ACCEPTANCE TEST PROCEDURE FOR CAPACITIVE HUMIDITY SENSORS IN SATURATED CONDITIONS

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ABSTACT

Continuous high humidity conditions are representing a great challenge for capacitive humidity sensors causing increased errors and calibration drift. During longer episodes of saturation some sensors tend to give readings well above 100 %RH and beyond tolerance. Although in some cases manufacturers cut off these values to limit the output range at 100 %RH the sensor internally is in a critical state which can lead to calibration drift or damage.

A simple laboratory acceptance test procedure is proposed to evaluate the sensors capability to reliably measure humidity in saturated conditions. The test procedure is described and the results - particularly on the differences between heated and unheated sensors- are presented.

1. Motivation

As humidity is a permanent environmental factor, its control and measurement are particularly important not only for many industries and technologies but also in meteorology and for human comfort. For accurate weather forecasting the precision of air humidity measurement is one of the basic parameters, as it is an indicator of the likelihood of precipitation, dew, or fog. Changes of high humidity conditions have to be detected immediately being important for indicating changing visibility and for deriving the spread.

The capacitive-type sensor is superior in linearity of sensor output and in stability at high humidity to the resistive-type sensor. However, many problems, i.e. hysteresis, stability at high temperature and in a highly humid atmosphere, and durability to some kinds of organic vapors, etc., still have to be clarified. In order to design a capacitive-type humidity sensor for operational use, selecting appropriate material for this type of sensor is important. The investigation of the water sorption behaviour in sensing polymers seems to be essential for this purpose.

Ten different capacitive polymer humidity sensors (see appendix) were tested in DWD laboratory prior to starting a tender to characterize their specifications. One essential demand for a new sensor was the accurate behaviour during high humidity conditions. Results from field tests showed increasing deviation up to ±20 %RH with decreasing temperature, higher humidity and life time. Particularly near the point of condensation -close to 100 %RH- some humidity sensors became inaccurate. Figure 1 shows the increasing deviation with decreasing temperature from 6 different humidity sensors compared to a chilled mirror dew point sensor Thygan VTP37 [Meteolabor AG, Wetzikon, Switzerland] used as reference during the 2 years field test. Only data with humidities over 90 %RH are shown as a function of the temperature.

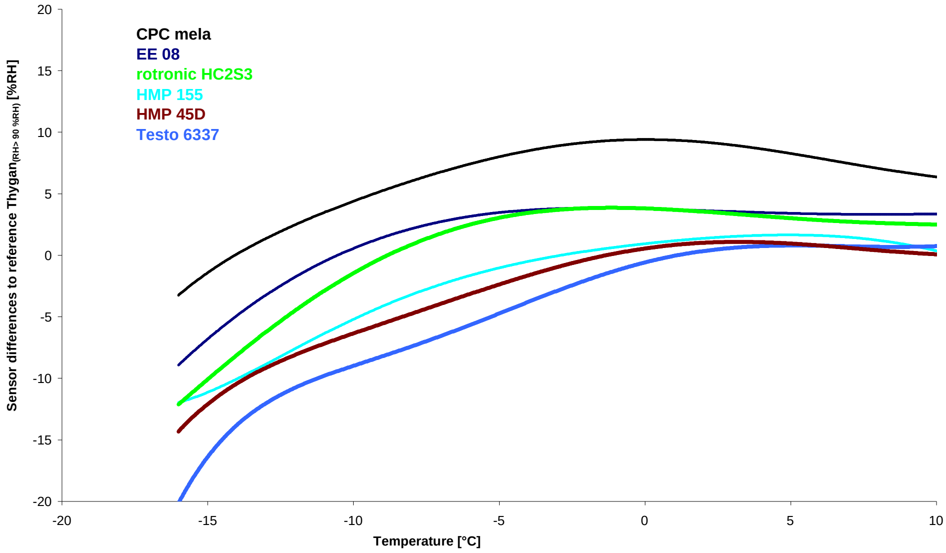

Figure 1: Results from the 2 years field test at DWD weather station Wasserkuppe. Deviation of humidity measurements of 6 different sensors compared to the reference (Thygan) as function of the temperature. Results only shown for humidity values >90 %RH

Looking closer into the data the response times of the different humidity sensors play an important role on this issue. Predominantly after long periods of high humidity conditions (>95 %RH) the sensors step response varied notably. Figure 2 shows an example for three different humidity sensors at the DWD weather station Wasserkuppe (950 m a.s.l.) were 220 fog days/a on average could occur. After 26 hours of high humidity the meteorological conditions changed. The visibility was measured by a forward scatter visibility meter FD12P [Vaisala Oyi, Helsinki, Finland] and the differences in response time become apparent compared to the Thygan.

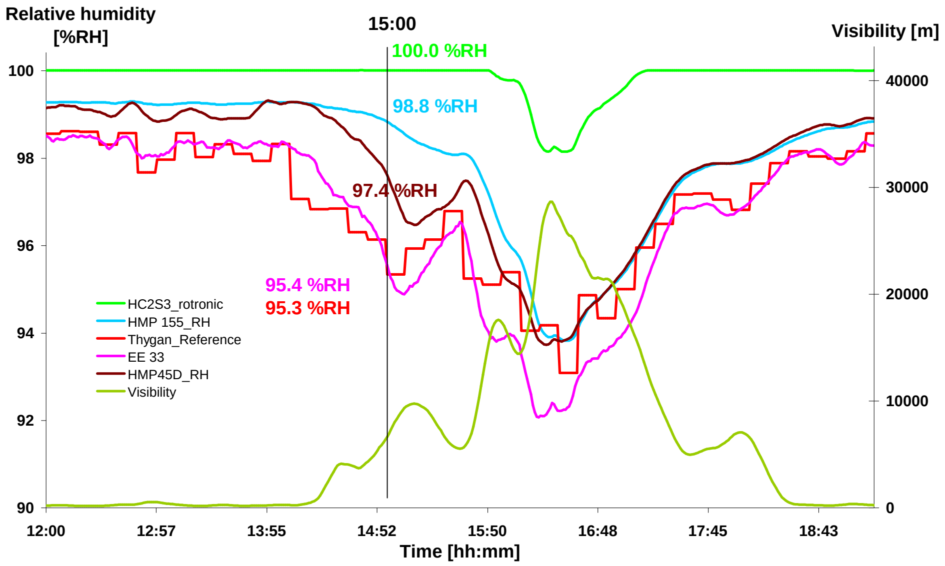

Figure 2: Results from the field test at DWD weather station Wasserkuppe. Differences in response time of humidity sensors after 26 h of high humidity. The meteorological situation starts to change at 14:20.

In a further paper we have investigated these response times and the response behaviour of humidity sensors [1]. Figure 3 shows the response time of 8 sensors for the response step from 95 %RH down to 30 %RH. By varying the humidity step, the temperature, and the used filters different sensor response times could be observed. But condensation or sublimation on the sensors or sensing elements were not detected at all. Therefore these tests are inappropriate to simulate sensor decalibration and aging observed in “real world” high humidity conditions.

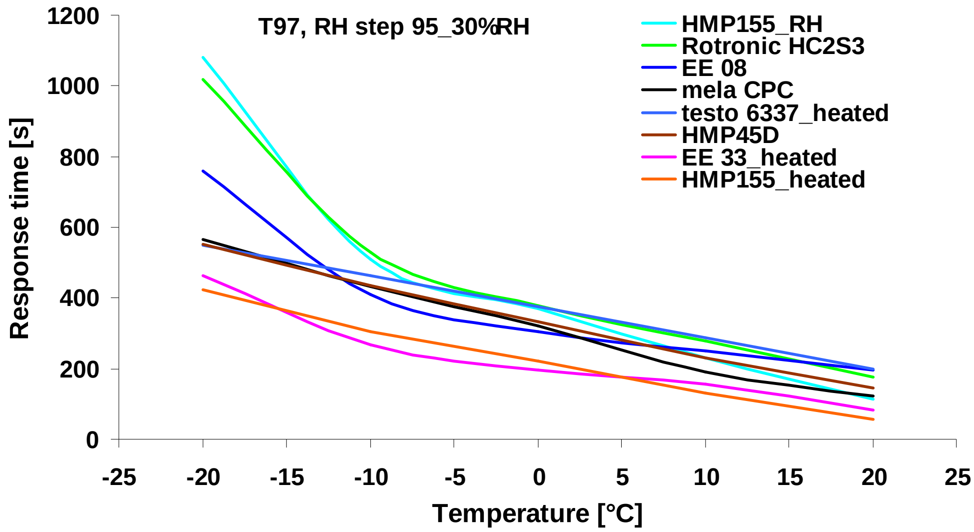

Figure 3: Results from laboratory tests. The sensor step response T97 at different temperatures for the humidity step from 95 %RH down to 30 %RH is shown for 8 different humidity sensors.

The aim of this paper was to develop a laboratory acceptance test procedure to evaluate the capability of capacitive polymer humidity sensors to correctly measure relative humidity while being constantly exposed to saturated conditions.

2. Laboratory test setup

For investigation of long-term stability and high-precision measurements under saturated conditions a laboratory acceptance test for humidity sensors was developed.

In the field of microelectronics a common evaluation method for device reliability determining resistance to prolonged operating stress is the use of accelerated high temperature operating lifetime tests (HTOL) [2]. These HTOL qualification tests were used to determine the effects of bias and temperature stress conditions on devices to evaluate the products life and guarantee the product reliability within the warranty period. Therefore the accelerated conditions are to simulate operating life over a shortened test period. In the case of the manufacturer Sensirion AG [Staefa, Switzerland], long term drift of humidity sensors is determined by exposing a sample of sensors to HTOL-operation at 125 °C during 408 hours. The exposure at 125 °C corresponds to aging at 25 °C during a much longer time period, which than can be calculated by a formula [3]. For our laboratory test set up we stressed the capacitive polymer humidity sensors with extended temperature (40 °C) and humidity (> 100 %RH) to evaluate their behaviour under accelerated conditions.

The initial situation was recorded by calibrating the sensors to be tested in a two pressure humidity generator Thunder scientific 2500 ST-LT [Thunder Scientific, USA] at 20 °C and different humidities. A special test chamber was build where saturated conditions could be performed (see Figure 4).

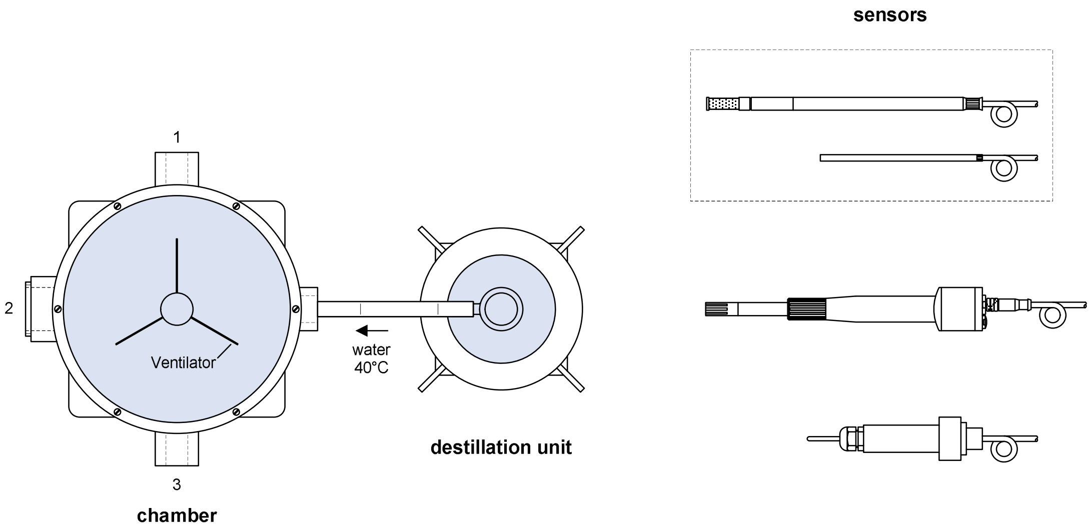

Figure 4: Laboratory setup (top view). The sensors shown on the right side were installed alternately at sensor ports 1, 2 or 3 of the chamber

The bottom of the chamber was filled with water and the sensors were be placed some cm above the surface of the water. The sensors were installed alternately together with temperature sensors at sensors ports 1, 2 or 3 shown in Fig. 4. Homogeneous conditions in the chamber were kept by a ventilator stirring the air. In order to force saturated conditions water was heated in a distillation unit (cucurbit). Water at 40 °C was delivered into the chamber for 3 hours. With the sensors being at room temperature this generates condensation on the sensor.

After 3 hours the sensors were taken out of the chamber and exposed to room conditions. The sensors were allowed enough time to stabilize. The response curve was recorded and after 4 cycles of repetition the sensors were recalibrated in the reference humidity generator.

3. Results

The acceptance test procedure was conducted with different capacitive humidity sensors. In this way different behaviour of the sensors was observed representing the varied field conditions. During this test procedure the sensors are in a extreme situation. The continuous high humidity conditions could cause condensation at the sensor and even below the filter at the sensing element itself.

Different results of the saturation test were observed:

1) Some sensors show reading beyond tolerance, e.g. in Figure 5 humidity values up to 130 %RH are shown.

2) For most of the sensors condensation situations could not be detected at all because their output is limited to 100 % RH. An example is shown in Figure 6.

3) Some sensors could not withstand continuous high humidity condition at all and cut off data acquisition (see Figure 7).

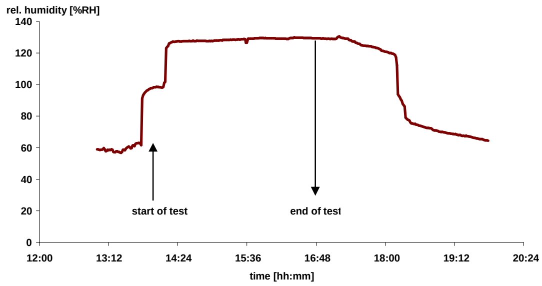

Figure 5: Results for humidity sensor showing humidity values up to 130 %RH.

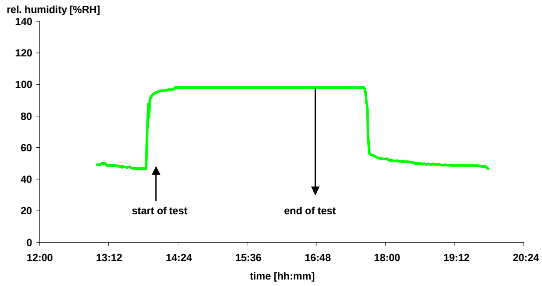

Figure 6: Results for humidity sensor showing limited output signals to 100 %RH.

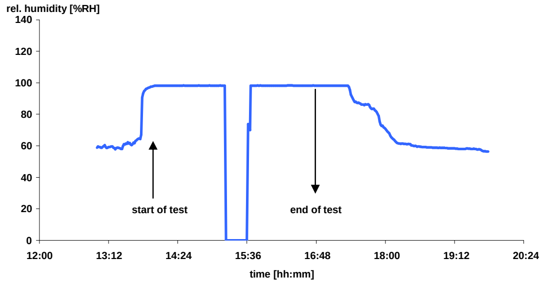

Figure 7: Results for humidity sensor howing cut off data acquisition during the test

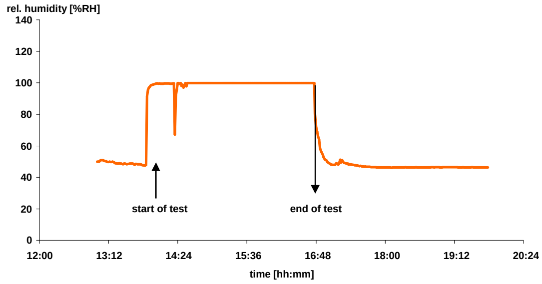

Figure 8: Results for heated humidity sensor.

4) Results for heated sensors

In Figure 8 and 9 the results for heated sensors are shown. Figure 8 points out the fast response time and Figure 9 shows 4 cycles of the test procedure for a heated sensor.

5) Condensation at the sensor

To demonstrate the differences between unheated and heated sensors, two sensors with identical design were investigated. Figure 10 shows the sensors after 3 hour of high humidity – one cycle of the test procedure. While the unheated sensor showed enormous condensation at the surface and at the sensing element the heated one remained dry even inside at the sensing element.

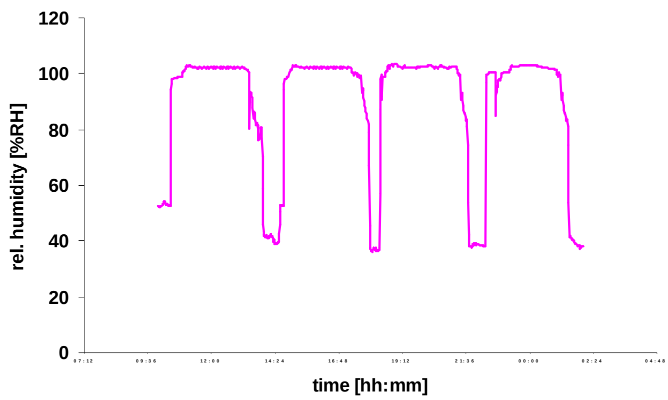

Figure 9: Results of the heated humidity sensor EE33 with 4 cycles of repetition of the test procedure.

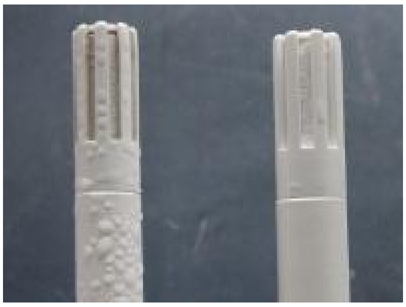

Figure 10: Two HMP 155 sensors after 3 hours of high humidity conditions during the laboratory test. The HMP155 sensor on the right is heated, the one on the left is unheated.

6) Calibration drift

Being recalibrated after 4 cycles of the high humidity test procedure the sensors show drift in relative humidity measurement. Particularly with regard to high humidity (> 70 %RH) results deviate more than acceptable. An example is shown in Figure 11 for an unheated sensor. Measurements compared to the reference are shown before, after 2 cycles and after 4 cycles of our high humidity test procedure.

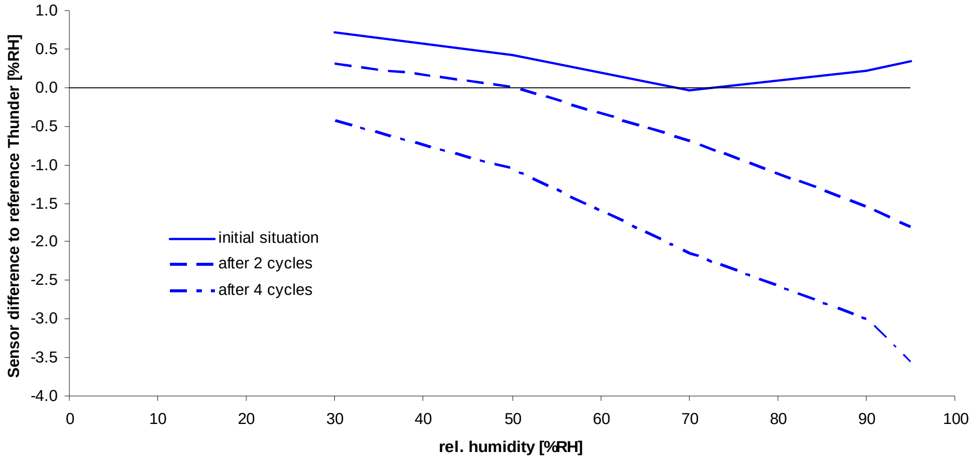

Figure 11: Calibration of humidity sensor before and after the laboratory test

4. Conclusions

In field tests and in the operational network of DWD problems with polymer humidity sensors under condensing conditions were observed leading to unacceptable time response and decalibration. The reason for this is condensation or sublimation on the sensor or the sensing element. Commercial humidity calibrators or saturation chambers are not suitable to generate these conditions. Thus sensors passing these laboratory tests could fail in extended high humidity conditions in the field.

A fast acceptance test procedure (stress test) was developed to examine the sensors capability to measure correctly in a condensing environment. Humidity sensors were mounted in a saturation chamber at room temperature and exposed to warm saturated water vapour to force condensation on the sensor.

Sensors showed different results like readings well above 100 %RH, signal limitation to 100 %RH, calibration drift or even damages. Differences in response time could also be observed during the test procedure. Heated polymer sensors showed better performance than unheated ones.

As the test conditions are more extreme than in natural environment, sensors passing this acceptance test are expected to work without problems under high humidity field conditions.

References

[1] Temperature dependency of capacitive polymer humidity probes
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[3] RH Accuracy guide: Sensor Specification Statement
How to Understand Specification of Relative Humidity Sensors
www.sensirion.com (version 1.0 2010)

Appendix

List of sensors tested with manufacturers specification

Relative humidity	Range	measurement uncertainty	sensor time constant
Galltec+mela CPC 1/9-ME	0 - 100 %RH	2 %RH [5 - 95 %RH, 10 - 40 °C] < + 0.1 %/K [for <10°C, >40°C]	not specified
Galltec+mela F1CF	0 - 100 %RH	1.5 %RH [10 - 90 %RH, 23 °C] 2 %RH [<10 %RH>90 %RH; TK<0.005 K	not specified
EE 08	0 - 100 %RH	2 %RH [0 - 90 %], 3 %RH [90 - 100 %] TK = 0.03 %RH/°C [at 20°C]	not specified
EE 33*	0 - 100 %RH	1.3%RH+0.3*reading %RH [-15 - 40°C, <90%RH]	t 90 =<15s [20°C]
Physicus HumiAir8	0 - 100 %RH	3 %RH	not specified
Rotronic HC2-S3	0 - 100 %RH	1 %RH	t 63 = 12 - 15 s [at 23°C]
Vaisala HMP45D	0.8 - 100 %RH	1 %RH [Laboratory, 20 °C], 2 %RH [Field 0 - 90 %RH], 3 %RH [Field > 90 %RH]	15s [at 20°C]
Vaisala HMP155A* HMP155D	0 - 100 %RH	1 % RH [0-90%RH, +15 - +25°C] 1.7 % RH [90-100%RH, +15 - +25°C] 1.0+0.008*reading %RH [-20 - +40°C]	20s [for 63% at 20°C] 60s [for 90 % at 20°C]
testo 6337 9742*	0 - 100 %RH	2,5 % RH [0-100%RH, 25°C]	not specified

* heated versions