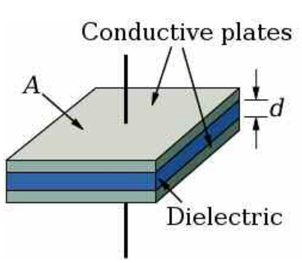
The Capacitive Humidity Sensor – How it Works & Attributes of the Uncertainty Budget

Principle of Operation

The humidity sensor is a small capacitor consisting of a hygroscopic dielectric material placed between a pair of electrodes. Most capacitive sensors use a plastic or polymer as the dielectric material, with a typical dielectric constant ranging from 2 to 15. When no moisture is present in the sensor, both this constant and the sensor geometry determine the value of the capacitance.

At normal room temperature, the dielectric constant of water vapor has a value of about 80, a value much larger than the constant of the sensor dielectric material. Therefore, absorption of moisture by the sensor results in an increase in sensor capacitance. At equilibrium conditions, the amount of moisture present in a hygroscopic material depends on both ambient temperature and ambient water vapor pressure. This is true also for the hygroscopic dielectric material used in the sensor.

By definition, relative humidity is a function of both the ambient temperature and water vapor pressure. There is a direct relationship between relative humidity, the amount of moisture present in the sensor, and sensor capacitance. This relationship is at the base of the operation of a capacitive humidity instrument.

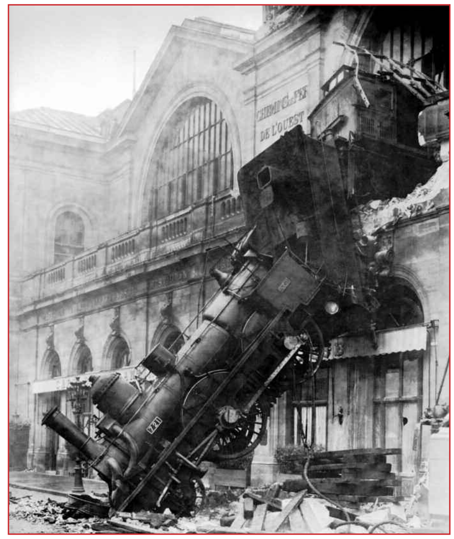


As we recall our relative humidity basics, we remember that relative humidity is the ratio of the actual water vapor pressure present compared to the maximum water vapor pressure (saturation vapor pressure) possible at a given temperature. The dielectric material varies at a rate that is related to the change in relative humidity.

In a hygrometer utilizing a capacitive sensor, humidity is measured by a chain process as opposed to being sensed directly. The chain is made up of the following components:

1. Capacitive sensor
2. Probe
3. Cable
4. Electronics
5. Output signal

Instrument performance is determined by all the elements of the chain and not by the sensor alone. The sensor and associated electronics cannot be considered separately. Any factor that can disturb the chain process of measurement is bound to have an effect on instrument performance.



Small errors can lead to big failures.

Classification of Errors

Affecting the Final Uncertainty of a Capacitive Sensor Hygrometer

For the purpose of analysis, errors of measurement can be divided conveniently into two broad categories:

Systematic errors are predictable and repeatable both in magnitude and sign. Errors resulting from a nonlinearity of the instrument or from temperature effects fall into this category. Systematic errors are instrument specific.

Random errors are not fully predictable because they are essentially dependent on factors external to the instrument. Errors resulting from sensor hysteresis, as well as those resulting from the calibration

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process, are random errors. Usually, random errors are estimated on the basis of statistical data or on the basis of experience and judgment.

Because they are predictable, systematic errors can potentially be eliminated. However, random errors cannot be entirely eliminated.

Linearity Errors. The typical response of a relative humidity capacitive sensor (between 0 and 100 percent RH) is not linear. Depending on the correction made by the electronic circuits, the instrument may have a linearity error. Assuming that both the sensor and associated electronics have reproducible characteristics, the linearity error is a systematic error.

Typically, the measurement points recommended by the instrument manufacturer for calibration are determined to minimize the linearity error. Calibrating at those points should produce an even plus and minus distribution of the linearity error.

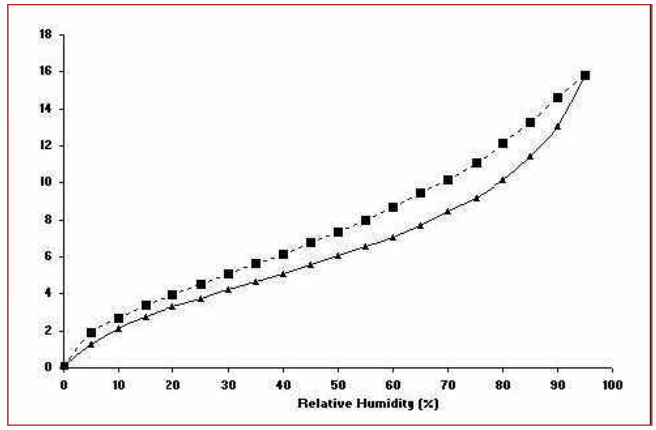
Temperature Errors. Temperature can have a major effect on several elements of the chain process of measurement described earlier. The hygroscopic properties of the sensor vary with temperature. A relative humidity instrument operates correctly based on the assumption that the relationship between the amount of moisture present in the sensor dielectric and relative humidity is constant. However, in most hygroscopic materials, this relationship varies with temperature.

The dielectric properties of the water molecule are affected by temperature. At 20°C, the dielectric constant of water has a value of about 80. This constant increases by more than 8 percent at 0°C and decreases by 30 percent at 100°C. Similar effects can be noted regarding the other physical properties of water such as electrical conductivity.

The sensor dielectric properties also vary with temperature. The dielectric constant of most dielectric materials decreases as temperature increases. The effect of temperature on the dielectric properties of most plastics and polymers is usually more limited than in the case of water.

Temperature and humidity will affect the electrical properties of a cable connecting the sensor to the electronics. Any length of cable connecting the sensor to the electronic circuits has its own capacitance and resistance. The electronic circuits cannot discriminate between the sensor and its connecting cable. From the point of view of the electronic circuits, the relative magnitude of the effects described for the sensor may vary, depending on both the length and the nature of the cable used to connect sensor and electronics.

It is important to ensure that the humidity measurement instrument electronics automatically compensate the measurement for different temperatures. Using a non- compensated humidity instrument at temperatures that greatly differ from the temperature of calibration results in large measurement errors.



Hysteresis. Hysteresis is the maximum difference that can be measured between corresponding pairs of data obtained by running an ascending and a descending sequence of humidity conditions. Hysteresis determines the repeatability of a humidity instrument.

For any given instrument, the value of hysteresis depends on a number of factors including total span of the humidity cycle used to measure hysteresis, exposure time of the sensor to each humidity condition, temperature during measurements, criteria used to define sensor equilibrium, and previous sensor history. Hysteresis increases as the sensor is exposed to high humidity and high temperature over longer periods of time. There are strong indications that hysteresis is the result of the time required by a humidity sensor to settle at high humidity conditions and to recover when conditions are returned to normal.

It is not very meaningful to state the value of hysteresis in an instrument specification without providing any details about how it was measured. The measurement

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of hysteresis can be manipulated to make a bad instrument look good.

In actual measurement practice, conditions are extremely diverse and hysteresis may or may not reach its maximum value. Therefore, it is reasonable to consider that hysteresis is a random error that can be neither fully predicted nor compensated. When the uncertainty of an instrument is specified, half the maximum value of hysteresis is equally distributed as a positive and a negative error. However, instrument repeatability should not be specified at a value less than the full value of hysteresis.

Calibration Errors. Calibration and the associated adjustment consists of comparing an instrument reading to the reading of an approved standard and adjusting the instrument output or readout to the values provided by two or more reference humidity conditions. The accuracy to which these conditions are known is critical. Calibration should be as physically direct a process as possible to eliminate the substantial errors that frequently result from an indirect calibration process, such as relative humidity calibration with a dew point instrument and a thermometer.

A frequent concern of humidity instrument users is traceability to a national lab such as NIST and the maintenance of this traceability in the field. The best approach is to send a primary standard to a national lab for calibration. Unfortunately, this is rather costly and does not address field maintenance requirements.

UNCERTAINTY FACTORS DURING CALIBRATION:

REFERENCE UNCERTAINTY	UNCERTAINTY OF THE UUT	CALIBRATION PROCESS
• Calibration Uncertainty • Long Term Stability • Conditions During Calibration	• Conditions During Calibration • Stability (Short Term) • Repeatability • Linrarity • Hysteresis • Resolution	• Stability and Homogenity of the Measured Quanity

Table 1
Complete list of errors contributing to the uncertainty in the calibration process for a relative humidity instrument.

$$u_c = \sqrt{u_A^2 + u_{B,1}^2 + u_{B,2}^2 + \ldots}$$

Final Uncertainty

The final uncertainty is determined by taking the square root of the sum of the squares of each of the separate uncertainties of the error types listed above.

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