HUMIDITY MEASURING APPARATUS

The present invention relates to apparatus for measuring relative humidity.

An electronic thermometer having a variable resistance type sensor for measuring the temperature is disclosed in Japanese Published Patent No. 15134/1983.

It may be thought to be possible also to measure humidity by employing this structure. However, if such a sensor is employed for detecting moisture and a current is caused to flow in one direction for a long time in the sensor, electrolysis may occur and the moisture sensitivity may change, whereby accurate humidity measurement over a long period is prevented.

A further problem with many known humidity sensors is that they suffer from variation in their characteristics, so that much time and labour is required in adjusting the measuring apparatus, which is expensive.

According to the present invention there is provided humidity measuring apparatus comprising: a humidity sensor having an impedance which varies in accordance with changes in humidity, means for generating a signal indicative of the impedance of the humidity sensor, means for calculating the humidity from said indicative signal, and means for periodically switching the direction of current flow through the humidity sensor with a variable period.

The present invention will be described further, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a block diagram showing an embodiment of apparatus for measuring humidity according to the present invention;

Figure 2 is a circuit diagram of the apparatus shown in Figure 1;

Figure 3 is a flow chart representing the operation of the apparatus shown in Figure 1;

Figure 4 shows a portion of the circuit of Figure 2 for explaining switching between charge and discharge conditions;

Figure 5 shows a connection within this portion of the circuit at the time of discharge;

Figure 6 shows the connections within this portion of the circuit at the time of selecting a humidity sensor of the apparatus;

Figure 7 is a waveform diagram for explaining the function of sensor switching means of the apparatus;

Figure 8 is a table for explaining the function of one form of humidity determining means of the apparatus;

Figure 9 shows a modification of an oscillation frequency counter of Figure 1;

Figure 10 is a sectional view through a humidity sensor of the apparatus; and

Figure 11 shows the characteristics of the humidity sensor.

An embodiment of the present invention will be explained in detail with reference initially to Figures 1 and 2 of the accompanying drawings. The illustrated apparatus includes a humidity sensor 101, which has a sensitivity to moisture such that its impedance varies in accordance with changes in humidity. Switching means

108 including analog switches 208a and 208b provided at both ends of the humidity sensor 101 serve for switching the direction of current flow through the sensor 101. An analog switch 206 connected to one terminal of a reference capacitor 103 provides charge-discharge switching means 106 for switching between capacitor charging and discharging conditions.

In order to measure humidity, a reference resistor 102 is first selected by charge switching means 104 comprising an analog switch 204 to establish a connection as shown in Figure 4. Then, the analog switch 206, which is the charge-discharge switching means, selects the charging condition to establish a connection as shown in Figure 4. In this condition, a terminal voltage V_c of the reference capacitor 103 increases with time. Voltage judging means 105 comprising a logic inverting gate 205 having hysteresis are connected to the reference capacitor 103. When the terminal voltage V_c reaches an upper threshold voltage V_H of the logic inverting gate 205, as shown in Figure 7, the output V_a of the gate goes to the level L and the analog switch 206 is switched to select the discharging condition. At the time of discharging, the reference capacitor 103 is connected to a discharge resistor 107, as shown in Figure 5, whereby the terminal voltage V_c decreases with time. When the terminal voltage V_c drops to a lower threshold voltage V_L of the logic inverting gate 205, as shown in Figure 7, the output V_a of the gate goes to the level H and the analog switch 206 is once again switched to select charging. In this way, a cycle of charge and discharge is repeatedly generated.

An oscillation frequency counter 109 counts the number of cycles of charging and discharging of the reference capacitor 103 occurring within a predetermined

period of time T. In this embodiment, a micro-computer 212, composed of a CPU 209, a ROM 210 and a RAM 211, serves as the counter 109. Alternatively, however, the oscillation frequency counter 109 may comprise a counter circuit 901, which is re-settable by the micro-computer 212, as shown in Figure 9. This is convenient when the micro-computer is used for multi-tasking. It may be assumed that the count value obtained when the reference resistor 102 is selected is N.

The humidity sensor 101 is then selected by the analog switch 204 to establish a connection as shown in Figure 6. The cycle of charging and discharging of the reference capacitor 103 is repeated in the same way as when the reference resistor 102 was selected, and the number of cycles is again counted by the micro-computer 212. The count value obtained this time may be assumed to be N_s.

The analog switches 208a, 208b switch the direction of the connection of the humidity sensor within the circuit for alternate charging portions of the cycle. More specifically, the analog switches 208a, 208b are controlled by a frequency divider 213 in the form of a flip-flop. Assuming that the two terminals of the humidity sensor 101 are a and b, respectively, for convenience of explanation, the directions of the current flowing between a and b in the humidity sensor 101 are switched at every cycle of charging and discharging. This switching function has the advantage of avoiding electrolysis or the like associated with the humidity sensor 101, and effectively solves the related problems in the prior art.

The resistance value R_s of the humidity sensor 101 is calculated from the following formula (1) on the basis of N, Ns, obtained in the above-described way, and

the resistance value R_n of the reference resistor 102:

$$R_s = (N/N_s)R_n \quad \ldots(1)$$

This formula (1) will briefly be explained below:

If it is assumed that the charging time in the case of charging by way of the reference resistor 102 is T_{nc}, the charging time in the case of charging by way of the humidity sensor 101 is T_{sc}, the discharging time is T_d, the resistance value of the reference resistor 102 is R_n, the resistance value of the discharge resistor 107 is R_d and the capacitance of the reference capacitor 103 is C, the following three formulae hold:

$$T_{nc} = CR_n \cdot \ell n\,[(V-V_L) / (V-V_H)]$$
$$T_{sc} = CR_s \cdot \ell n\,[(V-V_L) / (V-V_H)]$$
$$T_d = CR_d \cdot \ell n\,(V_H/V_L).$$

In accordance with the definitions of N and Ns, the following formula is introduced:

$$T = N\,(T_{nc} + T_d) = N_s\,(T_{sc} + T_d).$$

If the resistance value Rd of the discharge resistor 107 is set at a sufficiently small value in comparison with R_n and R_s,

$$Tnc >> Td,\ Tsc >> Td$$

Therefore, the following formula holds:

$$NT_{nc} = N_s T_{sc}$$

Therefore,

$$NR_n = N_s R_s$$

This leads to the formula (1) above.

Humidity sensor resistance value calculating means 110 incorporated in the micro-computer 212 execute the calculation of the value R_s from the formula (1) above.

The reason why N is first obtained using the reference resistor 102 is that the capacitance of a capacitor is generally apt to change with temperature. However, by using the reference resistor 102, accurate humidity measurement is possible even if the temperature

does change. The capacitance of the reference capacitor 103 need not be strictly measured, but it is used as the reference for determining the measuring time T.

Humidity determining means 111 determine the humidity from the resistance value of the humidity sensor 101 as calculated by the humidity sensor resistance value calculating means 110. For example, a table 801 of resistance value and humidity, as shown in Figure 8, may be stored in the ROM 210 and read from it by the CPU 209 in a conventional manner. Alternatively, if a humidity sensor as described below is used having characteristics as shown in Figure 11, it is possible to determine the humidity by executing a simple calculation by the micro-computer. The formula for calculating the humidity Rh (%) from the resistance value R_s of the humidity sensor 101 is as follows:

$$Rh = P \log R_s + Q \qquad \ldots(2)$$

wherein P and Q are constants determined by the characteristics of the humidity sensor.

Figure 3 is a flow chart of the procedure for measuring humidity. Measurement may be carried out at predetermined times or in response to an external command. In step P1, a decision is made as to whether measurement by way of the reference resistance 102 (step P2) or measurement by way of the humidity sensor (step P4) is to be carried out. Since the capacitance of the reference capacitor 103 changes with temperature, measurement by way of the reference resistor 102 in step P2 is carried out from time to time in order to establish the value of N accurately and thereby minimise errors. If the temperature changes in the measuring atmosphere are small, such measurement need not be carried out frequently but only on start up of the apparatus. It is possible to repeat the measurement in

step P2 several times in order to enhance the measuring accuracy, and whether or not to select this option is determined in step P3. In steps P2 and P4, the numbers N and Ns of cycles repeated within the predetermined time T are obtained by the micro-computer. In step P5, the resistance value of the humidity sensor is determined. More specifically, the formula (1) is calculated. After the resistance value of the humidity sensor is calculated, the humidity is determined in step P6.

Since the counting of pulses, calculation of the formulae (1) and (2) and reading of ROM data are carried out by known techniques, detailed explanations thereof will be omitted.

A method of producing the humidity sensor in accordance with the present invention will briefly be described below with reference to Figure 10.

On an alumina substrate 11, a Cr comb electrode 12 is formed by sputtering, and at the portion to which a lead wire is connected, Au, NiCr and Au are further sputtered in that order. In other words, the electrode 12 comprises a first sensor electrode portion composed only of Cr, and a second sensor electrode portion to which a lead wire is connected and which comprises a four-layered portion composed of Cr, Au, NiCr and Au laminated in that order on the substrate. A porous silica film 13 with carbon particles dispersed therein is formed on the first sensor electrode portion as a main moisture sensing film.

By way of example, 1300g of ethanol and 240g of 0.02 N hydrochloric acid were added to 270g of tetraethoxysilane ($Si(OC_2H_5)_4$) and the mixture was stirred for one hour, after which 76g of glycerin and 8g of silica fine powder were added thereto, the resultant

mixture being stirred for 30 minutes. Thereafter, 3.6g of activated carbon and 14g of carbon black were added, and the mixture was stirred and ultra-sonically dispersed for 1 hour. 25 lots of sol were produced in the same way and the viscosity was measured. The results are shown in Table 1 (in the row against 2.5% by weight). As is clear from Table 1, the variation in viscosity was very small. For comparison, the amount of carbon particles (activated carbon and carbon black) was varied and the viscosity was measured. The results are also shown in Table 1. When the amount of carbon particles was in the range of 1 to 4% by weight, the reproducibility was good.

Table 1

Amount of carbon particles (wt%) and viscosity

Carbon particles (wt%)	Viscosity (cp)		
	Average	Maximum	Minimum
2.5	102	106	99
1.0	71	73	70
2.0	93	95	92
3.0	156	160	153
4.0	308	310	303
6.0 (unstable)	673	859	320

A sol containing 2.5% by weight of carbon particles as applied to the alumina substrate 11 with the electrode 12 formed thereon by dip coating, was dried at 100°C for 10 minutes and was sintered at 430°C for 30 minutes, thereby obtaining the porous silica film 13 with carbon particles dispersed therein as the main moisture sensing film.

A solution was prepared by adding 35 ml of ethanol and 4ml of 0.02 N hydrochloric acid to 50 ml of tetraethoxysilane, stirring the mixture for 1 hour, adding 10 g of silica fine powder thereto and stirring the resultant mixture for 30 minutes. The thus obtained solution was applied to the main moisture sensing film 13 by dip coating, dried at 120°C for 30 minutes and sintered at 400°C for 20 minutes, thereby forming a silica film 14.

In the thus obtained humidity sensor, the relative humidity and the logarithm of the resistance have a linear relationship, as shown in Figure 11, and the measurement of humidity is possible by simple calculation, as described above. Since both silica and carbon are chemically very stable, the moisture sensitivity is unlikely to change with temperature, so that satisfactory results may be obtained without providing a special temperature compensation circuit. In addition, since the electrodes are formed by sputtering, it is possible greatly to reduce the gap between the electrodes and to limit the resistance value of the humidity sensor to a very small value. Thus, a humidity sensor suitable for practical use may be obtained.

The described humidity sensor has a structure wherein a porous silica film with carbon particles dispersed therein is formed on an insulating substrate and wherein the substrate has a multi-layered thin film

electrode formed thereon. However, other structures for the humidity sensor wherein the impedance varies in accordance with changes in humidity are also applicable to the humidity measuring apparatus of the present invention.

Further, in the described apparatus, it is possible to use a small size relay and other switching elements for the analog switches 204 etc., to use means other than the flip-flop for the frequency divider 213 for switching the direction of current flow in the humidity sensor, and to use a comparator element for the voltage judging means 105.

The described embodiment offers the following advantages:

(a) Since means for switching the direction of the current flow in the humidity sensor are provided, there is little change in the characteristics of the humidity sensor due to electrolysis or the like, and it is possible to measure humidity accurately over a long period. Thus, humidity measuring apparatus having a high reliability may be realized.

(b) Since a porous silica film with carbon particles dispersed therein is used for the humidity sensor, accurate humidity measurement is enabled in an atmosphere of high temperature and humidity.

(c) Since the moisture sensitivity of the humidity sensor is stable with respect to changes in temperature, the need for a complicated temperature compensation circuit is avoided and so the structure of the apparatus is simple and the cost thereof is low.

(d) Since the humidity sensor has a moisture sensitivity in which the logarithm of the impedance varies linearly in accordance with changes in relative humidity, the adjustment of the apparatus is very easy.

(e) Since silica and carbon, which constitute the humidity sensor, are chemically very stable, long term humidity measurement in an atmosphere of high temperature and humidity, which has previously caused some problems, may be achieved.

(f) By setting the amount of carbon particles in a sol as a material of the main moisture sensing film of the humidity sensor at not more than 4% by weight, the characteristics of the sol are made stable, and it is possible to obtain a humidity sensor having stable moisture sensitivity, thereby reducing any fluctuation in accuracy of the humidity measuring apparatus.

Consequently, the invention in its preferred form as described above provides a humidity measuring apparatus at a low price, which is capable of accurate humidity measurement over a long period.

CLAIMS

1. Humidity measuring apparatus comprising: a humidity sensor having an impedance which varies in accordance with changes in humidity, means for generating a signal indicative of the impedance of the humidity sensor, means for calculating the humidity from said indicative signal, and means for periodically switching the direction of current flow through the humidity sensor with a variable period.

2. Apparatus as claimed in claim 1 in which the signal generating means comprises a reference capacitor having a predetermined capacitance, voltage judging means for judging when a terminal voltage of the reference capacitor is at a high level or a low level, and charge-discharge switching means responsive to an output of the voltage judging means for controlling charging and discharging of the reference capacitor.

3. Apparatus as claimed in claim 2 in which the signal generating means further comprises a reference resistor having a predetermined resistance value, and charge switching means for selectively connecting either the reference resistor or the humidity sensor with the reference capacitor.

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4. Appararatus as claimed in claim 2 or 3 in which the signal indicative of the impedance of the humidity sensor comprises a number of charging and discharging cycles of the reference capacitor occurring within a predetermined period.

5. Apparatus as claimed in any of claims 2 to 4 in which the periodic switching means is responsive to an output of the voltage judging means for switching the direction of the current flow.

6. Apparatus as claimed in any preceding claim in which the humidity sensor comprises a multi-layered thin film electrode formed on an insulating substrate, and a porous silica film with carbon particles dispersed therein formed on the insulating substrate as a moisture sensing film.

7. Apparatus as claimed in claim 6 in which the porous silica film with carbon particles dispersed therein comprises a sol containing not more than 4% by weight of carbon particles.

8. Humidity measuring apparatus substantially as herein particularly described with reference to and as illustrated in the accompanying drawings.