APPRAISAL OF THE SHIGOMETER TECHNIQUE

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ABSTRACT

The Shigometer technique purports to detect decay and other timber defects in living trees. The presence or absence of a defect is predicted from measurements of electrical resistance recorded at intervals along a small-diameter, radially drilled hole.

The technique lacked any predictive ability when applied to **Nothofagus fusca** (Hook. f.) Oerst. (red beech) and the evidence that the technique reliably detects decay in other species is shown to be inconclusive.

In wood, the cell wall substance makes a large contribution to electrical resistance. The tissue in the vicinity of the drill hole is damaged by drilling and consequently its electrical resistance is modified. The factors affecting resistance measured by the technique remain largely obscure.

INTRODUCTION

Beech *(Nothofagus* spp.) forests form the largest indigenous wood resource in New Zealand. However, red beech forest has not been widely exploited, partly because its timber is notoriously defective (Kirkland 1973). The original objective of this study was to evaluate the Shigometer technique for assessing timber defects in red beech forest, but after disappointing results in practice it became necessary to examine the technique itself.

The Shigometer is a portable electrical device which generates, and measures electrical resistance to, a pulsed DC current. The meter is connected to probe electrodes, which permit measurement of electrical resistance (Shigometer resistance) at known depths along a small-diameter hole drilled radially to the pith. Shigo & Shigo (1974) describe the design, operation, and performance of the instrument. It is claimed that the presence or absence of decay and other timber defects in living trees and telegraph poles can be predicted from the radial pattern of resistance observations (Shigo & Shigo 1974; McGinnes & Shigo 1975; Shigo & Berry 1975; Shortle *et al.* 1978).

Working with living trees of several North American species and with telegraph poles, Shigo & Shigo (1974) reported that an abrupt decrease in resistance indicates discoloured or decayed wood, and furthermore that the magnitude of the decrease reflects the degree of wood tissue deterioration.

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McGinnes & Shigo (1975) claimed that the technique is capable of detecting ring shake and discoloured heartwood in black walnut (*Juglans nigra* L.); Shigo & Berry (1975) concluded that the technique detects decay in *Pinus resinosa* Ait; and Shortle *et al.* (1978) reportedly worked out predictive criteria which indicated internal condition in telegraph poles with 93% accuracy.

EXPERIMENTAL PROCEDURES

The Shigometer used in this study, Model 7950, was manufactured by North East Electronics, New Hampshire, and was bought (with the probe electrodes and drill bits) in November 1978.

Electrical resistance was measured in discs of red beech rather than in standing trees. Tattar *et al.* (1972) reported that resistance values in freshly cut discs were comparable to those in the standing tree, and other workers (Skutt *et al.* 1972; Shigo & Shigo 1974; McGinnes & Shigo 1975) have applied the technique to felled trees, logs, and bolts.

Discs 100 $\pm$ 40 mm thick were cut from freshly felled trees, wrapped promptly in heavy polythene bags, and stored in the laboratory for periods ranging from 4 hours to 4 weeks, before resistance was measured. Each radial hole used for measuring resistance was drilled at least 20 mm away from either cut surface of the disc. During drilling, a sharp bit (diameter 2 mm ($^3/_{32}$ in.)) was pushed about 20 mm into fresh wood tissue before being withdrawn and the flutes cleared of debris; the process was repeated until the drill bit reached the centre of the disc. The force of drilling was kept approximately constant but was difficult to assess when friction of the bit became appreciable.

The storage of discs has no perceptible effect on resistance in red beech (Wilson 1980). The pattern of resistance measured in one radially drilled hole in a freshly cut disc was compared with the pattern of resistance measured in an adjacent, freshly drilled hole after storage of the disc for up to 6 weeks. The differences between the two patterns of resistance, measured before and after storage, were slight and no greater than would be expected between the patterns of resistance from the adjacent holes drilled and measured at the same time. This result was obtained in several trials.

The measurement of resistance was begun about 1 min after drilling had been completed. Observations were made at intervals of 2.5 mm, as indicated by painted marks on the probe. Radial depth was measured to the mid-point between the electrodes (which are 5 mm apart and in contact with opposite faces of the hole). The probe electrodes were kept horizontal because in vertical orientation the resistance measured was found to be relatively high and variable. In all other aspects of procedure the manufacturer's instruction manual was followed. Each pattern of resistance was related to the actual condition of the wood, as assessed by the appearance of the disc surface. The categories recognised in this classification were defined in an arbitrary way and included "sapwood", "heartwood", "discoloured heartwood", and "decayed heartwood". In "decayed heartwood" the decay was sufficiently advanced to perceptibly weaken the wood against a pencil point jabbed into the disc surface. "Discoloured heartwood" consisted of heartwood which was markedly discoloured but was not so weakened.

PREDICTIVE ABILITY OF THE TECHNIQUE

In Red Beech

Shigo & Shigo (1974), McGinnes & Shigo (1975), and Shigo & Berry (1975) stress the importance of patterns of resistance rather than absolute values for predictive purposes. Patterns of resistance are the basic diagnostic tool in any practical application of the technique, and the ability of an observer to successfully detect decay from such patterns on a simple presence or absence basis was considered to be the first test of the technique in red beech.

Fourteen trees of red beech, with breast height diameters in the range 30 to 60 cm, were randomly selected and felled in part of Maruia State Forest, Reefton District. Three discs were cut from these trees at heights 1.3 m, 5.3 m, and 9.3 m, and resistance was measured along one radially drilled hole in each. The actual condition of the wood along each radius was then classified using the categories mentioned above. The first four patterns of Shigometer resistance to be measured were discarded subsequently because probe orientation had not been kept constant; the remaining 38 patterns were graphed but not annotated with information on their actual condition. A separate study of the same experimental material provided an unbiased sample of 15 graphed patterns of Shigometer resistance, on which the actual condition of the wood was recorded. The discs were also kept for examination. Three observers made themselves familiar with these patterns of resistance before making independent attempts to predict the presence or absence of decay ("discoloured heartwood" or "decayed heartwood") in each of the 38 unannotated patterns. Predicted condition was compared with actual condition and the results were classified in a two-way table according to whether the presence or absence of decay was predicted and whether decay was actually present or absent. The results were analysed by chi-square tests, one for each observer, to determine whether the technique had any predictive ability at the 95% confidence level (Table 1).

The computed χ^2 values are less than the tabular value, supporting the hypothesis that the presence and absence of decay is predicted independently of actual condition. However, conforming to the observations of other workers (e.g., Shigo & Shigo 1974),

TABLE 1—The attempts of three observers to predict the presence or absence of decay from 38 patterns of Shigometer resistance

Actual condition	n	Predictions					
		(1) Decay		(2) Decay		(3) Decay	
		Present	Absent	Present	Absent	Present	Absent
Decay present	25	20	5	13	12	13	12
Decay absent	13	7	6	7	6	8	5
		$\chi^{2*} = 1.71$		$\chi^2 = 0.05$		$\chi^2 = 0.05$	

* The χ^2 values have a correction for continuity applied to adjust for sample size. The tabular value of χ^2 0.05 with one degree of freedom is 3.84.

Shigometer resistance in red beech tends to decrease as decay progresses. The mean resistances for sapwood, heartwood, discoloured, and decayed wood were approximately 90, 170, 80, and 40 kΩ respectively.

In Previous Work

Quercus rubra L. (red oak) is a species to which the technique has been applied with apparent success (Shigo & Shigo 1974). However, the published data consist of only eight **typical** examples of resistance and do not fairly represent the full range of variability actually encountered. Indeed, the ranges in resistance given for the wood categories hardly overlap (Shigo & Shigo 1974, Table 2), indicating that absolute values of Shigometer resistance could be used for predictive purposes with almost complete confidence although the authors stress that relative rather than absolute values should be used. It is unfortunate that the publication of such selected data means that predictive ability of the technique for red oak cannot be re-assessed by the reader.

The other evidence that the technique works in practice is also inconclusive. McGinnes & Shigo (1975) examined several tree length logs of black walnut with the Shigometer. Unfortunately they did not state the number of logs examined, nor did they publish statistical analyses of their results. They presented data from the radii of only two discs. Shigo & Berry (1975) applied the technique to 71 trees of *Pinus resinosa,* at least 32 of which had patterns of resistance indicating infection. Fifteen of these possibly infected trees were felled and the presence of decay was confirmed in 14. This result appears very promising but it cannot be taken as a formal demonstration that all of the possibly infected trees were actually infected or that any of the possibly sound trees were actually sound.

Shortle *et al.* (1978) tried to develop criteria which could be used later for prediction of decay. Their criteria erred towards indicating decay in doubtful cases. Out of 174 transmission poles 136 were presumed sound and 38 decayed. Leaving aside the seven hollow poles (the internal condition of which was indicated by a sudden decrease in torque during drilling), only 18 of the 31 presumed decayed poles were in fact decayed. Predictive ability could therefore be represented as 58%. They were unable to establish any patterns of resistance which **invariably** meant that decay was present – all 18 of their decayed poles and the 13 sound poles had similar resistance patterns. The three observers who tried to predict the presence and absence of decay from 38 patterns of Shigometer resistance in red beech had a better preparation than they could have expected in a field situation; the patterns used for training were an unbiased sample from the test experimental material. Nevertheless, no predictive ability was demonstrated.

BASIS FOR SHIGOMETER RESISTANCE

Cation Concentration

Shigo & Shigo (1974) stated that the principles on which the technique is based are that resistance to a pulsed electric current decreases as concentrations of cations increase in wood; and that, as wood discolours and decays, the cations potassium, calcium, magnesium, and manganese increase. McGinnes & Shigo (1975) stated more specifically that the Shigometer measures mobile ion concentration within the tree. There have been many studies which report an increase in cation content in discoloured and decayed wood (Tattar *et al.* 1972; Tattar & Saufley 1973; Shortle & Shigo 1973; Safford *et al.* 1974; Tattar *et al.* 1974) and correlate this with electrical resistance. However, experimental procedures involve dry or wet ashing of wood which renders soluble many mineral constituents that would not otherwise contribute to electrical conductivity (Lin 1967). There may well be an increase in mobile ions in decaying wood but it cannot be reliably estimated from such treatments.

Alternatively, one might examine the correlation, if any, between Shigometer resistance and the resistance of the liquid expressed from the wood. This was determined in red beech. A radius along which Shigometer resistance had been measured was split at every third growth ring and then split again on each side of the radius to give rectangular pieces of wood about 90 mm (longitudinally) × 10 mm × 10 mm. The ends, corresponding to the disc surfaces, were shaved off and each piece was put in a small polythene bag and squeezed in a press to express the free liquid. This was collected in a small test tube and an equal volume of de-ionised water added so that the probe electrodes could be fully immersed. The Shigometer was used to measure changes in sap resistance so that a rough comparison could be made with changes in the Shigometer resistance along the radius. The results, illustrated in Fig. 1, show that

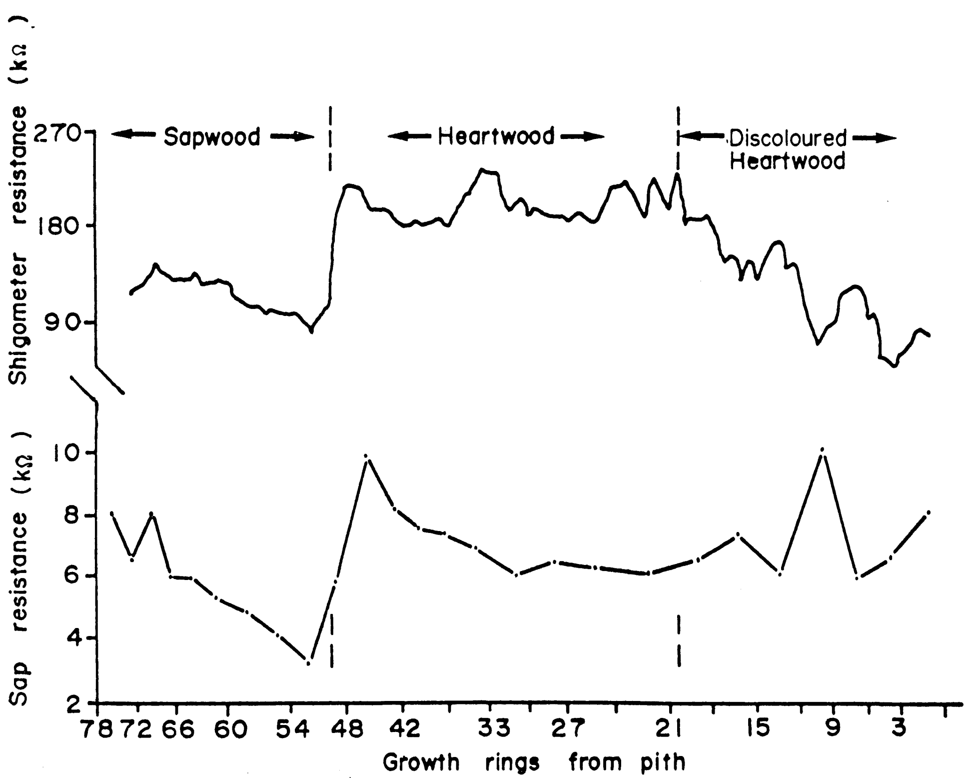

FIG. 1—Shigometer resistance and sap resistance along the same radius of a disc of red beech.

sap resistance is much less than Shigometer resistance and that there are no strongly related variations.

Tattar *et al.* (1974) recognised that interpretation of Shigometer resistance involves many other factors such as ion mobility, moisture content, and wood structure. It is probable that cell wall resistivity, drill hole characteristics, and probe geometry are largely responsible for the absolute differences in sap and Shigometer resistances. Indeed they may have as much influence on Shigometer resistance as does the concentration and mobility of ions in the undisturbed, surrounding, wood tissue. To test this hypothesis a hole was drilled to the centre of a disc and its resistance pattern measured with a probe. The disc was then split across its centre and another hole drilled starting at the pith. The second hole was displaced vertically by at least 20 mm from the first and followed a slightly different radius, emerging at the bark some 20 mm horizontally from the first drill hole. The resistance along this hole was measured. Figure 2 shows the patterns of resistance. Shigometer resistance measurements along two adjacent radii in one disc are expected to be very similar when the holes are drilled in the same direction (Wilson 1980), but Fig. 2 shows that when the holes are drilled in different directions the patterns of Shigometer resistance are not similar. It appears that the longer the drill bit is in contact with the wood tissue during drilling the higher Shigometer resistance tends to become; sapwood resistance is relatively high in the hole drilled from bark to pith and inner heartwood resistance is relatively high in the hole drilled from pith to bark.

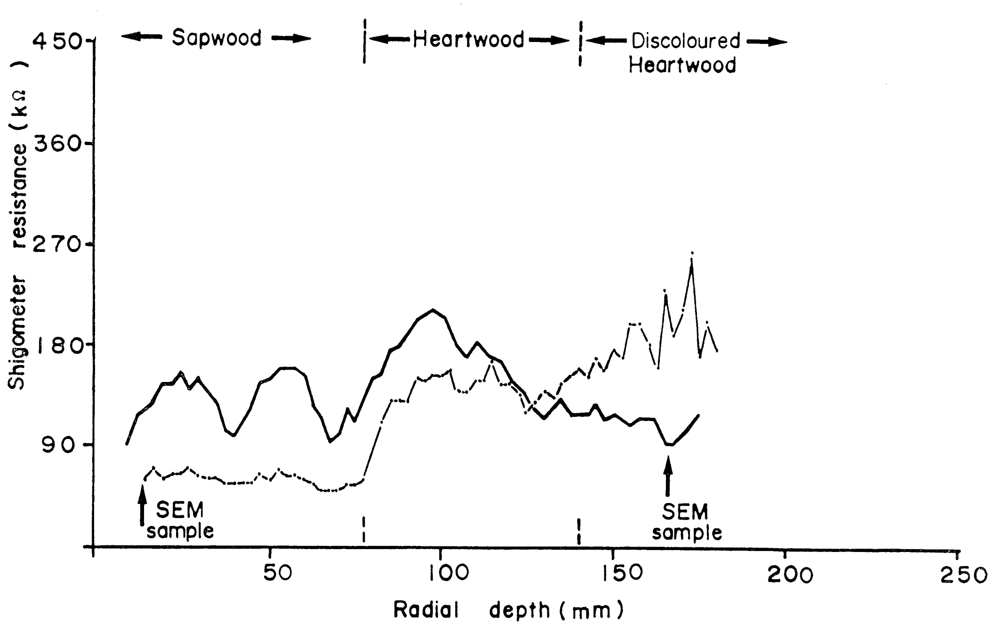

FIG. 2—Shigometer resistance along two adjacent radial holes drilled in opposite directions. Solid line = hole drilled from the outside of the disc to the centre. Broken line = adjacent hole, drilled from the centre of the disc to the outside.

Specimens for scanning electron microscopy (SEM) were taken of both drill holes at the radial depths of 20 mm and 170 mm. Any difference in the appearance of the two holes at these depths should be largely due to the cumulative effect of drilling. The specimens were prepared 18 hours after the measurement of resistance. They were dried in a critical point drier, coated with gold, and photographed in a Cambridge Stereoscan 600 SEM. Two photographs were taken of each specimen (Figs 3 and 4), one a tangential-longitudinal (TL) section and the other a plan view of the lower half of the hole exposed by a transverse section. The micrographs of the hole surface are oriented consistently in relation to the direction of drilling. The sides of the specimens closer to the entrance of the drill hole are on the left in Fig. 3 and on the right in Fig. 4.

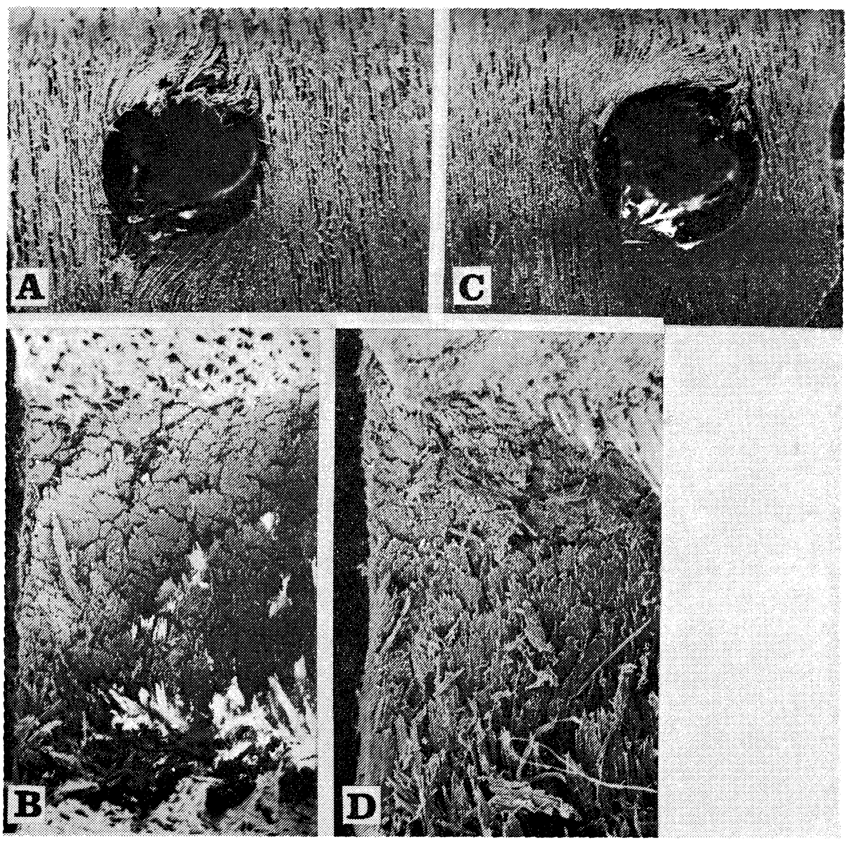

FIG. 3—Views of a radial horizontal hole (diam. approx. 2 mm) drilled from the outside of a red beech disc to the pith.
A and B: Sapwood (radial depth 20 mm).
C and D: Heartwood with incipient decay (radial depth 170 mm).

There are no differences in the appearance of the TL exposures of the drill holes to explain the observed differences in Shigometer resistance. Figures 3 and 4 do show, however, that one cumulative effect of drilling is to alter the characteristics of the hole

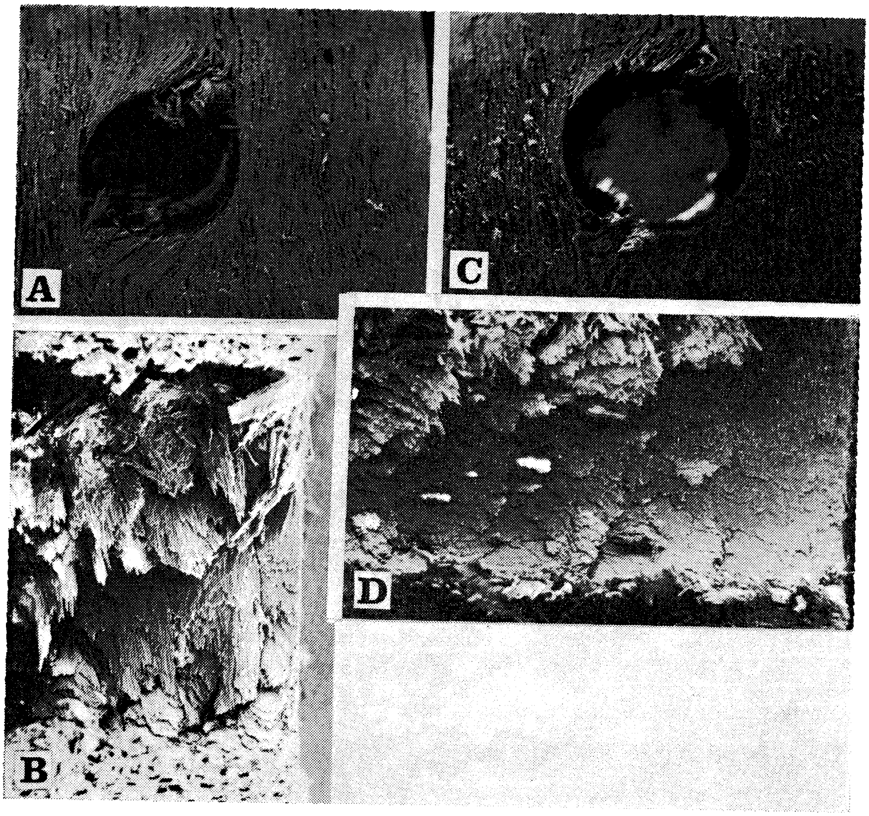

FIG. 4—Views of a radial horizontal hole (diam. approx. 2 mm) drilled from the pith to the outside of a red beech disc.
A and B: Sapwood (radial depth 20 mm).
C and D: Heartwood with incipient decay (radial depth 170 mm).

surfaces. At any radial depth the higher resistance is associated with the smoother, more thoroughly drilled hole. The disorganised fibrous tissue which constitutes the surface of the hole is oriented obliquely (towards the entrance of the drill hole), presumably because the withdrawal of the drill has dragged the fibrous tissue away from the perpendicular.

The electrical properties of the tissue in the vicinity of the drill hole are undoubtedly quite different from those of undisturbed wood. A considerable amount of tissue suffers damage and compression owing to the rotation of the drill, forcing liquid from the vicinity of the drill hole (at least in red beech); during drilling the radial position of the drill tip was often marked by the emergence of liquid on to the surface of the disc, at least 20 mm above the actual position of the drill tip. The fissures created by gross tissue failure in the longitudinal plane must also affect resistivity, and so may the heat generated by friction during drilling. The current flow between the two probe electrodes must pass through this distorted and modified wood tissue. The extent to which this influences Shigometer resistance is not known.

Figure 2 confirms that a variation in drilling technique has an appreciable effect on Shigometer resistance. However, even when drilling technique was kept as standard as practicable, variations in torque and speed of revolution were observed (as the friction of the bit against the hole varied), and no doubt the radial pressure at the tip of the bit, exerted by the operator, varied too. The influence of these individual factors on Shigometer resistance is not known.

Shigometer resistance may also vary with some aspects of measurement procedure such as the pressure, surface area, and quality of electrode contact. The electrodes are sprung apart slightly with the fingers before insertion into the drill hole, to give a firm contact, but the wires bearing the electrodes are not very strong and the pressure of contact could vary with the diameter of the hole or the depth of the electrodes from the surface. The electrodes are strongly convex and appreciable variations in the surface area of contact are possible. The hole surface is fibrous, often rough, and it is not known what effect variations in the smoothness of the hole, the orientation of the debris of the hole surface, or the pressure of contact might have on the quality of electrode contact.

CONCLUSION

Shigometer resistance is a different phenomenon from the resistance of undisturbed wood, and the relationship of the two remains obscure. Since it is not known what the Shigometer technique measures it is impossible to say that, even in theory, it should work. In practice it does not work, at least in red beech, and the evidence that it works in other species is inconclusive.

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