Dec. 27, 1955 J. W. CASE 2,728,228

WOOD MEMBRANE HYGROMETER

Original Filed Dec. 13, 1951 2 Sheets-Sheet 1

FIG. 1

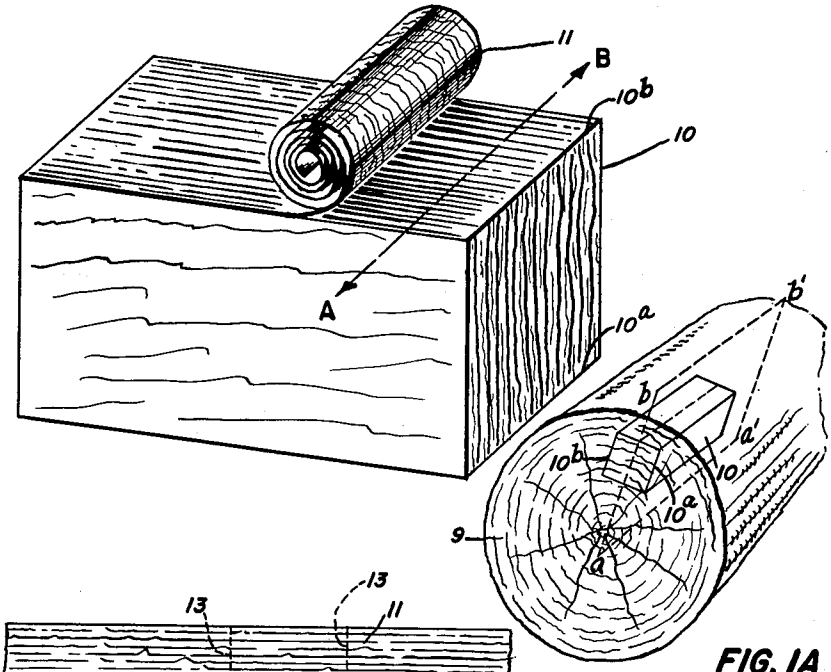


FIG. 1A

FIG. 2

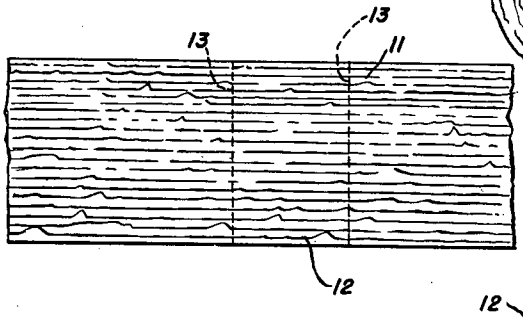
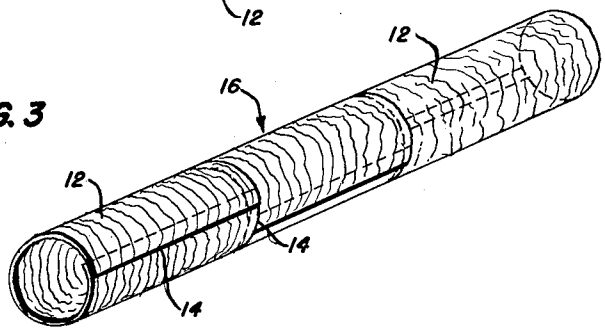


FIG. 3



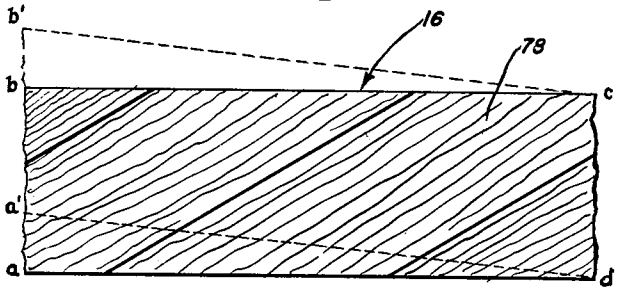


FIG. 4

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FIG. 5

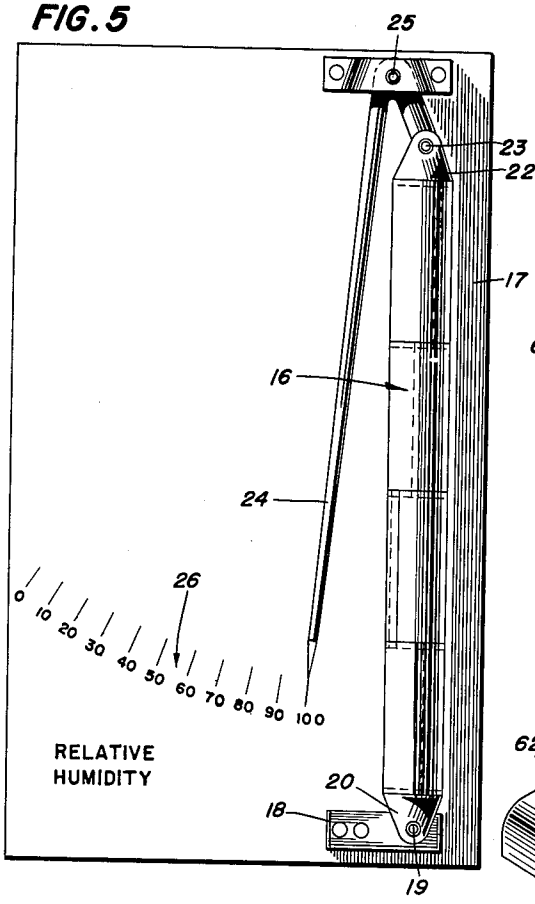
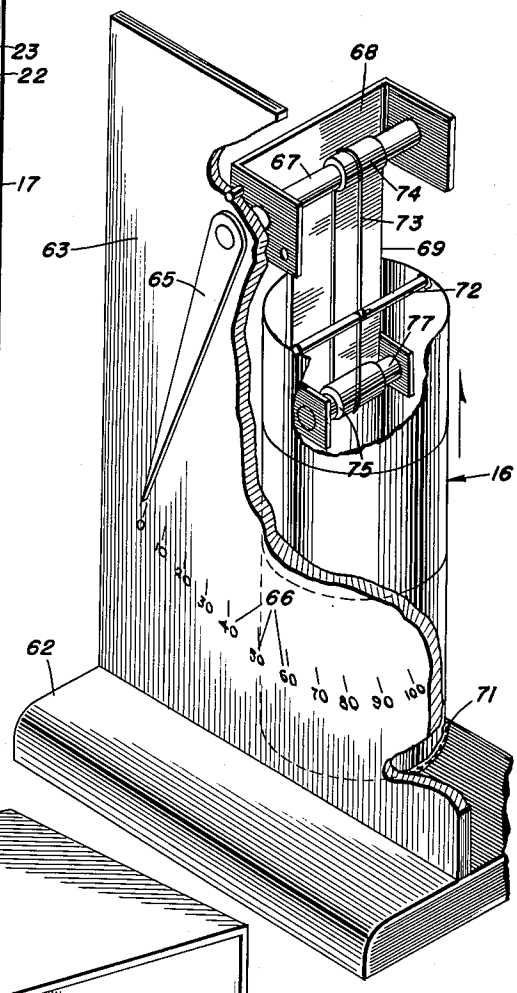


FIG. 6



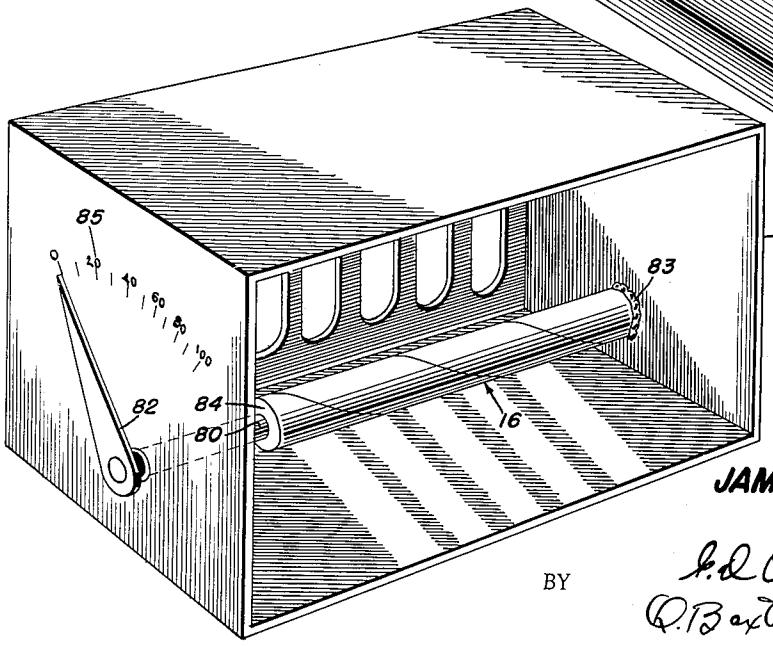


FIG. 7

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2,728,228

WOOD MEMBRANE HYGROMETER

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Original application December 13, 1951, Serial No. 261,570, now Patent No. 2,682,858, dated July 6, 1954. Divided and this application May 4, 1953, Serial No. 353,704

5 Claims. (Cl. 73—337)

(Granted under Title 35, U. S. Code (1952), sec. 266)

This invention relates to improvements in hygrometers, and more particularly relates to devices for determining the relative amount of moisture in the atmosphere by means of thin wood membrane sensitive elements.

This application is a division of copending application Serial No. 261,570 filed December 13, 1951, now U. S. Patent No. 2,682,858, issued July 6, 1954.

The purpose of this invention is to provide an inexpensive, accurate, rugged instrument which can be relied upon for visual indication of the relative humidity inside of packages, containers, shipping cases, igloos, buildings, etc., in which perishable material is shipped or stored in a dehumidified atmosphere as a means of preservation.

The technique of preserving perishable equipment by means of dehumidified air was developed during and succeeding World War II, when it was found by numerous investigators that rusting and corrosion of metals is greatly reduced in an atmosphere below 50% relative humidity; that positive protection against rust and corrosion is obtained in air below 30% relative humidity and that most forms of mildew are prevented from growing below 70% relative humidity. These discoveries led to the development of standardized procedures for dry air preservation which are being widely practiced by the military services and commercial contractors.

Essentially, the procedure consists of enclosing the material or equipment being preserved in a moisture vapor barrier with silica-gel, which takes the moisture out of the enclosed air space, either by static adsorption or by stripping the moisture from the air which is circulated through the silica-gel bed by mechanical means.

Since the moisture vapor barriers of such enclosures permit a continual small leakage of moisture from the outer atmosphere into the enclosures, some means of occasionally checking the moisture quality of the enclosed atmosphere is a necessary adjunct to this preservation process, thereby to inform maintenance and inspection personnel whether or not the atmosphere of the enclosure is below the safe upper critical limit of relative humidity and assure adequate protection of the material under preservation.

Presently available means for the indication of the relative humidity in dehumidified shipping packages and containers are inadequate because they are either too costly and cumbersome, or because they are not accurate within the critical values of moisture which must not be exceeded.

One conventional means utilizes cobalt-chloride impregnated silica-gel to indicate the moisture condition of the container atmosphere by certain characteristic colors, depending upon the atmospheric relative humidity at which the silica-gel is in moisture equilibrium. This indicating means is not only limited to a qualitative indication of the moisture in the air, but is also subject to false indication, due to its gradual accumulation of moisture with each daily peak of relative humidity (caused by atmospheric temperature change in the container). This false indication results in unnecessary expense in the

opening of the enclosure to inspect the contents, renew the silica-gel charges, etc.

Another available means employs mechanical hygrometers having sensitive elements of human hair, animal membrane, paper-metal laminate, etc. While such instruments give considerably more accurate indication of the relative humidity than the silica-gel indicators above described, they have not been generally adopted for use in shipping and storage packages, because they are too expensive in comparison with the value of material in the individual containers or packages; lack the desirable compactness for adaptation; are subject to accumulative scale errors due to aging effects on their sensitive elements and are in general too frail to withstand the shock and vibration to which packages and container are subjected during shipment.

The present invention contemplates the use of the hygroscopicity of wood and more particularly, the distortional characteristics of thin wood membranes in moisture equilibrium with the atmosphere as moisture sensitive elements in low-cost, compact, reliable hygrometers, humidity indicating devices, controllers, etc.

The constants of the characteristic deformation of various species of wood with changes of moisture content have been well established during the practice of kiln drying of lumber by the lumber industry and in research carried out by the Forest Products Laboratory of the U. S. Department of Agriculture To quote the latter authority:

"Wood shrinks most in the direction of the annual growth rings (tangentially), about one-half as much as this across these rings (radially) and very little, as a rule, along the grain (longitudinally)" . . . "The shrinkage that occurs when the moisture content is reduced below the fiber-saturation point is basically dependent upon the amount of moisture removed from the cell walls." . . . "For practical purposes, swelling may be considered the reverse of shrinking." . . . "For purposes of calculating shrinkage, or swelling, the moisture content-shrinkage relationship may be considered a direct one."

For reasons which are explained later, the selection of the radial shrinkage and swelling of wood are characteristics which can be dependent upon for accurate indication of the amount of moisture in the atmosphere by means of thin wood membranes. Further, there have been selected species of wood which are durable; which are easily worked and which have sufficient moisture-distortion gradients for actuation of indicating means in mechanical hygrometers. For example, the unit radial distortion of three typical species of wood, over the full range of relative humidity are calculated from Forest Products Laboratory data and are indicated in the following table.

Unit radial distortion of wood in moisture equilibrium at various relative humidities and 70° F. (DB)

RH	Moisture Content, Percent	Length—Inches		
		Eastern White Pine	Yellow Poplar	Hickory
100	31	1.000	1.000	1.000
90	20.8	.9925	.987	.976
80	16	.988	.98	.964
70	13	.986	.977	.9575
60	10.9	.984	.974	.9525
50	9.1	.983	.972	.948
40	7.6	.982	.969	.944
30	6	.981	.9675	.940
20	4.5	.980	.966	.937
10	2.5	.979	.963	.9325

It has been found that the moisture distortion characteristics of wood, above cited, are not useful for the moving force in a mechanical hygrometer in a thick sec-

tion cut from the tree, as in a piece of lumber, but the sensitive element must be made in a very thin membrane which can rapidly respond to changes of the atmospheric moisture. According to the literature, wood was one of the first materials utilized in the construction of hygrometer sensitive elements. However, all types of wood sensitive elements employed by previous inventors are of relatively thick sections, in which an appreciable time is required for equal wetting of the mass and swelling of the internal fibers. This circumstance causes objectionable time lag between changes of atmospheric moisture and the desired dimensional change of the sensitive element. The inherent time lag and sluggish nature of wood sensitive elements employed by previous inventors has generally prevented the used of this type of element in commercial hygrometers which normally employ human hair, animal membrane, paper-metal laminate, etc. as sensitive elements. It has been found, further, that all such organic fibers have an inherent time lag of at least 40 minutes between changes of relative humidity and that, for comparable performance, a wood fiber must be of approximately the same thin section, or at least, as thin as practicable within the limits of the mechanical factors incident to the service of the instrument.

There has therefore been produced a wood hygrometer sensitive element of comparable thinness, accuracy and sensitivity to other organic fibers which are employed in hygrometers.

From these statements it will be understood that one of the objects of the invention is to provide an improved moisture indicating instrument for the guidance of shippers and inspection personnel who are charged with the safe transit or storage of valuable equipment which is subject to rusting, corrosion and mildew and which is preserved by means of moisture vapor barriers and dry air.

Another object of the invention is to provide a moisture indicating device which is contrived to give warning, by means of a visual mechanical signal, when the critical value of relative humidity in dehumidified shipping packages or containers is reached.

Another object of the invention is to provide moisture sensitive elements of thin wood membranes for hygrometers and hygrosignals.

Another object of the invention is to provide moisture sensitive elements for hygrometers and hygrosignals which are resistant to the effects of solvent vapors, such as methyl-ethyl-ketone, ethyl alcohol, and petroleum solvent which are commonly used in moisture barriers and in metal preservatives.

Another object of the invention is to provide moisture sensitive elements for hygrometers which will have uniform moisture-distortion characteristics when produced in quantity, so that the hygrometers in which they are used may have duplicate scales and will assure acceptible accuracy over the full range of relative humidity.

Another object of the invention is to provide simplified mechanical magnification means for hygrometer sensitive elements to eliminate accumulative instrument errors due to strain on the elements and shock or vibration during service.

Another object of the invention is to provide moisture sensitive elements which are responsive with a minimum of lag to the fluctuating moisture vapor conditions in the atmosphere.

Another object of the invention is to utilize the steps of a method of producing the critical membraneous-wood tube which is the sensitive element of the hygrometer.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a perspective view illustrating the first mechanical step of the method of producing the sensitive element;

Fig. 1A is a diagrammatic perspective view showing the method of cutting a block from a log preparatory to obtaining a wood membrane which is expansive and contractive radially in the tree;

Fig. 2 is a plan view of the membraneous-wood shaving, stretched out preparatory to cutting;

Fig. 3 is a perspective view of a tube wherein the membraneous wood sections are joined for rectilinear expansion and contraction;

Fig. 4 is a diagram illustrating a development of a spiral winding of the wood membrane for rotational expansion and contraction;

Fig. 5 is an elevation of a typical wood membrane hygrometer wherein the sensitive element is rectilinearly expansive and contractive;

Fig. 6 is a perspective view of a modification of the hygrometer wherein rectilinear dimensional changes of the sensitive element are changed into rotary motion, parts being broken away, and

Fig. 7 is a perspective view of a modification of the hygrometer utilizing a spirally wound wood membrane for the sensitive element.

The method of making the sensitive element is described first, then its applications. In Fig. 1, **10** designates a block of close-grained, well seasoned soft wood. Species that are regarded as suitable for the instant purpose include white pine (*Pinus strobus*), yellow poplar (*Liriodendron tulipifera*) and red cedar (*Juniperus virginiana*). The block **10**, Fig. 1, is cut from a log **9**, Fig. 1A, according to the common commercial practice of "quarter sawing" to bring out the radial grain of the wood. As shown in Fig. 1A, the block **10** is cut from the timber so that the faces **10***a*, **10***b* of the block are purposely in parallel orientation with the radial plane *a*, *a'*, *b*, *b'*. Now when a shaving is cut from the face **10***b*, Fig. 1, in the direction of the grain and across the ring growth laminations, there is produced a thin membrane **11**, Fig. 2, which utilizes only the radially distortional constants of the wood along the line A—B, Fig. 1. This manner of cutting the block insures a uniformity of distortion in the active element of the hygrometer which could not be obtained in any other known way. It is this uniformity of distortion which is responsible for the manner of response of the hygrometer element to ambient moisture as set out herein. The desired specimen having been selected, a shaving **11** is cut from one side in the manner described above.

A sharp carpenter's plane is used for this purpose, or any equivalent instrument that will produce a uniform, unbroken shaving from .0035 of an inch to .005 of an inch thick. The width of the block, hence of the shaving, is about 1⅜ inches. Much wider shavings could be produced with proper tools. This would avoid the necessity for piecing as below, and would make possible a sensitive element in one piece. The shaving thus produced is quite flimsy and has but little strength across its width. Consequently, care has to be taken in the next step of smoothing the shaving out as in Fig. 2 and cutting from it sections **12** of uniform length. The cuts are made along the lines **13**.

These sections **12** are assembled on a mandrel (not shown) and united at the joints **14** with an alkyd resin, cellulose nitrate, or phenolic cement, available commercially. The longitudinal joints are desirably staggered around the mandrel. The result is the cylinder **16** in which the joints furnish reinforcement to the otherwise frail sections. This cylinder is the sensitive element. Now, since the sections **12** are assembled end on end with their axes corresponding, in the tree, to the radial plane *a*, *a'*, *b*, *b'*, Fig. 1A and the line A—B, Fig. 1, the cylinder **16**, Fig. 3, forms a moisture-sensitive element which is responsive only to the radially expansive constant of the tree wood. When the humidity is on the increase the cylinder will expand lengthwise and as the moisture

content diminishes the cylinder will contract. Tests to date show that a maximum dimensional change of an element as shown in Fig. 3 when made of white pine is on the order of .002 inch per inch length.

Having made the sensitive element according to the foregoing method, the cylinder **16** is embodied in the typical wood membrane hygrometer shown in Fig. 5. Any desired kind of supporting panel **17** is used for the mount. A mount composed of a metal piece **18** is desirably but not necessarily riveted on the panel. This piece carries the stationary pivot pin **19** which by means of the adapter **20** allows the cylinder **16** to swing on a slight arc. The cylinder **16** has its lower end secured to the adapter **20** by means of the same air-drying cement used for fabrication of the cylinder **16** of sections **12**.

A similarly shaped and secured adapter **22** at the upper end of the cylinder makes connection at the movable pivot **23** with the short arm of an indicating needle **24**. The adapters assist in preserving the tubular form of the sensitive element and augment the reinforcement of the membrane. This needle has a stationary pivot **25**, and its free end traverses a scale **26** which is graduated in percentages of relative humidity. The needle setting illustrated in Fig. 5 indicates a 100% absorption of moisture by the cylinder **16**. As the cylinder loses moisture it shrinks axially, whereupon the needle swings clockwise and indicates a diminishing moisture content both of the cylinder and the ambient air.

The form of hygrometer in Fig. 6 primarily is for use on a desk or the like. It has a base **62** from which a panel **63** is rigidly erected. The indicating needle **65** plays over the graduations **66** which are numbered in percentages of humidity. The pivot spindle **67** of the needle has bearing in a support bracket **68** which is fastened to the back of the panel and has a part **69** that extends downward and inside of the upper end of the sensitive element **16**.

This element **16** still is of the type in Fig. 3, and one end of it is cemented to the base as at **71**. A thin but strong crossbar **72**, preferably but not necessarily of hardwood, is cemented at its ends to the element **16** and in bridging position across the upper open end. This crossbar raises and lowers with the axial expansion and contraction of the element **16**, and these motions are reflected in the needle **65** through a Fiberglas thread **73** to which the crossbar is affixed by an adhesive such, for example as cellulose nitrate, alkyd resin or phenolic cement.

The thread **73** is a loop, being made so, conceivably, by connecting the ends by the same spot of cement that affixes the loop to the crossbar. The thread is stretched rather tightly over upper and lower sheaves **74**, **75**, respectively on the spindle **67** and on a pin **77** that spans the distance between the extremities of the part **69**. The sheave **75** is an idler. Being composed of Fiberglas hence non-hygroscopic in character, the thread **73** will remain as tight as it is originally stretched since it will not respond to the humidity changes to which the element is expected to respond.

It is readily seen in Fig. 6 that the linear dimensional changes of the sensitive element **16** will be converted into circular motion at the spindle **67** and needle **65**. The choice of the right sheave diameter and indicating needle length will produce the desired scale deflection.

Fig. 4 illustrates the first and only modification of the sensitive element itself. Here, instead of being made in sectional form the shaving in Fig. 1 is left intact and is formed into a unitary wood shaving **78**, spirally wound into a tubular element and made to remain so by spots of cement at intervals. The purpose is accomplished, for example, by winding the shaving spirally on a 7/16" mandrel and lightly cementing the edges at points about ½" apart with cellulose nitrate, alkyd resin or phenolic cement.

The object of this is to produce a non-rigid tube which will permit respective rotation between the two opposite ends, due to spiral distortion upon the accretion and loss of moisture. It has been found that such a tube 6" long will rotate approximately 30° between opposite ends from ambient conditions of between 50% and 100% relative humidity.

In further explanation of Fig. 4, the rotative effort caused by the expansion (or contraction) of the wood membrane will be understood from the development of the spirally wound element. In accordance with the transverse grain expansion set out before, the maximum dimensional change of the developed sheet is diagonally between points *b* and *d*. This represents a distortion of the rectangular sheet into a parallelogram as shown at *a'*, *b'*, *c*, *d*. With points *c*, *d* fixed, as they will be by the cementing down of the tube, the movement of points *a*, *b* to *a'*, *b'* corresponds to clockwise motion at the free end of the tube, in other words to an extent where the element is in equilibrium with the particular moisture content of the ambient air.

Fig. 7 illustrates the utilization of the element in Fig. 4. An instrument case **79** of any chosen type forms the housing for the element **16** and the mount for the spindle **80** of the needle **82**. One end of the tube (*c*, *d* in Fig. 4) is cemented at **83** to one wall of the case. A hole in the opposite wall forms a bearing for the spindle. The inner end of this spindle is affixed to a plug **84** in the otherwise open end of the tube. The needle **82** is affixed to the outer end of the spindle and, as in the other instances, plays over a set of humidity graduations **85**.

The operation of the various forms of the hygrometer is generalized thus: The accretion or loss of moisture by the wood-membrane sensitive element **16** causes a dimensional change therein which is utilized to shift the indicating needle. This occurs either by axial elongation or contraction or by the twisting of the tubular body. Under the first setup the humidity indicator needle is moved either by a sheave system (Fig. 6) or by a system of levers and pivots (Fig. 5). Under the second setup the indicator turns in conformity to the twisting of the sensitive element (Fig. 7).

The invention described herein may be manufactured and used by and for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. In a hygrometer, a mounting means and a relatively movable means said means being located a distance apart from each other, and a moisture sensitive element spanning said distance being connected at one end to the mounting means and having its other end in operative proximity to the movable means, said element consisting of a wood membrane having a wall thickness up to five-thousandths of an inch and being made in tubular form for requisite mechanical strength, said tube having the wood grain extending spirally thereof.

2. In a hyrogrometer, a moisture sensitive element consisting of a tubular membrane fixed at one end and movable at the other end due to changes in its moisture content, a spindle mounted to turn according to said changes and having a needle to indicate percentages of humidity by movement in respect to a reference point, an idler in established relation to the spindle, and a loop of non-hygroscopic thread embracing the idler and spindle and connected to the movable end of the sensitive element.

3. In a hygrometer, a support, a moisture sensitive element consisting of a tubular membrane fixed on the support at one end and bodily rectilinearly movable for displacement of its other and free end due to changes in its moisture content, a bracket attached to the support and carrying an idler sheave in proximity to the free end, a spindle journaled on the bracket and having an indicating needle, a loop of non-hygroscopic thread embracing the spindle and idler, and means by which the thread is fixedly connected at one place in its length to the free end of the sensitive element.

4. A moisture sensitive expansible and contractible element for a hygrometer or the like comprising a thin walled open ended tube formed of a single ply of seasoned wood shaving material and having uniformly parallel grain fibers spirally encircling the tube.

5. A moisture sensitive element for a hygrometer comprising a thin wall tube formed of seasoned wood shaving material having grain fibers spirally encircling the tube.

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