A Sensitive Wood Element Hygrostat

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THE HYGROSCOPIC property of wood that causes it to absorb or lose moisture, depending upon the relative humidity of the surrounding atmosphere, has long been used as a means of controlling relative humidity at normal indoor temperatures. With more emphasis being placed upon problems of air conditioning in recent years there is a demand for hygrostats that are both more sensitive and more reliable than those now in use. Many instruments using wood as a hygroscopic element lack the sensitivity and reliability desired at present. The purpose of this article is to indicate in one way how wood can be used in a hygrostat as a hygroscopic element and still be both sensitive and reliable.

FUNDAMENTALS

A hygrostat that uses wood or any other hygroscopic substance as its sensitive element does not actually maintain a definite value of relative humidity where temperature fluctuations exist, but varies the relative humidity in response to the temperature changes so that the moisture content of the element tends to remain the same. If wood is used as the hygroscopic element it controls the equilibrium moisture content; that is, the moisture content to which wood will eventually come when subjected to a definite temperature and relative humidity. The degree to which a control of relative humidity is gained with a wood element hygrostat is dependent upon the relationship between the temperature of the atmosphere, the relative humidity, and the equilibrium moisture content of wood. The Forest Products Laboratory has determined these relations for Sitka spruce and they are shown in Fig. 1. Other species might show some slight variations, but the general shape of the curves would be the same for all species. For practical engineering purposes these values can be considered about the same for all species of wood.

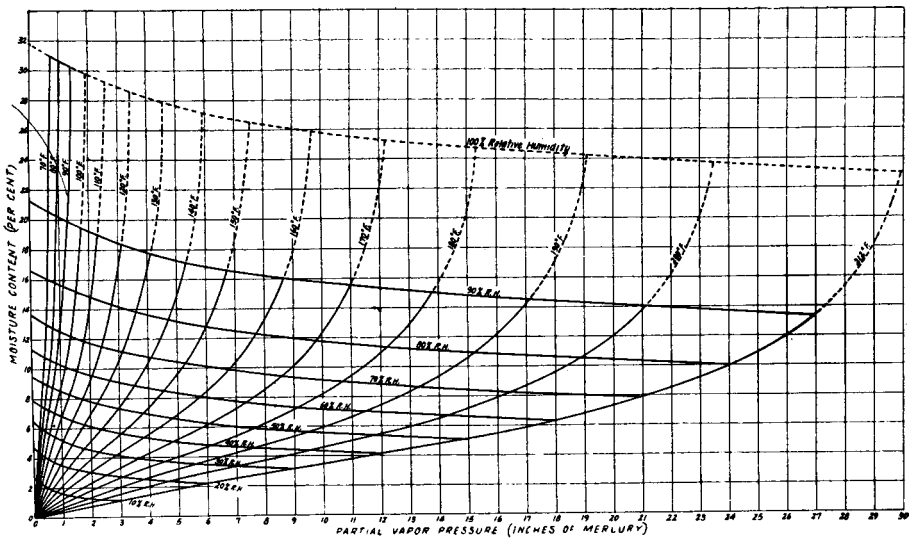
The moisture content of wood at 70°F. and 50% relative humidity, for example, is about 9% . Assume, for instance, that the dry-bulb temperature changes to 80°F. in an atmosphere being humidified under the control of a hygrostat using wood as the sensitive element: Then the relative humidity that results at this higher temperature when the element remains at 9% moisture content is about 52%. In other words, a variation in temperature of 10° at about 70°F. results in a change of 2% relative humidity. Generally this degree of control of relative humidity is sufficiently refined to meet most engineering requirements.

DESIGN REQUISITES

The following qualifications are considered essential in the design of any sensitive and reliable hygrostat employing wood as the hygroscopic element:

1. The wood element must have little lag in absorption or drying. This qualification involves sensitivity, which in this case is defined as the time and moisture content change required to actuate the controls. The spe-

Fig. 1. The moisture content of Sitka spruce at equilibrium with the indicated temperature, partial vapor pressure, and relative humidity



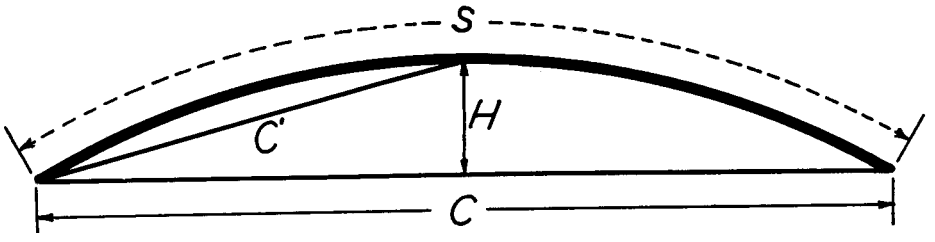


Fig. 3. Geometrical arrangement of one element of the sensitive wood element hygrostat

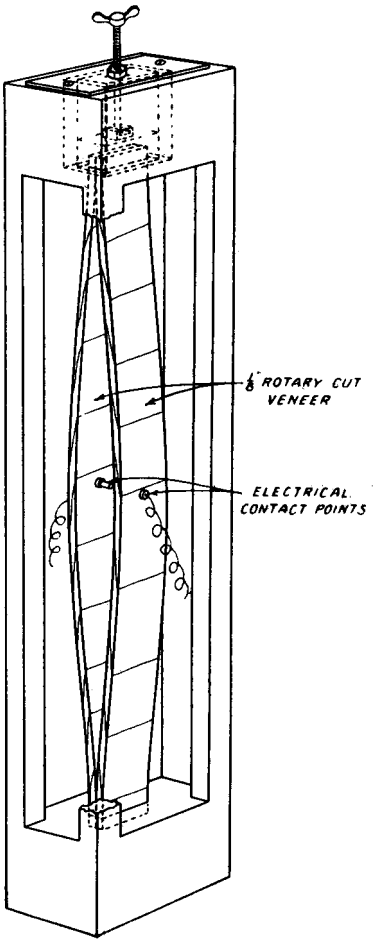


Fig. 2. (at right) A sensitive wood element hygrostat designed at the Forest Products Laboratory

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cies of wood used and the design of the wood element are the determining factors.

2. The design of the hygroscopic wood element must be such that sufficient shrinkage and swelling is obtained to give a reasonable amount of movement with small changes in moisture content.

3. Design of the instrument must be such that little if any stress is involved in the action of the sensitive wood element when used under normal conditions of operation. The elimination of mechanisms for the magnification of the movement is desirable because of the reduction in load on the element.

FOREST PRODUCTS LABORATORY HYGROSTAT

A highly sensitive hygrostat having wood as the actuating element has recently been designed at the Forest Products Laboratory to control the equilibrium moisture content conditions in experimental kilns during the drying of lumber. The dry-bulb temperature variations in the kilns where the hygrostat is used amount to 1° or 2° F., and the equilibrium moisture content conditions within are controlled by the hygrostat to about 0.1% of moisture content. This hygrostat maintains its calibration and has possibilities of adaptation to many other moisture control problems.

The general nature of the Forest Products Laboratory hygrostat is shown in Fig. 2. The elements are $^1/_8$ in. in thickness and $^3/_4$ in. in width, and are made of rotary cut veneer. Elements thinner than $^1/_8$ in. would be more sensitive to moisture changes, but so flimsy that in a brisk air movement they would tend to vibrate. Basswood was selected for the element because it responds to moisture changes readily and meets the particular requirements for stiffness. Sawing elements so that the faces are end grain increases the sensitivity but sacrifices the bending strength.

The effective length of the element described here is about 10 in. The shrinkage and swelling of the wood with small changes in moisture content is therefore sufficient to actuate the controls without further magnification other than that obtained in the geometrical arrangement of the elements. With two elements placed in a frame as shown in Fig. 2, the responsiveness of the instrument is doubled.

The geometrical arrangement of the two wood elements is such that a small change in the length of the element produces a much larger change in the rise of its arc. The relation shown in Fig. 3 between H, C′, and C for small arcs is given in the following formula:

$$S = 1/3\ (8C' - C) \qquad (1)$$

As C′ is the hypotenuse of a triangle whose other sides are H and C/2, the equation becomes:

$$S = 1/3\left(8\sqrt{\frac{C^2}{4} + H^2} - C\right) \qquad (2)$$

Solving for H, this equation shows that the change in the rise of the arc is approximately equal to the change in the arc length S, multiplied by 3/16 of the ratio of the chord C to the original rise H. For instance, with a 10 in. chord having a fixed rise of 0.1 in., a change of 0.01 in. in the arc S gives a change in the rise H of

$$\frac{3}{16} \times \frac{10}{0.1} \times 0.01 = 0.19 \text{ in.};$$

that is, a magnification of about 19 fold when the original rise is 0.1 in., or 38 fold when both elements are considered. If the original rise is say 0.5 in., and there is a change in the arc of 0.01 in., the rise becomes;

$$\frac{3}{16} \times \frac{10}{0.5} \times .01 = 0.037 \text{ in.}$$

In order to get a higher sensitivity the arc S should approach the length of the chord C, making the rise of the arc H at the controlling point very small.

This geometrical arrangement of the wood elements results in a hygrostat more sensitive and more reliable than when shrinkage and swelling are employed directly to open and close electrical contact points or an air relay. With the great magnification of the shrinkage and swelling of the elements at the control points, little change in moisture content of the elements is required to actuate the control. It is believed that the required amount of change in length of the arc to open or close the controls is obtained with changes in moisture content of the very surfaces of the element, resulting in a situation where it only requires a moisture content change of the "skin" of the wood to operate the control, whereas the moisture content of the element remains substantially the same.

RANGE

By fixing one end of the elements in a frame and making the other end adjustable as shown in Fig. 2, the instrument can be used as a controller over a wide range in equilibrium or relative humidity. For the low relative humidities the moisture content of the wood is lower and the elements are shortened, while for the higher relative humidities the elements are adjusted at a longer length. The tangential shrinkage of basswood is about 9.3% of the green dimension when it is oven dry, so that the total amount of change in length of a IO-in. element from a very high relative humidity to a very low relative humidity is about 0.9 in.

OPERATION

The operation of the arrangement is briefly as follows: Assume that the instrument is to be used in a room where steam must be admitted for humidification and that the element is electrically operated. The adjustable end of the strips or elements is moved out so that the contacts make, resulting in the opening of an electrically operated steam valve through some sort of an electrical control circuit. The relative humidity increases through the introduction of the vapor and finally the increased wood equilibrium moisture content conditions will cause the elements to swell, breaking the electrical contact, which results in the closing of the steam valve. The operation can be performed using air operated mechanisms by the use of a simple air relay and a diaphragm steam valve. Very little if any stress is introduced in the wood element by the action of the instrument, provided the supply or source of humidification is compatible with the requirements. If the rate at which the vapor is introduced so as to increase the relative humidity is too slow, there will be a tendency for the element to continue to shrink after the contact has been made, resulting in a tension stress. If this stress becomes too severe, it will cause a tension set, necessitating a readjustment of the hygrostat for it to maintain the dd-sired humidity condition.

PRECISION

The instrument is very sensitive to slight changes in equilibrium moisture content conditions. The actual control as far as equilibrium moisture content is concerned when the dry bulb temperature varies a degree or two Fahrenheit is less than 0.1% of the moisture content, which represents a relative humidity control to within 1%. Under normal operating conditions where the source of humidification is in proper relation to the requirements, the control will not vary from its adjustment. Repeated tests with the hygrostat described here have shown that only because of some accident have the

elements become stressed to the point where the instrument has to be readjusted or the elements replaced.

As previously pointed out, under a fluctuating condition of about 10° at about 70°F., hygrostats using wood as the hygroscopic element can only be expected to control relative humidities to within 2%. This particular design approaches these limitations in the control of relative humidity and the useful temperature range of the instrument is only limited to the temperature at which the hygroscopic nature of the wood is destroyed.

The hygrostat cannot be used throughout wide ranges in temperature without some adjustment or some compensation being made for the variations in length of the element at various temperatures. Wood is very sensitive to thermal changes, and though its coefficient of thermal expansion is not large, it is sufficient so that when a long element is used a wide temperature fluctuation causes a change in control setting. Under normal operating conditions a 5° or 10°F. temperature variation does not change the control sufficiently to warrant the introduction of compensating thermal devices.

SIGNIFICANCE

The value of this or any other type of hygrostat lies in the ability to use the instrument to control conditions of equilibrium or relative humidity which in many cases is more important than the control of temperature. In the drying of wood, for example, there are many instances where variations of temperature of 10°F. are immaterial insofar as the drying is concerned, but if such a temperature variation results in a wide variation in equilibrium moisture content conditions, considerable harm may result in the way of damaged stock. In this case the hygrostat controls the more important equilibrium moisture content conditions, which, with a 10° temperature change, would not result in damaged lumber but only in increasing or decreasing the drying rate.