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# A PROBE FOR ACCURATE DETERMINATION OF MOISTURE CONTENT OF WOOD PRODUCTS IN USE

## Summary

The fabrication and use of a simple, inexpensive, reliable probe for determining moisture content of a wood product in use is described. The probe, made primarily from a strip of wood, can be used at moderate temperature, at high and low moisture conditions, and for determining average atmospheric moisture conditions. Furthermore, the probe is likely to have use for wood–moisture measurements in kiln drying, high–temperature drying, fire testing, paint studies, and investigations of low–temperature environments where moisture amounts and changes are of major significance.

# A PROBE FOR ACCURATE DETERMINATION OF MOISTURE CONTENT OF WOOD PRODUCTS IN USE


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## Introduction

The right moisture content is the key to maximum performance of wood products that are in service. The U.S. Forest Products Laboratory has initiated an extensive program to secure information on the average moisture contents various wood products are likely to encounter in service.

To help secure this information to improve the service of wood products, an economical and easily adaptable research method has been devised that offers greater adaptability versatility, economy, and accuracy for many research purposes than does the use of the conventional pronged moisture meter.

This system used with a conventional moisture meter introduces a sensory element of wood, a probe. However, it does not have the limitations of the conventional pronged type of moisture meter.

Became of the ease of fabrication, many moisture elements can be fabricated in various sizes. The elements, unlike the prongs of the conventional moisture meter, can be placed in a number of positions in wood products in use and left there. Thus they give moisture content measurements over seasons and years. The long-term readings, in turn, can be used in conjunction with an automatic data system.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Because of their adaptability, these elements can be made to be placed to depths of 10 to 12 inches for use in laminated beams. They can be used, too, in remote positions, such as in otherwise inaccessible interior walls.

Significant, too, is the elimination of the variation of the electrical resistance of the wood tested, for accuracy in moisture content readings is within 1 percent. Also, as contrasted to the conventional moisture meter, in using this system moisture contents can be read effectively at a lower range of moisture contents.

The element, or probe, for this system consists of a small rectangular piece of wood coated on two opposite faces with conductive silver paint, (fig. 1). The silver paint electrodes are connected to a resistance-type moisture meter by two wire leads.

More than 100 of these moisture elements are being used at the U.S. Forest Products Laboratory for determining moisture content profiles in composite wood wall sections of an experimental structure under winter and summer exposures. Approximately 1,000 are being used to determine moisture gradients in laminated members in structural use. In addition, some hundreds are used for determining moisture profiles in laminated bridge timbers.

The primary purpose of this report is to discuss the design and fabrication of these wood probes for use in research.

## Design of the Probe

An element for determining the moisture content of wood involves careful design and fabrication. Significant factors considered were: (1) the response of the element to the range of electrical resistance measured by the resistance moisture meter, (2) convenient shape, and (3) overall accuracy.

### Electrical Resistance

The probe is essentially an electrical-resistance sensor that changes its resistance in response to variation in moisture and temperature. Thus it replaces the pin electrodes used with a conventional resistance-type moisture meter. The element was made to respond, at a particular temperature, to a range of electrical resistance that a conventional resistance moisture meter could accept. The moisture meter used in testing the probe has a resistance-measuring range of $10^5$ to $10^{10}$ ohms, or of approximately 35 to 7 percent moisture content.

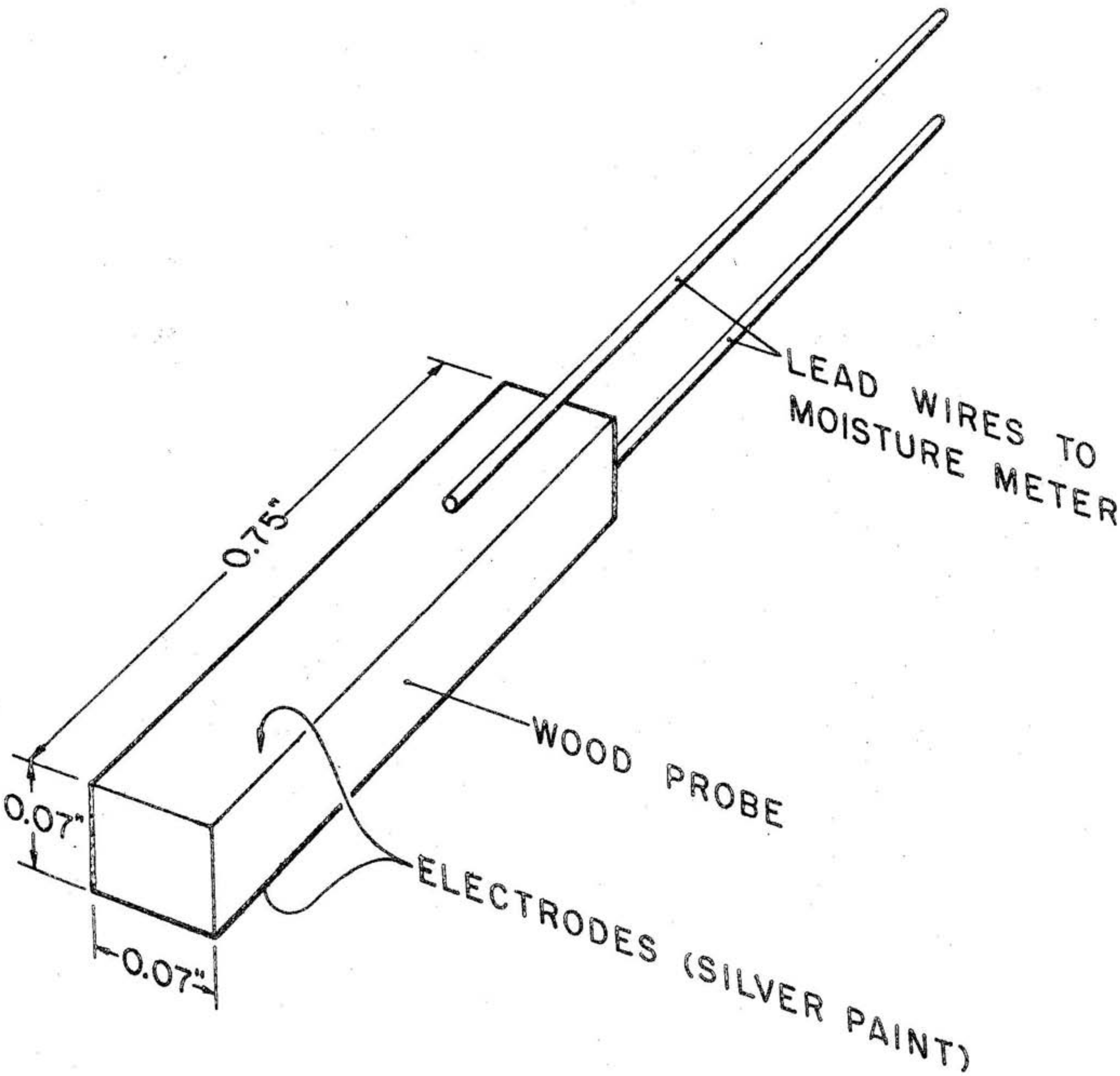


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Figure 1.--Plan of the wood probe.

To design a direct-reading moisture probe from wood material, knowledge of the relationship between the geometry and the electrical resistance of the probe is required. In general, the electrical resistance of the probe follow the equation:[2]

$$R = \rho \frac{d}{A} \tag{1}$$

where

R = electrical resistance, ohms
ρ = electrical resistivity, ohm-inch
d = distance between electrodes, inch
A = area of the electrode, square inch

The electrical resistance R of a probe at different moisture content values must follow the resistance-moisture content relationship shown in figure 2. The optimum resistance is designed into an element in the following manner:

As shown in equation (1), the electrical resistivity of the wood material must be known to calculate the required d and A. A value of the resistivity of a wood specimen was obtained by cutting a rectangular piece of flat-sawed material to convenient dimensions (1/4 x 1/4 x 2 inch) with the long dimension along the grain. The material was conditioned to about 7 percent moisture content before the dimensions were measured for calculation purposes.

Conductive silver paint was spread on the two opposite flat-sawed surfaces and allowed to dry. The electrical resistance was measured, and the electrical resistivity was calculated from equation (1). In addition, the ovendry moisture content of the sample was determined for subsequent use. For convenience, any value of resistivity obtained was assumed constant for the wood sample of specific grain orientation and moisture content used. Good results were obtained with tangential electrode surfaces and a sample moisture content of 7 percent at 70° F.

The value of R in equation (1) was found by using the curve of figure 2 and the 7 percent moisture content. Thus the moisutre content of 7 percent gives an R value of $1.5 \times 10^{10}$ ohms. Equation (1) was used to determine the relative values of d and A which gave a desirable shape for the probe. The author assumed a fixed length of 0.75 inch for calcuation purposes.

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[2] Sears, F,W., and Zeanansky, M.W. University Physics, 2nd ed., Addison Wesley Publishing Co., Inc., Reading, Mass., 1955.

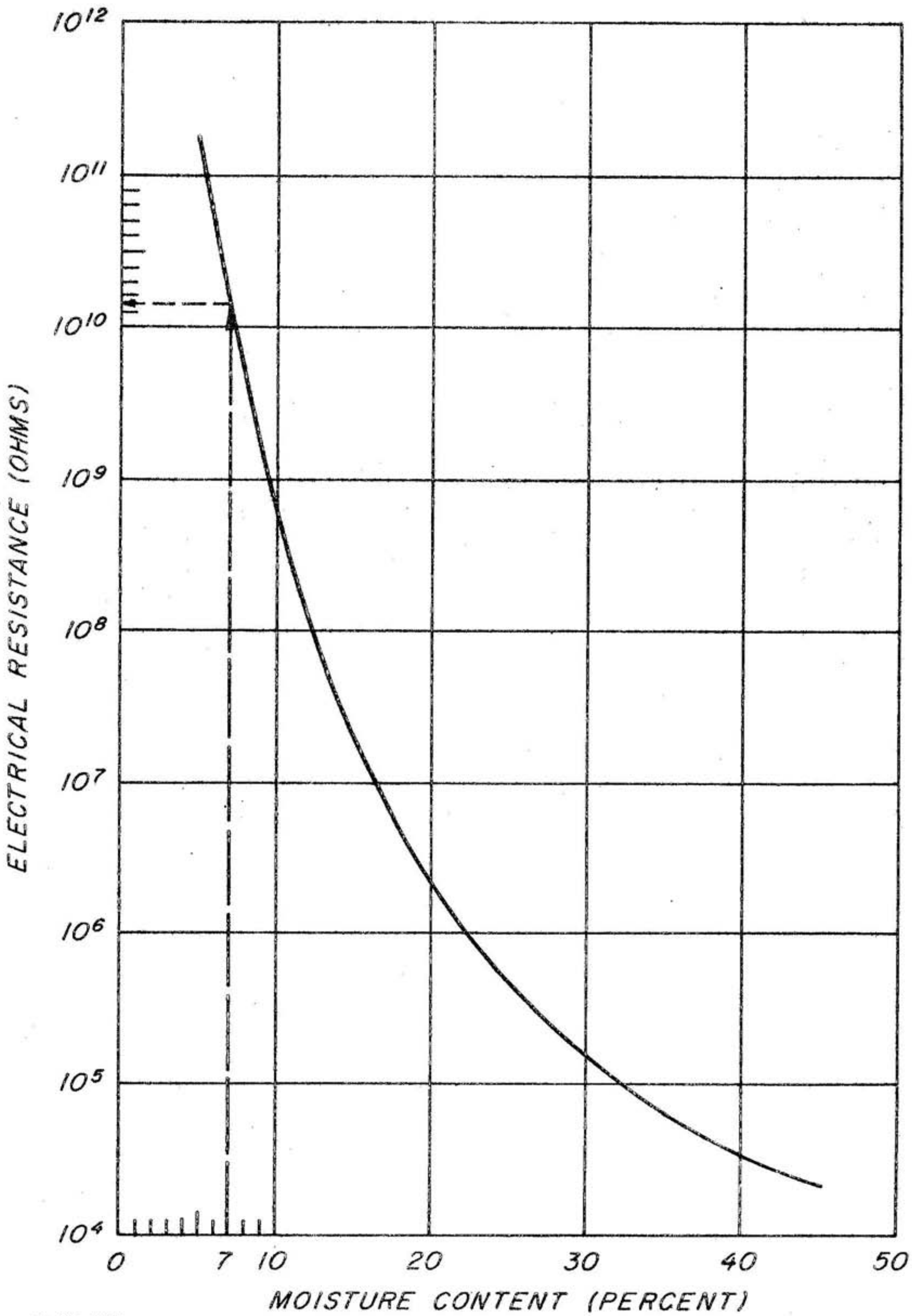


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Figure 2.--Relationship of moisture content to electrical resistance, showing resistance value at 7 percent moisture content.

Since temperature change has an inverse effect on the electrical resistance of a probe, independent of moisture content, temperature adjustments are necessary when the probe is exposed to temperatures above and below a base temperature of 70° F. This temperature was selected because most conventional moisture meters are calibrated at 70° F. Temperature corrections that have been published for pin electrodes can be used for moisture elements.[3]

## Shape of Probe

The shape of a device for determining moisture content is strongly influenced by its use. For convenience, measurement of wood moisture content involves the use of a small-diameter hole drilled to the needed depth. Thus a long slender design is a convenient shape for a moisture element.

Because of the slender shape the conductive silver paint electrodes can be applied easily. This shape also facilitates uniform control of the electrode area and the distance between electrodes ($d$ and $A$, equation (1)). This factor is important in minimizing variation between probes.

Usually, in making moisture content measurements, a number of probes are needed; consequently, ease of fabrication is desirable. The slender design is fabricated easily because the cross-section dimension for at least two dozen probes can be machined at once.

## Accuracy of the Probe

The probe registers accurately to within 1 percent moisture content. Factors that contribute to the small deviation are: (1) variations among individual moisture elements, (2) hysteresis, and (3) calibration differences for species.

Preselection of elements reduces the element-to-element variability. The author exposed a group of elements to 98 percent relative humidity at 70° F. and selected those that read ± 0.5 percent moisture content at adsorption equilibrium conditions.

Only in registering atmospheric moisture conditions was the variation due to hysteresis significant, since wood from which the readings are taken is also subjected to the effects of similar hysteresis. The maximum variation amounted

[3] James, W.L. Electric moisture meters for wood. U.S. Forest Service Research Note FPL-08. Forest Products Lab., Madison, Wis., 1963.

to 1-1/2 percent moisture content in the laboratory tests. Thus the prediction for atmospheric moisture must include the correction.

In calibrating the meter-read moisture content against the ovendry basis moisture content of Douglas-fir (Pseudotsuga menziesii), a ± 0.5 percent variation was noted in moisture content to fiber saturation point. Further investigations for other species indicated but small variations. These variations have been attributed to variations in sorption behavior.

## Fabrication of Probe

Since this type of moisture probe is not available commercially, the details for its fabrication are discussed under the headings of wood species, machining, electrode placement, and wire lead attachment.

### Wood Species

Careful selection of uniformly close-grained wood material is essential for minimizing interprobe variation. Good results were obtained using sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). The sample wood should be straight grained and cut either radially or tangentially. Uncontrolled variation in grain results in difficult fabrication and differences between probes.

### Machining

Blanks for the probes can be machined from strips cut in the longitudinal direction of the wood. Thus thickness and width can be machined accurately before the probes are cut to length.

A simple tool can be used effectively to shape the wood strips to dimension. This tool is a quarter-inch hardened steel plate with 1/2- by 1/8-inch slots along one or two edges (fig. 3). The rough-sawed wood strips are drawn through the slots to remove excess surface wood. Several passes diagonally across the 1/8-inch slot may be necessary to bring the wood to desired dimension.

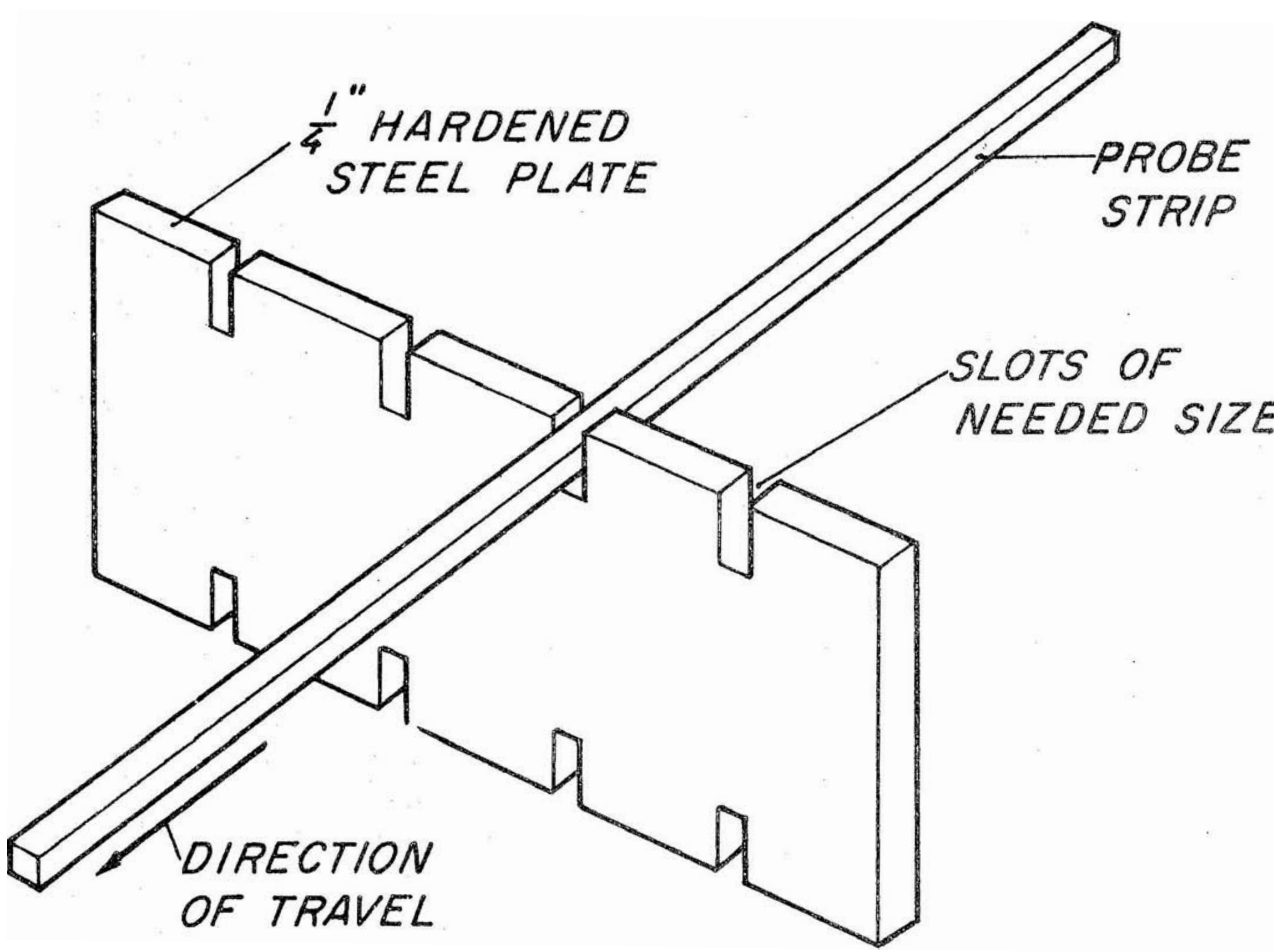


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Figure 3.--Tool for shaping strips for probes to final thickness and width.

The moisture content of the wood strips must be controlled to obtain accurate dimensions for all the finished probes. Succcss has heen obtained when the strips have a uniform moisture content of 7 percent. The finished probe strips may be lightly sanded to remove any wood splinters.

Good results have been obtained with a square dimension of 0.07 inch for the tangential and radial surfaces. Other thickness and width dimensions can be used depending on the resistivity of the particular species sample and the kind of moisture reading to be made.

## Electrode Placement

When large numbers of probes are prepared, the electrode surfaces should be applied while the probes are in strip form. Complete paint coverage of the two opposite tangential surfaces is required for good results.

When the electrode surface is dry, the unpainted surfaces should be inspected for paint spill. If found, the paint can be easily removed by scraping with a razor blade or a similarly sharp instrument. The probe strips are cut to 0.75-inch lengths with a sharp razor blade.

Either a representative sample or all the partially finished probes should be placed in a standard environment, preferably a high equilibrium moisture content condition. When the samples reach equilibrium moisture conditions, the probes are temporarily connected to a moisture meter to check for probes that do not read within tolerance. An equilibrium moisture content level of 20 ± 0.5 percent in a 90 percent relative humidity at 70° F. has commonly been used for such checks.

## Wire Lead Attachment

Copper wire leads are attached to one end of the probe by the following technique. Two small-diameter insulated copper wire leads, 6 to 8 inches long, are stripped of insulation at both ends. At one end of each lead the wire is clipped so that 1/4 inch of bare wire is exposed. Each such lead is bent slightly and the 1/4-inch exposed portion is placed on one end of the element electrode in a direction parallel to the length of the probe. The other lead is similarly placed, but on the opposite electrode surface. A small, clamp is placed over the end of each wire to hold the wires firmly in place on the electrode surfaces.

A small amount of adhesive, a cellulose acetate glue, is placed over part of each wire Bead for effective bonding to the electrode surfaces. For increased lead-to-electrode bond strength, additional adhesive can be placed between the leads at the end of the probe. The adhesive is allowed to dry before the clamps are removed.

To complete construction, a small amount of the conductive paint is placed over the exposed copper wire, establishing electrical contact between the copper lead and its corresponding electrode. When the paint is dry, the probes are ready for use.

## Other Uses for the Probe

Use of the wood probe is not limited to moderate temperatures and normal moisture contents. Some research investigations require moisture-measuring devices that will be useful in both subzero and high-temperature conditions as well as in extremely dry (below 6 percent) and wet environments above the fiber saturation point. The probe can also be used to measure average atmospheric moisture conditions.

### High and Low Temperatures

As noted previously, temperature affects the electrical resistance properties of an element. Use of the probe in subzero or extremely high-temperature environments causes such a large resistance change in the probe that the resistance sensitivity of the moisture metes is exceeded for the total moisture content range of the probe.

The temperature range of the probe can be partially extended to subzero and moderately high temperatures (130° F.) without element modification, so long as temperature adjustments are made to a base of 78° F. For example, high moisture conditions in subzero temperatures can be accurately determined with this device. However, low moisture conditions at subzero temperatures cannot be determined because the probe's resistance exceeds the resistance limits of the moisture meter. Likewise, low moisture coniditions can be predicted at moderately high temperatures, but high moisture conditions at the same temperatures cannot be determined because the resistance sensitivity of the moisture meter is exceeded.

When wide ranges of moisture information are desired in subzero or high-temperature environments, the probe must be modified (adjustment of A and d) to shift its resistance range to a new base temperature. For instance, the distance between electrodes can be reduced, thus reducing the probe's resistance under room-temperature conditions.

When this modified probe is used at a base temperature of 0° F., the resistance will increase to a level comparable to the unmodified probe at 70° F. Likewise, the probe can be modified. for high-temperature environments, such as in a dry kiln, by increasing its resistance relative to 70° F. (increasing d). When the modified probe is exposed to a base temperature of 160° F., its resistance will decrease to a point comparable to the unmodified one at 70° F. The temperature-adjustment data for the low- and high-temperature probes are being analyzed at the Forest Products Laboratory.

## Low and High Moisture Conditions

Many moisture-measurement situations require accurate information at moisture levels below 6 percent moisture content and at levels above the fiber saturation point. Both extremes pose specific problems that require some modification of the moisture element.

Lithium chloride treatmenit.--The measurement of low moisture content values at moderate temperatures with a conventional resistance moisture meter fa limited by the resistance sensitivity of the instrument. The probe, however, can be designed to exhibit different resistance values at my moisture content and temperature combination. For example, it can be treated with a lithium chloride aqueous solution of sufficient concentration to decrease the electrical resistance of the element without destroying its hygroscopicity. The modified probe when exposed to dry moisture environments can be read with a conventional moisture meter.

Actual moisture content values of a wood specimen can be obtained by a calibration plot of actual moisture content of a wood specimen and the indicated meter reading. Moisture content values as low as 3 percent have been measured with the lithium chloride-modified probe. Use of the modified device has been limited to environments under 40 percent relative humidity at room temperature. Primary use of the lithium chloride moisture probe has been for determining moisture content of furniture exposed to dry indoor environments during winter.

Pentachlorophenol treatment.--Long-term use of moisture probes in wet environments at moderate temperatures involves some risk of mold or decay contamination of the probe. Such contamination would certainly give questionable results since fungal activity on or in the probes will decrease their effective resistance by short circuiting the electrodes. In addition, fungal growth on or in probes could permanently damage the wood, rendering them unusable.

A method to reduce the fungus hazard involves use of a pentachlorophenol treatment. Evaluations of the overall effectiveness of the pentachlorophenol treatment are under way. Preliminary results indicate that suitable concentrations of pentachlorophenol in ethyl alcohol do not affect electrical resistance, and that they are effective in preventing fungal activity on and in the moisture probe.

For treatment the probes are placed in a 10 percent solution of pentachlorophenol crystals dissolved in 95 percent ethyl alcohol for 5 minutes. This period insures adequate penetration; then the probes are carefully spread out to air dry for 12 hours. While treating, skin contact with the pentachlorophenol solution should be avoided.

### Measurement of Atmospheric Moisture

The probe can also be used to determine average atmospheric moisture conditions. Normally such a probe is fabricated to smaller dimensions (0.05 x 0.05 x 0.75 inch) than the unit used in wood moisture content measurements (fig. 1.), because the need is for faster response to moisture. These smaller probes are being used for atmospheric moisture determinations at moderate temperatures (70° F. base temperature). Evaluations of similar devices for low- and high-temperature environments are in progress at the U.S. Forest Products Laboratory.

## Use of the Moisture Probe

Because of the fragility of the probe, care is required when making measurements of wood and atmospheric moisture. In making measurements at remote points, the lead wires can be run for considerable distances to a central point for convenience. The best results are obtained when lead wires are used that have insulation with high electrical resistance, Actual wire size is not critical, since my lead wire resistance is not significant when compared to the resistance of the probe.

If the temperature of the probe is unknown, actual measurement can be made with a thermocouple or thermistor placed alongside the probe. In my instances, temperature data are also desired.

In addition to current uses, others planned for the wood probe are for wood materials used in kiln drying, high-temperature drying, fire testing, paint studies, and investigations of low-temperature environments where moisture magnitudes and changes are of major significance.

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