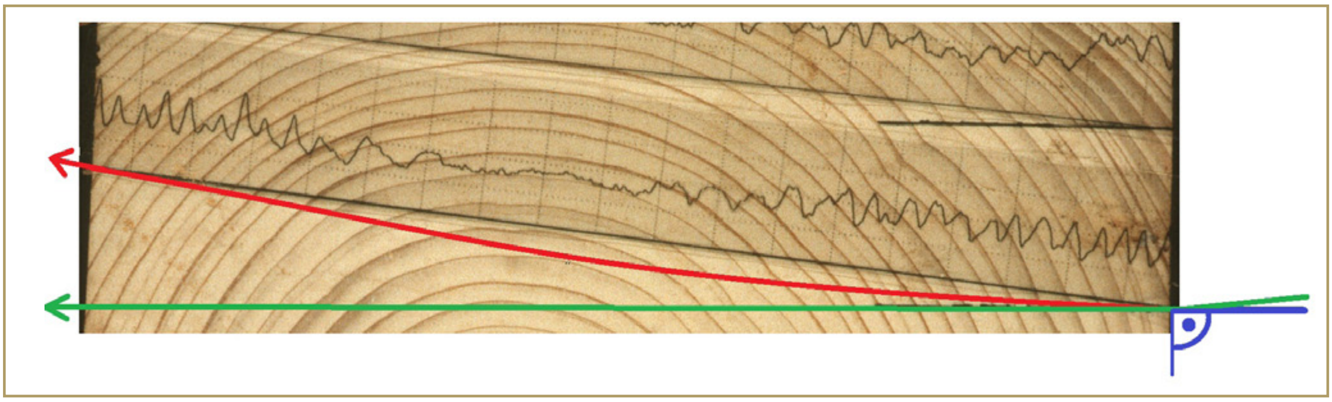

Fig. 5: If the tree-ring borders are not perpendicular to the drilling direction, the needle is deflected from the straight path (red line). This can be prevented by drilling in a slight opposite angle if the tree-ring orientation is known, as in full-size beams. The green line indicates the proper drilling direction for full size beams right of the center line.
Abb. 5: Wenn Jahrringgrenzen nicht senkrecht durchbohrt werden, kann die Bohrnadel abgelenkt werden. Dies kann bei Vollholz verhindert werden durch leichtes Verkippen des Gerätes, wie hier durch die Grüne Line angedeutet.

resistance drills. It has to be taken into account, that only some special kinds of modern high-capacity lithium batteries, for example, are shock proved and cannot burn or explode even while being "mistreated" mechanically.

Printout and storing

Not only because clients may be present while drilling beams, for analysis and evaluation too it was shown to be best to have a profile printout in hand right on the spot after drilling, providing a 1:1 scaled curve. Only in 1:1 scale, the expert can easily and directly evaluate the meaning of the curve as the major measurement result. And this can be easily explained and shown to others in a 1:1 scaled curve. And, in addition, a paper printout is always a useful backup for the case of any electronic storing problem.
If the machine has an implemented printer, it may be required to exchange the paper after every drilling. This takes time and may require opening the machine what can result in dust, dirt or rain entering the casing. If the implemented printer is built as a pin scratching on pressure-sensitive paper, it has to be taken into account that the paper has to be handled with care because touching or scratching can "erase" the profile. Thus, the pressure sensitive paper has to be marked and stored carefully in order to not destroy the profile information (Do not touch!). In other systems, a thermal printer stores the information on long paper rolls, allowing the user to carry out dozens of consecutive drillings without the need of paper change and paper storage handling. Such a machine may allow far more than 100 drillings a day because much less time is needed for paper handling. However, in many inspection projects, most time is required by taking notes and moving from one spot to the next. Since the machines drill much faster, the drilling itself is only a small part of the complete job in terms of time consumption.

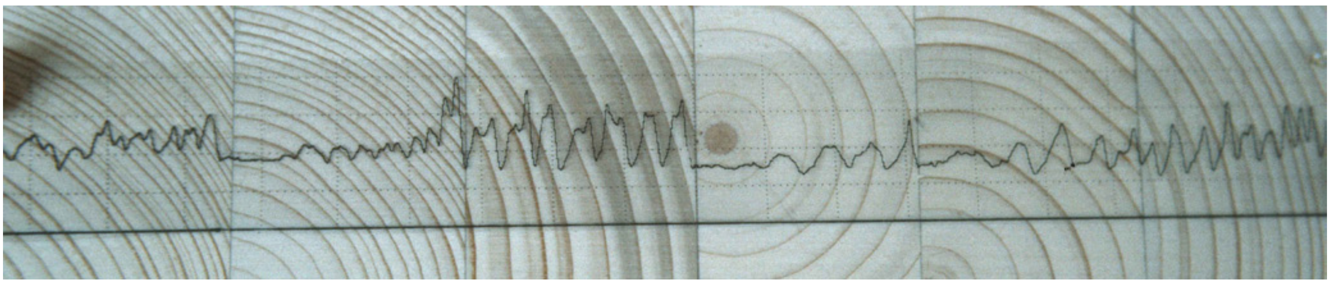

Fig. 6: Section of a laminated beam showing how the angle between drilling path direction and tree-ring border changes with every lamella. A perpendicular entry angle is important in order to achieve minimum deflection but cannot prevent deflection completely. Stiffer needles tend to drill more straight, either by being hardened, by having a bigger shaft diameter.
Abb. 6: Teil eines Brettschichtträgers, an dem deutlich wird, wie sehr sich der Bohrwinkel zwischen Jahrringgrenze und Bohrnadelrichtung von Lamelle zu Lamelle ändern kann. Ein zur Oberfläche senkrechtes Einbohren ist zwar in solchen Fällen die wichtigste Grundlage, sie kann jedoch eine Ablenkung nicht immer verhindern. Steifere Nadeln können dieserart Ablenkungen minimieren, z. B. durch Härtung oder dickeren Nadelschaft – sofern das betreffende Bohrgerät deren Verwendung ermöglicht.

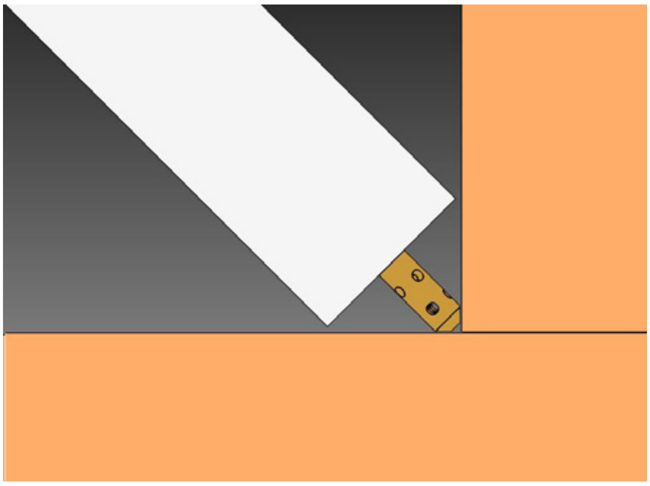

Fig. 7: In both historic and modern structures it is often required to drill in an angle. Because the needle is made of a flexible thin steel, it would not penetrate the wood in such an angle without being guided. This front adapter has to be long enough to hit the corner of the wood while the front edges of the device touch the beams on one or both sides.

Abb. 7: Sowohl in historischen wie auch in neuen Holzkonstruktionen kann es erforderlich sein, in einem schrägen Winkel in eine Holzoberfläche zu bohren. Auch weil die Bohrnadel aus einem flexiblen Stahl besteht, kann sie in solchen Winkeln nicht ins Holz eindringen. Daher wird ein Front-Adapter benötigt, der die Nadel führt und dazu mindestens halb so lang sein muss, wie die längste Seite des Frontquerschnitts.

Some drilling machine types store each profile in an internal memory or, in addition, transmit them via Bluetooth or cable to a portable computer, probably even at the same time.

In timber structures, drillings often have to be done while standing on scaffolds or on a ladder or while crawling and squeezing oneself into narrow edges to reach joints. Consequently, paper handling possibilities are very limited. Interrupting the inspection after every drilling is time consuming and not efficient. The same applies for projects, where many drillings have to be carried out in a short time.

Efficiency and reliability of the application on the spot as well as the later reporting depend on the way, how quick the machines can be operated and how they display and store the results. For reporting, digitally stored profiles are preferable because the software can allow printing hundreds of profiles with one click. Or they can be saved as a PDF for being attached to the report as an appendix.

Because a reliable documentation of the obtained results is pre-requisite for reliable reports and inquired not only by law but the engineers insurance, profiles only stored on paper should immediately be copied or scanned after the inspection for a safe long-term storage.

Experience from thousands of drillings since 1987 clearly showed, that printed profiles, preferably in 1:1-scale, are very helpful and required on the spot for interpretation and evaluation. Such profiles even may be given to clients or other interested people. Digitally stored profiles are best for efficient and reliable reporting.

Resolution, precision, and linearity

There are basically two groups of resistance drilling machines used on the market: electric or electronic recording, and mechanical recording. The first prototype of the inventors Kamm & Voss recorded the resistance mechanically with a scratch pin on wax paper within the drill. Due to resonance and damping effects, these profiles were not linearly correlated to wood density and therefore could not be interpreted reliably. Because of that, Kamm & Voss developed an electrically recording drill that was then further developed and equipped with electronic regulation and recording. With these machines it was possible to prove the method's suitability for tree and timber inspection. These electronically recorded profiles can be linearly correlated to wood density. Within this group of machines, the provided resolution in both drilling depth and measured signal differs strongly, leading to a correspondingly different precision as measured by the coefficient of determination of the correlation to density. Some machines record one value per mm penetration depth, other up to 100. The resistance itself in some machines is digitized in eight bit (0-128), others provide twelve bit (0-4096). Machines with high resolution can reveal tree-ring density variations and incipient decay in contrast to soft intact wood and only such machines are allowed to be labeled with the internationally registered trademark "Resistograph".

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ABSTRACT

Praktische Anwendung der Bohrwiderstandsmessung zur Holzuntersuchung

Bohrwiderstandsmessungen werden seit 1987 angewendet, um Bäume und Hölzer zu untersuchen, wobei manches Einsatzgebiet sehr spezifische Anforderungen an Genauigkeit und technische Eigenschaften des Gerätes stellt. Da es mittlerweile fast zehn verschiedene Gerätetypen mit sehr unterschiedlichen technischen Eigenschaften gibt und für viele Einsatzgebiete nur wenige Gerätetypen sinnvoll anwendbar sind, sollten vor Kauf oder Miete viele praktische Aspekte berücksichtigt werden.

***Schlüsselwörter:** Bohrwiderstand, Holzuntersuchung*

PRODUKTE/MELDUNGEN

RESISTOGRAPH® als Marke bestätigt

Die im Sommer 2011 beim Landgericht Mannheim eingereichte Löschungsklage gegen die Marke RESISTOGRAPH® (der Name sei zu einem Gattungsbegriff geworden), wurde 2012 als unbegründet abgewiesen, wie anschließend auch die beim OLG Karlsruhe eingelegte Berufung. Nach Ablauf der entsprechenden Fristen ist das Urteil nun rechtskräftig.
RESISTOGRAPH® bleibt damit die Qualitäts-Marke zur ausschließlichen Kennzeichnung von hochauflösenden, kalibrierfähigen Bohrwiderstandsmessgeräten, deren Profile eine hohe lineare Korrelation zur Dichte des durchbohrten Holzes aufweisen und damit eindeutig interpretierbare Kurven liefern – im Gegensatz zu den vor 1985 verwendeten Einfachbohrgeräten mit federgetriebener Aufzeichnung.
Die mechanische Aufzeichnung führte zu systematisch fehlerhaften Bohrkurven, weswegen die Erfinder Kamm & Voß 1985 zur elektrischen Aufzeichnung des Eindringwiderstands übergingen. Im Auftrag einer an der Kamm-Voß-Patentanmeldung interessierten Firma erforschte Frank Rinn in seiner Diplomarbeit ab 1986 Möglichkeiten und Grenzen der Kamm-Voß-Idee. Ab 1988 entwickelte er in seiner Firma RINNTECH neue Bohrnadeln, patentierte hochauflösende, elektronische Bohrwiderstandsmessgeräte, bewies deren Präzision und Tauglichkeit und bezeichnete diese ab 1993 mit dem von ihm erfundenen Namen RESISTOGRAPH®. Mit dieser Marke dürfen seither nur präzise messende Gerätevarianten gekennzeichnet werden, die eine eindeutig zu interpretierende Messkurve liefern. Andere Bohrwiderstandsmessgeräte, z.B. mechanisch aufzeichnende, als RESISTOGRAPH® zu bezeichnen, war und ist also weiterhin rechtswidrig.
Weitere Informationen, wissenschaftliche Grundlagen wie auch die zugehörigen Gerichts-Urteile hierzu sind unter www.resistograph.com zu finden.

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