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Effect of humidity on the calibration of the four-terminal-pair air-dielectric capacitance standards

Hyung-Kew Lee *, Dan Bee Kim, Wan-Seop Kim

Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea

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ABSTRACT

In this work, the effect of relative humidity (RH) on two commercial four-terminal-pair (4TP) air-dielectric capacitance standards has been measured and analyzed. The capacitance is linearly proportional to the RH under 50% owing to the dependence of the dielectric constant of air on the RH. Over 50%, a clear dielectric dispersion has been observed. It is probable that this dispersion is caused by the interfacial polarization of the adsorbed water molecules on the oxidized aluminum electrodes. In calibration aspect, it is recommended to store at least for a day to stabilize the RH inside the standard and calibrate it at RH lower than 50%. The RH coefficient of the capacitance under 50% was estimated as 3 (μF/F)/% from the measurement.

1. Introduction

A four-terminal-pair (4TP) air-dielectric capacitance standard set from Keysight Technology, HP 16380A, has been used widely as a standard for calibrating LCR meters and impedance analyzers up to 13 MHz frequency. It consists of four standard capacitors: 1 pF, 10 pF, 100 pF, and 1000 pF. At Korea Research Institute of Standards and Science (KRISS), we have been developing the calibration technology for this standard set based on the method established by Suzuki [1–3]. In the course of development, we found that the capacitance measured at 1 kHz, which is the reference value for the Suzuki method, is influenced significantly by the humidity and reported a preliminary observation at the Conference on Precision Electromagnetic Measurements in 2014 [4].

The humidity dependence of air-dielectric capacitance standards has been also reported by a few NMIs with different perspectives [5–7]. Some of them focused on the power factor [5,6] and the other one on the capacitance [7]. Astin and So reported that the power factor (PF) of a custom parallel plate air-dielectric capacitor increased with the increasing relative humidity (RH) below 70% [5,6]. Rietveld also reported a dramatic increment of the capacitance of the cylinder type air-dielectric capacitor at 0.05 Hz with respect to the RH [7]. Astin observed some dielectric dispersion in aluminum electrodes from the PF measured at three frequencies (60 Hz, 200 Hz, and 1 kHz) [5]. However, none of these works have provided the RH dependence of both the capacitance and the loss of the standard air capacitors for the characterization of their dielectric behavior.

In this work, we conducted a controlled experiment to see the effect of humidity on the frequency characteristics of a 10 pF capacitance standard model, HP 16382A, in a HP 16390A set. The frequency spectra of the capacitance and the DF of the two standards with different serial numbers have been measured and analyzed with respect to five RH levels.

* Corresponding author.
E-mail addresses: hyungkew.lee@kriss.re.kr (H.-K. Lee), danbeek@kriss.re.kr (D.B. Kim), ws2kim@kriss.re.kr (W.-S. Kim).

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2. Experiment

We installed a temperature/humidity sensor, TANDD TR-3110, in one of the two standards with a serial number of 1840J00216 (C0216) in order to monitor the RH inside the standard. Fig. 1 shows the internal structure of the standard and the installed temperature/humidity sensor. The electrodes are made from aluminum. A detailed description of this capacitance standard set can be found in Ref. [8].

The standard equipped with the sensor has been put into a climatic chamber, Kambic PKK-50, whose temperature and humidity can be controlled accurately. The temperature has been maintained at (23.0 ± 0.3) °C over the whole measurement period. The RH has been varied from (35.0 ± 0.3)% to (65.0 ± 0.3)%. The high potential (Hpot) and low potential (Lpot) terminals of the standard were connected to a precision capacitance bridge, AH2700, via coaxial cables. An average from seven measurements has been taken as a single data point. By using custom software, the capacitance and dissipation factor (DF) have been measured at frequencies from 50 Hz to 20 kHz. The frequency cycle was repeated twelve times with five-minute interval. It takes around one and half hours to complete the twelve cycles.

3. Results

The capacitance and the DF of the C0216 have been recorded once every five minutes for a week at 1 kHz changing the RH setting of the climatic chamber from 35% to 65%. For each setting, we monitored the RH inside the standard and the capacitance and the DF of the standard at least for a day. The results are displayed in Fig. 2. The humidity in the climatic chamber, which is not shown in the figure, reached its set value within five minutes. The RH trace in the figure presents humidity inside the standard. A clear correlation between the measurement and the RH is observed. Besides, the change in the capacitance and the DF and the internal RH is synchronized in time. The time after which the capacitance settles within 2% deviation of the stabilized amount of change of about 80 μF/F from 50% to 65% RH is estimated as 17 h. This settling time has been used as a guidance for the handling of the standards. The capacitance and the DF at 1 kHz appears to have a non-linear relationship with the RH. The capacitance increased by about 80 μF/F from 50% to 65% RH in comparison to around 40 μF/F from 35% to 50% RH. From time to

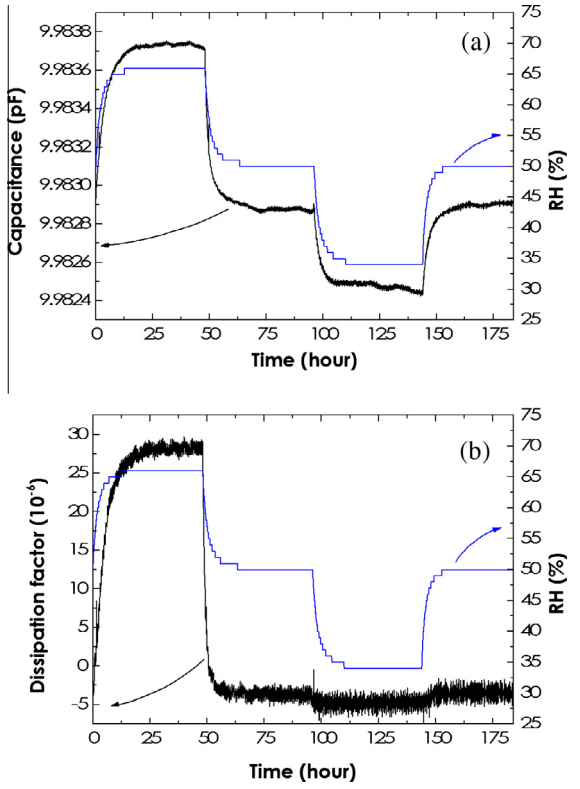

Fig. 2. (a) The capacitance and (b) the dissipation factor of one capacitance standard (S/N: 1840J00216) monitored for a week with varying RH.

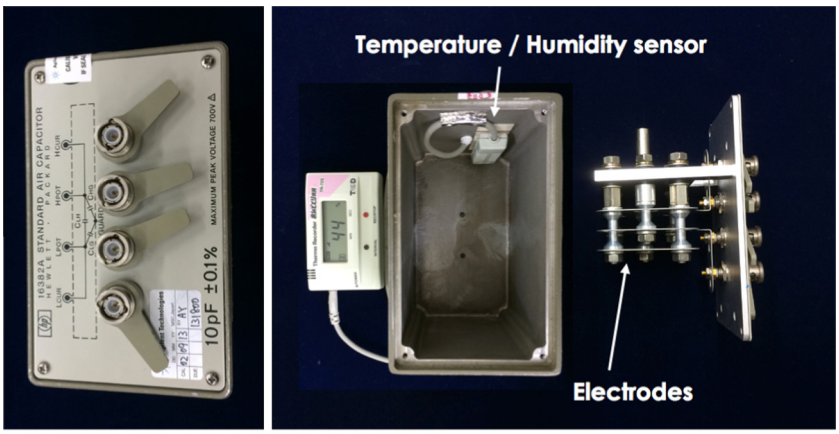

Fig. 1. (a) A four-terminal-pair air-dielectric capacitance standard (HP 16382A) and (b) the installed temperature/humidity sensor inside the case.