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DETECTION OF DISCOLORATION AND DECAY IN LIVING TREES AND UTILITY POLES

by Alex L. Shigo
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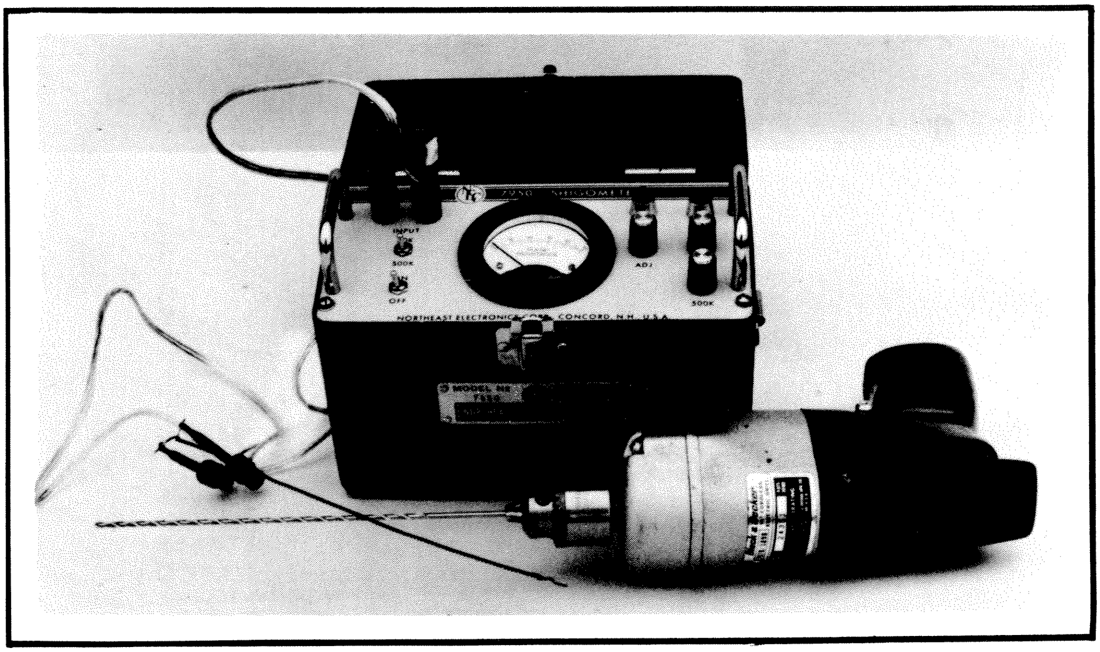

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Abstract

A method is described for detecting discoloration and decay in living trees and creosoted utility poles. The method and devices have come from research involving many people over a seven-year period. A probe was inserted into a 3/32-inch (2.4 mm) diameter hole made by drill bits 8 inches (20.32 cm) and 12 inches (30.48 cm) long mounted in a portable, light-weight, battery-operated drill. The probe was attached by a flexible cable to a portable, light-weight, battery-operated meter, a "Shigometer", that delivered a pulsed electric current and measured resistance to it. As the probe was inserted into the hole, the meter measured in ohms the resistance of the wood in contact with the probe tip. As the probe was pushed inward, if the tip contacted only sound tissues, slight changes in resistance were measured. When the probe tip passed from sound wood to discolored or decayed wood there was an abrupt decrease in resistance. The magnitude of the decrease in resistance indicated the degree of discoloration or decay. The depth of the probe when the needle on the meter began to decrease indicated the position of the discolored or decayed wood.

DISCOLORATION and decay are major causes of damage to living trees, utility poles, and wood products throughout the world. Too often the defects are not detected until it is too late: a tree falls on a house, car, power line, or person; a bridge collapses; a tree that appeared valuable for timber turns out to be valueless because of discolored and decayed wood on the inside; or a utility pole falls during a storm or while being climbed. The wood has been weakened by decay.

Discoloration and decay of wood are caused by bacteria and fungi that digest wood inside of trees and poles, hidden from view. In a living tree, wounds start the processes; microorganisms often invade the exposed wood and discoloration and decay may follow when conditions are proper (for details on discoloration and decay processes see *Shigo and Larson 1969*). In utility poles, decay microorganisms are sometimes active in the poles before they are put in service, or microorganisms may invade at any time later when conditions are proper (for details on decay process in poles see *Eslyn 1970*). In North America, nine species of fungi cause most of the decay in utility poles (*Eslyn 1970*).

In living trees wounds should be prevented. When wounds are inflicted they should be treated properly (*Shigo and Wilson 1971*). Poles should be treated properly with preservatives to prevent decay. But many times even when proper measures are taken for prevention, some microorganisms still invade and discoloration and decay develop. Then early detection of discoloration and decay become all-important. The earlier discoloration and decay are detected, the earlier a decision on action can be made: remove the tree or pole, lower the timber value of the tree, increase tree vigor by pruning, fertilizing, watering, etc.

The need for a method of detecting decay in trees and utility poles has been long recognized and research has been done with X-ray units (*Eslyn 1959*), ultrasonics (*Miller et al. 1966*), and a needle that measures resistance to pressure (*Zycha and Dimitri 1962, Eslyn 1968*). Eslyn (*1968*) reviews other methods for detecting decay in utility poles. The methods and equipment now available have not been accepted widely and put into practice, especially in living trees. The equipment is either too expensive, not easily portable, or not accurate, or the methods require a high degree of training. And, at best, they detect advanced decay and not incipient decay and discoloration.

A new method of detecting discolored and decayed wood in living trees was described by Skutt et al. (*1972*). The basic information for the method came from research on the electrical properties of wood (*Lin 1965, 1967*) and the pioneering work on electrical properties of trees by Fensom (*1957, 1960, 1963, 1965*). The new method is based on two principles: resistance to a pulsed current decreases as concentrations of cations increase in wood; and as wood discolors and decays the cations potassium, calcium, manganese, and magnesium, increase (*Shigo and Sharon 1970, Tattar et al. 1972, Shortle and Shigo 1973, Safford et al. 1974*). As wood decays, cations increase and resistance decreases. Skutt et al. (*1972*) and Tattar et al. (*1972*) showed that the method detected discolored wood and decayed wood in living trees when the wood was above the fiber-saturation point (approximately 30 percent w/w). The method not only detected discolored and decayed wood but indicated the degree of tissue deterioration.

Skutt et al. (*1972*) reported these results from experiments that used a meter first constructed by Ronald M. Lessard.[1] The measurements were made with steel nails insulated except for their tips. As two nails were driven parallel at 2 cm apart into a tree, the resistance to a pulsed current of the wood between the nail tips was measured. Measurements were also made on freshly cut wood sections with the nails and with needle probes of the type used for making moisture readings in wood.[2]

Although the reports on the method showed that discolored wood and decayed wood could be detected accurately in living trees, two important weaknesses kept it from being accepted for wide use in the field: only expensive, fragile laboratory models of the meter were available, and the nail probes and other probing methods were not practical.

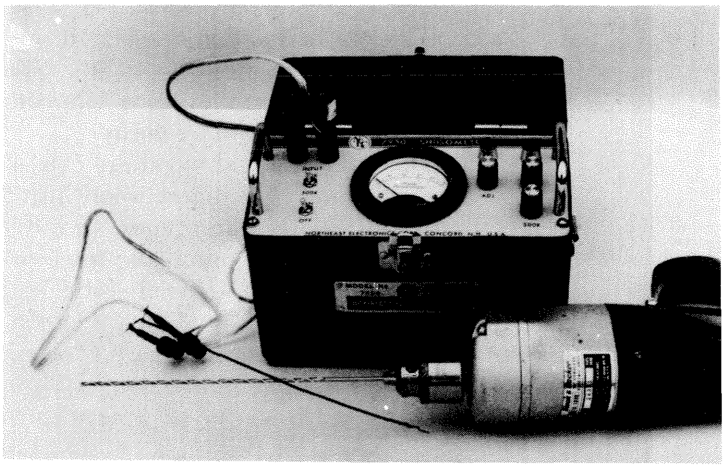
This paper reports a method of detecting discolored and decayed wood in living trees and creosoted utility poles that uses a relatively inexpensive, durable meter with a printed circuit, manufactured by Northeast Electronics Corporation, Concord, New Hampshire,[3] and an inexpensive, single probe developed by the second author.[4,5] The method and devices have been developed through the efforts of many people over a 7-year period.

MATERIALS AND METHODS

The Shigometer

The meter manufactured by Northeast Electronics Corporation has a circuit similar to that described by Skutt et al. (*1972*). The meter is small and light in weight (fig. 1). The printed circuit makes it reliable and durable for field use. It is powered by six 1.4 volt batteries. (Newer models will use 1.5 volt batteries also). It has scales of 50 and 500 K ohms. Both scales and zero can be adjusted by front panel knobs.[6]

Figure 1.—Pulse resistance meter, "Shigometer," twisted wire probe, and drill for detection of discolored and decayed wood in trees and utility poles.



The Probe

The probe was made of two enamel-insulated copper wires, the type used on electric motor armatures. The two wires were twisted together by placing two ends in a vise and the opposite ends in the chuck of a twist drill. Probes of two diameters were made; one from gauge 19 wires and the other from gauge 20 wires. A bell-shaped curve was formed with pliers in each wire at the probe tip (fig. 2).

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[1] Mr. Ronald M. Lessard was a graduate research assistant in the Department of Electrical Engineering, University of New Hampshire and a part time employee of Dr. Alex L. Shigo of the Northeastern Forest Experiment Station, U.S. Forest Service, Durham, New Hampshire when the first meter was developed, and the method first tried.

[2] Probe handle and pins manufactured by Delmhorst Instrument Company, 607 Cedar Street, Boonton, New Jersey 07005.

[3] The use of trade, firm, or corporation names in this paper does not constitute endorsement by the Forest Service or the U.S. Department of Agriculture.

[4] Patent on probe pending by Northeast Electronics Corporation, Airport Road, Concord, New Hampshire.

[5] The commercial model of the meter is called a Shigometer Model 7950 by Northeast Electronics Corporation.

[6] Additional details on the Shigometer Model 7950 can be obtained from the Instruction Manual published by Northeast Electronics Corporation, Concord, New Hampshire.

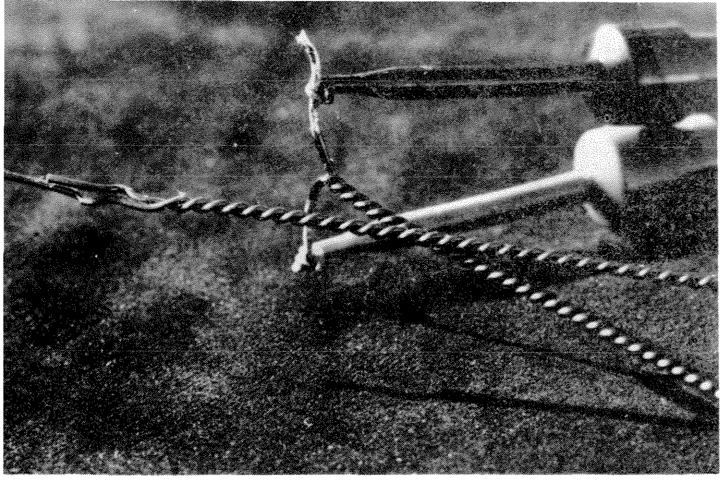


Figure 2.—Twisted wire probe for detecting discolored and decayed wood. Solder coats the exposed portions of the bell-shaped curves to increase sensitivity. Opposite end of probe is attached to flexible cable.

The curves were offset slightly at the tips, as one wire was longer than the other. The enamel coating was removed from the tops of the bell-shaped curves and this exposed portion of the wire was coated with solder. On the opposite end of the probe the two wires were spread at right angles. The enamel coating was removed from these ends to 1 cm and these exposed portions of the wires were coated with solder. Probes 20 and 30 cm long were made. Probes made from 19 gauge wire were 1.7 mm in diameter and had approximately 5 twists per cm. Probes made from 20 gauge wire were 1.3 mm in diameter and had approximately 6 twists per cm (fig. 2).

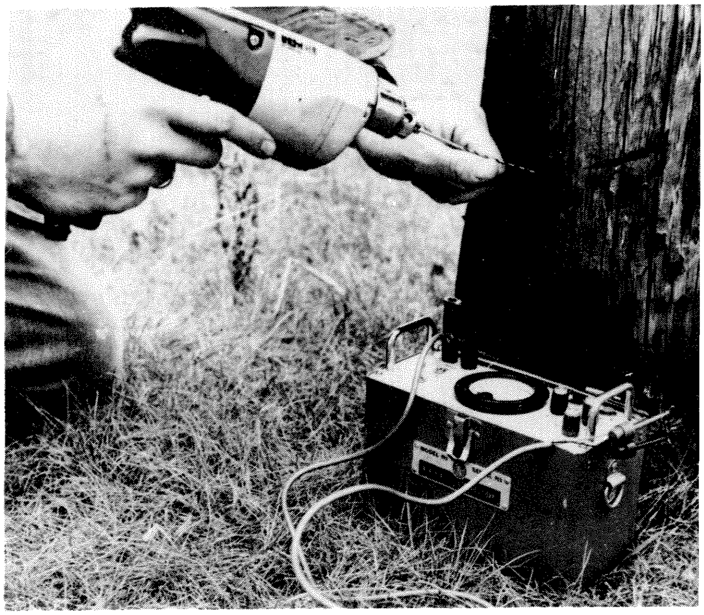
The Method

The meter is turned on and adjusted for the zero, 50, and 500 K ohm scales (K=thousand). The probe is attached to the meter with a long flexible cable (fig. 1). A hole is drilled and the probe is inserted slowly into it. The exposed portions of the wires at the top of the bell-shaped curves at the probe tip press against the walls of the hole. The pulsed current from the meter passes through one wire and into the wood at the exposed top of the curve. The current passes through the wood and returns to the meter through the exposed top of the curve on the other wire. The resistance to a pulsed current of the wood between the exposed tips of the probe is indicated in K ohms on the meter. The probe is pushed slowly into the hole and the needle of the meter watched. When abrupt changes in resistance occur, the probe is pulled out of the hole slightly, and then pushed in again to verify the change and its depth. The probe is pushed in again very slowly to determine the exact depth of the tip when the needle on the meter begins to drop. This indicates the position of the defect. Before the probe is used again the tips are spread apart to restore tension. Care is taken to keep the probe tip clean, especially when used in conifers that ooze sap and in freshly creosoted utility poles. A clean probe tip registers beyond 500 K ohms in open air and in deionized water.

Living Trees

One hundred white pine, *Pinus strobus* L. logs were measured a few days after they were cut. Several holes were drilled to depths of 8 inches (20.32 cm) and 12 inches (30.48 cm) 5 cm from the cut ends. The resistance measurements were compared with the wood at the exposed cut end. The same procedure was done for 13 red oak, *Quercus rubra* L., 9 eastern hemlock, *Tsuga canadensis* (L) Carr., 12 red maple, *Acer rubrum* L., 4 yellow birch, *Betula*

Figure 3.—The long drill bit should be supported between fingers until it is deep into the wood. The turning drill bit will not harm fingers.



alleghaniensis Britt., and 8 black walnut, *Juglans nigra* L. In preliminary studies many species of trees were measured: sugar maple, *A. saccharum* Marsh., paper birch, *B. papyrifera* Marsh., sweet birch, *B. lenta* L., American ash, *Fraxinus americana* L., aspen, *Populus tremuloides* Michx., beech, *Fagus grandifolia* Ehrh., elm, *Ulmus americana* L., balsam fir, *Abies balsamea* (L.) Mill., and white Oak, *Q. alba* L.

Utility Poles

Fifty poles were measured in the field at the groundline and 1 ft (30.48 cm) aboveground. Increment cores were extracted 1 cm from the drill holes and taken to the laboratory for examination and comparison with the meter measurements. Nine additional poles were pulled from the ground and the lower 6 ft (1.83 m) sections were taken immediately to the laboratory. Eight holes to a depth of 8 inches (20.32 cm) were made at groundline, 1 ft (30.48 cm) aboveground, and 1 ft (30.4 cm) belowground. Additional holes were made between these points and below the 1 ft (30.48 cm) belowground position. At least 30 holes per section were made, and the resistance at 1 cm intervals inward was recorded. The sections were dissected to determine the actual condition of the wood at the position of each measurement.

Condition of Wood Surrounding Drill Holes

From May to September 1972, hundreds of holes 3/32 inch (2.4 mm) in diam to 6 inches (15.24 cm) deep were made in 10 each white pine, red oak, paper birch, and red maple on the Massabesic Experimental Forest near Alfred, Maine. The objective of the study was to determine the changes in resistance measurements in the same trees over a 5-month period. Most trees received over 50 holes during this period. Many holes were clustered together while others were separated. The holes were in the trunks of trees ranging in diameter from 10 to 20 cm at 1.4 m aboveground. The holes were concentrated in the trunk from 0.5 to 2 m aboveground. In December 1973, 4 white pine, 3 paper birch, 4 red maple, and 2 red oaks were cut and dissected to determine the condition of the wood surrounding the holes.

Other Probes and Probing Techniques

On living trees and utility poles a wide variety of other probes and probing techniques were tested: steel nails 85 x 3 mm insulated except for their tips, single rods of stainless steel 200 x 2 mm coated with alternating layers of conducting and non-conducting materials, drill bits of varying lengths and diameters insulated except for their tips, and double needle probes of the type used with moisture meters.

On 95 standing utility poles the probes were tested alone and in combination with others: the nails were placed at different positions around the pole and driven to varying depths; a nail was used as a reference probe at one depth and a drill bit insulated except for its tip was driven inward at one position; the single steel rod with alternating coats of conducting and non-conducting materials was pushed slowly into the holes; the double needles were pushed into the poles at varying positions and depths. Similar tests were done on 70 logs from 26 hemlock, *T. canadensis*, as part of a study by the State of Vermont on more effective use of hemlock.

The objectives of our part of the study was to determine whether any meter reading or combination of meter readings could be related to the quality of boards sawn from the logs. The needle probes were used on over 100 balsam fir, *Abies balsamea* and red spruce, *Picea rubra* L. to determine whether the resistance measurement at the cambial area were related to the degree of decline due to defoliation by the spruce budworm. A similar study was done on white pine to determine whether some relationship existed between resistance measurements and vigor. Over 25 mature trees, obviously vigorous and obviously declining, were measured. Details on these preliminary studies and others on the method can be obtained from the first author. Mention of these and other studies is made only to indicate that a wide variety of tests have been conducted with the meter.

RESULTS

The twisted wire probe and Shigometer detected discolored and decayed wood in living trees and utility poles. Discolored and decayed wood was detected not on the basis of absolute resistance measurements but on the pattern of resistance measurements (tables 1, 2, 3, and 4). In sound wood in trees and poles there were only slight changes in the resistance measurements as the probe was pushed inward. In some trees and poles the measurements were beyond 500 K ohms the entire length of the hole. In poles this occurred usually where the wood was dry and sound or freshly saturated with creosote. As the probe was pushed inward through obviously sound tissues, discolored and decayed wood was detected by an abrupt decrease in the resistance. The magnitude of the decrease indicated the degree of tissue deterioration. For example, a decrease from 400 to 20 K ohms indicated advanced tissue deterioration. An abrupt decrease was verified by pulling the probe out slightly beyond the suspected area and pushing it in again slowly through the suspected area. The depth of the exposed top of the bell-shaped curve farthest from the probe tip at the moment the needle began to drop marked the exact position of the interface between sound and discolored or decayed wood. This sharp boundary was most pronounced in living trees where there was an abrupt margin between sound and unsound wood.

In poles the change from sound to unsound tissues was usually more gradual. To determine the exact depth of any tissue change, the probe was extracted at the point where the change occurred and the length to the farther bell-shaped curve was measured. Or, the portion of the probe out of the hole was measured and subtracted from the total length of the probe to the farther bell-shaped curve.

In white pine, red oak, and black walnut that have a heartwood core, the resistance measurements were low in the inner bark (5 to 15 K ohms) slightly higher in the sapwood (20 to 50 K ohms) and higher still in the heartwood (60 to 300 K ohms). Wardell and Hart (*1973*) reported that P, K, Mn, Mg, and Ca decreased as sapwood died and heartwood formed in white oak, *Quercus alba.* The decrease in these cations would result in an increase in resistance to a pulsed current. In some trees the sapwood-heartwood boundary was detected accurately as resistance increased abruptly. In other trees, the gradation of tissue changes from sapwood to heartwood was gradual. Here the probe did measure an increase in resistance but it was not abrupt. In sound heartwood, the resistance measurements decreased only slightly as the probe moved inward through older tissues. Low resistance readings were common near the pith. In many trees discolored heartwood was present. In white pine, the resistance of sound, clear heartwood was usually above 300 K ohms, that of discolored heartwood was from 250 to 200 K ohms, and the resistance of decay was below 200 K ohms. Discolored heartwood in white pine was difficult to detect visually. Although these results are based on 100 trees, it must be emphasized strongly that *the pattern* and not the absolute reading is important in determining the internal condition of a tree, and the resistance measurements given here are examples only.

In red oak and black walnut a similar pattern of changes occurred. The resistance measurements for oak were higher than those for walnut. Discolored and decayed wood in oak and walnut often had resistances below 50 K ohms. Wetwood or advanced discolored heartwood was detected in these trees.

In red maple and yellow birch, which have no heartwood core, the abrupt changes in measurements were the most dramatic. The boundaries between discolored wood, decayed wood, and sound wood were detected accurately.

In hemlock the colored central core, which is commonly called heartwood, had resistance measurements lower than sapwood. This discolored core could be discolored wood that formed as a result of branch stubs, or heartwood that was discolored throughout. More dissections and measurements are needed before the true nature of this discolored core can be resolved. The hemlock had many abrupt increases and decreases in resistance as the probe was pushed inward, indicating that alternating columns of discolored wood, decayed wood, and sound wood were common in these

Table I.—Examples of resistance patterns in red maple

Sound Sapwood, bark to 8 inches inward							
1	2	3	4	5	6	7	8
300	250	220	310	280	260	340	290
500	450	500	500	475	475	500	500
400	320	375	450	400	350	200	210
275	300	260	240	200	205	200	200

Sound Sapwood to 5 inches				Discolored wood 5 to 8 inches			
1	2	3	4	5	6	7	8
300	250	320	310	40	45	35	30
500	450	500	500	80	65	75	50
400	320	375	450	30	40	35	25
275	300	260	240	25	20	18	15

Sound Sapwood to 4 inches			Discolored wood 4 to 6 inches			Decayed wood 7 to 8 inches	
1	2	3	4	5	6	7	8
300	250	320	40	45	35	5	2
500	450	500	80	65	75	3	1
400	320	375	30	40	35	2	2
275	300	260	25	20	18	8	6

Sound Sapwood to 3 inches		Discolored wood 3-5 inches		Decayed wood 5-7 inches		Hollow center 7-8 inches	
1	2	3	4	5	6	7	8
300	250	40	45	5	2	>500	>500
500	450	80	65	3	1	>500	>500
400	320	30	40	2	2	>500	>500
275	300	25	20	8	6	>500	>500

Table 2.—Examples of resistance patterns in red oak

Sound Sapwood to 2 inches		Sound Heartwood 2-4 inches		Discolored Heartwood 4-6 inches		Decayed Heartwood 6-8 inches	
1	2	3	4	5	6	7	8
50	70	130	200	80	60	20	25
70	80	200	320	120	130	15	10
100	90	290	250	60	40	5	3
120	150	400	450	150	125	30	35

Sound Sapwood to 2 inches		Sound Heartwood 2-4 inches		Discolored Heartwood 4-5 inches	Decayed Heartwood 5-6 inches	Hollow Center 6-8 inches	
1	2	3	4	5	6	7	8
50	70	130	200	80	7	>500	>500
70	80	200	320	120	15	>500	>500
100	90	290	250	60	5	>500	>500
120	150	400	450	150	35	>500	>500

Table 3.—Examples of resistance patterns in white pine

Sound sapwood to 2 inches		Sound Heartwood 2 to 8 inches					
1	2	3	4	5	6	7	8
150	200	350	380	340	400	425	325
200	250	300	325	250	320	350	275
300	350	450	475	500	500	400	375
400	425	500	500	>500	>500	>500	400

Sound sapwood to 2 inches		Sound Heartwood 2 to 6 inches			Discolored Heartwood 6 to 8 inches		
1	2	3	4	5	6	7	8
150	200	350	380	340	275	250	225
200	250	300	325	250	200	175	200
300	350	450	475	500	400	375	350
400	425	500	500	>500	450	350	375

Sound sapwood to 2 inches		Sound Heart-Wood 2-4 inches		Discolored Heartwood 4-6 inches		Decayed Heartwood 6 to 8 inches	
1	2	3	4	5	6	7	8
150	200	350	380	275	250	225	200
200	250	300	325	200	175	150	150
300	350	450	475	400	375	200	230
400	425	500	500	450	350	220	210

Table 4.—Examples of resistance patterns in utility poles

Sound wood 1 to 8 inches							
1	2	3	4	5	6	7	8
400	450	425	400	410	450	425	430
300	325	300	330	350	320	360	300
450	400	425	475	500	>500	400	450
500	>500	>500	>500	>500	>500	>500	>500

Sound wood to 4 inches				Decay from 4 to 8 inches			
1	2	3	4	5	6	7	8
400	450	425	400	200	150	100	50
300	325	300	330	200	175	100	125
450	400	425	475	150	125	50	175
500	>500	>500	>500	400	450	275	300

trees. Results of the studies on hemlock suggested that resistance measurements of the tissues midway through the pith and the sapwood-discolored wood boundary were most related to the grades of boards sawn from the logs. When low resistance was measured in these tissues, more low quality than high quality boards came from the log (detailed results of this study can be obtained from the first author).

In all trees that had hollows, they were detected. The tissues surrounding the hollow were discolored or decayed, and very low measurements resulted. When the probe tip penetrated the hole, the needle on the meter swung from low readings on the left abruptly to the right, off scale, indicating infinite resistance; probe in air. When the tip of the probe touched the opposite side of the hollow, the needle swung abruptly back to the left; on scale. The diameter of the hollow was determined from the depths of the probe when the needle swung off scale to the right and then back to the left on scale.

In some trees the drill hole penetrated columns of advanced wetwood. (Wetwood is wood that has high moisture, pH, and concentrations of cations, and gas resulting from invasion of microorganisms, especially certain species of bacteria). Water and sometimes gas flowed from the holes. The water flowing out the hole soaked the walls with cations, and only low readings were recorded the entire length of the hole. Wetwood was common in paper birch, yellow birch, red maple, and black walnut.

Utility Poles

Of the nine poles that were pulled and dissected, all had some decay; four had decay 1 ft (30.48 cm) belowground, five had decay at groundline, and five had decay 1 ft (30.48 cm) aboveground. The meter detected decay accurately in all poles. At 1 ft (30.48 cm) aboveground the resistance was over 500 K ohms in sound, dry, or creosoted wood. When the probe tip touched incipient decay, the needle on the meter swung from the right abruptly to the left, on scale. The abrupt needle movement from off scale on the right to on scale on the left was indicative of an early stage of decay. The magnitude of the decrease in resistance indicated the degree of tissue deterioration. At the groundline when some moisture was in sound wood, the resistance was lower than in dry poles, but there was no abrupt drop in resistance as the probe was pushed the entire depth of the hole. And again, any abrupt decrease indicated decay. The same pattern occurred at 1 ft (30.48 cm) belowground.

In some poles the central core of heartwood had not been penetrated by creosote. This is common. In sound heartwood cores, whether penetrated by creosote or not, there was a slight increase in resistance over the creosoted sapwood; but in decay in the heartwood cores, the resistance decreased.

In the 50 poles measured in the field at 1 ft (30.48 cm) aboveground and at groundline, the same pattern of measurements occurred as in the dissected poles. At groundline, 19 poles were sound and had resistance readings beyond 500 K ohms, the entire depth, 11 had some decay with readings between 0 and 200 K ohms, and 10 had small pockets of incipient decay. At 1 ft (30.48 cm) aboveground 20 poles had resistance measurements beyond 500 K ohms, 4 had some decay with resistance below 500 K ohms, and 16 were generally sound with very small areas of unsound wood. The presence and position of decay in the poles was confirmed by close examination in the laboratory of the large increment cores. The meter was accurate in detecting decay in all poles.

Decay was most advanced at the groundline to 1 ft (30.48 cm) belowground in the nine poles that were pulled and dissected. Poles with decay at the groundline were sound at the bottom and 2 ft (60.96 cm) aboveground.

Measurements on trees and poles were continued until February, 1974. The meter was kept outside in temperatures near 0°F (−18°C) for 8-hour periods during the tests. The meter performed perfectly under winter conditions and decay was detected except when the wood was frozen. But in most cases with living trees the wood was seldom frozen more than 5 cm in and decay was still detected when it occurred deeper in the trunk.

Results of Drilling Holes in Trees

Discolored wood was associated with all drill holes after 1 and 2 years, although all but a few were healed. The discolored column associated with the hole was approximately the diameter of the hole and extended from 1 to 20 cm above and below the hole. The discolored columns were most advanced where many holes were clustered. The wood that formed after the hole was made was not discolored. The discolored columns were most advanced in paper birch and red maple. Very small columns–1 to 5 cm in length–were in oak. The slight discoloration in the heartwood was difficult to see after the wood dried. In white pine it was difficult to see the faint outline of the discolored column, even immediately after it was dissected.

Drill Procedures

A 30 cm deep hole was drilled in a pine in 15 sec. In birch and maple a 20 cm deep hole was drilled in less than 30 sec., and in oak, 30 to 50 sec. In poles a 20 cm deep hole was drilled in 10 to 20 sec. From drilling to measurements took less than 3 min in poles and trees.

In many cases the drilling procedure alone detected advanced decay, wetwood, or a hollow. A sudden release on the torque pressure indicated decay or a hollow. And the dark drill bit shavings also indicated that discolored or decayed wood was present.

Other Probes and Probing Techniques

The nails that were insulated except for their tips did detect discolored wood and decayed wood in trees as reported by Skutt et al. (*1972*) and Tattar et al. (*1972*) when the tips touched the defect. They detected decay in poles also. But it was very difficult to pound them in and extract them. The nails used in various patterns around poles and trees did not accurately detect internal decay unless the tips of the nails touched the decay.

The single steel probe with the alternating coats of conducting and non-conducting material gave inconsistent results. When the probe tip made close contact with the walls of the hole, decay was detected. The coatings were very fragile and slight cracks in the coatings made the probes useless. The probe often would not penetrate the hole because the holes were slightly curved and the probes were straight. The close layers of conducting and non-conducting materials caused the probes to give false readings due to capacitance effects. The drill bits that were insulated except for their tips detected decay, but it was difficult to operate two drills at the same time. The technique was cumbersome.

Combinations of probes and other probing techniques were not consistently accurate. The nail-reference probe used with a drill insulated except for the tip was not accurate.

The double needle moisture probe was accurate in detecting discolored and decayed wood on the freshly cut ends of logs. The probe detected discolored heartwood and slightly colored wetwood in sapwood. As a research tool, the needle probes indicated the gradation of tissue deterioration from advanced decay to the early stages of discoloration.

The results of studies on white pine, balsam fir, and red spruce suggest that there is a relationship between low resistance (5 to 10 K ohms) and high vigor, and higher resistance (11 to 30 K ohms) and low vigor or advanced degree of decline.

DISCUSSION

Discolored and decayed wood was detected in trees and utility poles by the pattern of changes in resistance to a pulsed current. An abrupt decrease in resistance indicated the presence of discolored or decayed wood. The Shigometer with the twisted wire probe has the potential for practical use in the field. Compared to X-ray units and ultrasonics, the equipment for the resistance method is very inexpensive, safe, and requires very little training. The equipment is light in weight, easily portable, and very durable under winter and summer field conditions. And, when it is used properly, the measurements are accurate.

Some discolored wood was associated with the holes made by the drill bits after two growing seasons even though most of the holes healed. The discolored wood associated with holes in white pine and red oak was very slight. The number of holes—often over 50 in one area of the trunk—would never be drilled in one tree under normal field testing. Where the tree was to be cut in a few months, little or no discoloration would be associated with the hole. When conifers or deciduous hardwoods that have a heartwood are to be drilled, very little discolored wood would result. The minute column of discolored wood would not harm an ornamental tree. Discolored and decayed wood is compartmentalized in living trees. The tissues that form after a wound are not infected unless other wounds are inflicted (*Shigo and Hillis 1973*).

The question may be asked concerning the value of the twisted wire probe when a hole must be made first. Why not just extract an increment core? The hole made by an increment borer is many times larger in diameter—8 to 12 mm—than that made by the drill bit—2 to 3 mm. The columns of discolored wood, and sometimes decay of wood associated with such large increment borer holes are many times larger than those associated with the holes made by the minute drill bits (*Lorenz 1944, Hepting et al. 1949*). Houston (*1971*) showed that increment borer holes treated with some chemicals, especially those that restricted oxygen, retarded the development of discoloration in red maple and yellow birch. If the slight amount of discolored wood was considered a problem in the small drilled holes, the holes could be treated with chemicals to minimize the development of discoloration. The same could be said for poles, where creosote could be applied to the drill hole.

The increment core presents some more serious problems. The major one is that the core must be examined carefully by an expert before incipient decay or discolored wood, especially discolored heartwood, could be detected with certainty. Often, the core must be taken to a laboratory for such an examination. The normal change of color of heartwood not penetrated by creosote in utility poles would be very difficult to differentiate from the color of incipient decay. With the twisted wire probe, the slightest changes in the tissues are detected.

The probe and meter indicated the position of discolored and decayed wood, and it indicated how advanced the deterioration was. From this information the hazard risk of poles and ornamental trees, and the timber value of forest trees could be determined.

There are still some situations where the probe will not detect discolored or decayed wood. When the drill hole is flooded by water from a wetwood zone is an example. Still the boring at such a zone and the rush of water and gas from the hole indicates an advanced wetwood zone. The question then is: do you need the probe where the condition of the wood surrounding the hole is obvious? Another situation where the probe does not function properly is in dry decay such as that associated with some wounds on conifers. But, preliminary results (*Joe Clark, Forest Products Laboratory, U.S. Forest Service, Personal Communication*) suggest that dry areas in wood products can be rewetted with deionized water and then the probe will detect decay. Also preliminary results (*James Ward, Forest Products Laboratory, U.S. Forest Service, Personal Communication*) suggest that the probe can be used to sort timbers for kiln drying. Boards with bacterial wetwood gave low readings. Such boards often require special kiln schedules. And because moisture and concentrations of cations in the cambial area of living trees are altered as they wane, the meter may be helpful as an indicator of tree vigor, or the degree of decline.

Zhuravleva (*1973*) showed that the resistance of cambial tissues in *Picea abies* was inversely correlated with annual radical increment. Vigorous trees had low resistances while low vigor trees had high resistances. The method can also help as a research tool to quantify changes in wood tissues after wounding and invasion by microorganisms. At moisture contents below the fiber-saturation point the meter acts as a regular moisture meter. An expanded scale to 3000 K ohms with other minor changes in the electrical circuit would convert the present meter to a moisture meter that could measure moisture to 5 percent w/w. (This is now being done by Northeast Electronics Corporation.)

Many other possibilities exist for the use of the meter with other types of probes and for the single probe in trees, poles, bridges, houses, and a wide variety of wood products. The details of these uses must come from additional research.

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