Further Effects of Test Voltages, Relative Humidity and Temperature on Air Discharge Currents from Electrostatic Discharge Generator

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***Abstract*— Air discharge immunity testing for electronic equipment is specified in the standard 61000-4-2 of the International Eelectrotechnical Commission (IEC) under the climatic conditions of relative humidity from 30 to 60 % and temperature from 15 to 35 degrees Celsius. This implies that the air discharge testing is likely to provide significantly different test results due to a wide climate range. To clarify effects of the above climate conditions on air discharge testing, we previously measured air discharge currents from an electrostatic discharge (ESD) generator with test voltages from 2 kV to 15kV at an approach speed of 80 mm/s under 6 combinations of relative humidity and temperature in the IEC specified and non-specified climate range. The result showed that the same absolute humidity provides almost the identical waveforms of the discharge currents despite different relative humidity and temperature, and also that the current peaks at higher test voltages decrease as the absolute humidity increases. In this study, we further examine the effects of air discharges on test voltages, relative humidity and temperature with respect to two different approach speeds of 80 mm/s and 20 mm/s. As a result, the approach speed of 80 mm/s is confirmed to provide the same results as the previous ones under the identical climate conditions, while at a test voltage of 15 kV in the IEC specified climate range 20 mm/s approach speed causes the current waveforms entirely different from those at 80 mm/s despite the same absolute humidity, and the peaks are not affected by the absolute humidity, however, under the IEC non-specified climate conditions, likewise the case at 80 mm/s, the peaks decrease at higher test voltages as the absolute humidity increases.**

Keywords—Air dischaege; Test voltage; Relative humidity; Absolute humidity; Tempareture; Discharge current

I. INTRODUCTION

Air discharge immunity testing for electronic equipment specified in 61000-4-2 of the International Eelectrotechnical Commission (IEC) standard [1] causes unstable testing reproducibility due to many factors such as the approach speed of an electrostatic discharge (ESD) generator, relative humidity, ambient temperature and so on. Nevertheless, the air discharge method is a mandatory test in the present IEC standard which also specifies climatic conditions of relative humidity from 30 to 60 %, temperature from 15 to 35 degrees Celsius and atmospheric pressure from 860 to 1060 hecto-pascal (hPa). The above situation implies that the air discharge test is likely to provide significantly different test results due to various factors including the climatic conditions. To improve the test reproducibility, therefore, the effects on air discharges of approach speed, relative humidity and temperature have extensively been investigated so far [2]-[5], one of which reports that very low approach speed or high ambient humidity increases the ESD testing repeatability [3]. However, concerning how the relative humidity affects air discharges in conjunction with the ambient temperature, it still remains unknown. For this reason, to clarify such combined effects of the above climatic conditions on air discharge testing, we previously measured air discharge currents from an ESD generator with test voltages from 2 kV to 15 kV at an approach speed of 80 mm/s under several combinations of relative humidity and temperature, which showed that the same absolute humidity provides almost the identical waveforms of the discharge currents despite different relative humidity and temperature [6].

In this study, to further investigate the above-mentioned effects, we examine the dependence of air discharge current behavior from an ESD generator on test voltages, relative humidity and temperatures with respect to two different approach speeds of 80 mm/s and 20 mm/s.

II. METHOD

A. Measurement environment and setup

Fig. 1 shows the IEC specified climate conditions for air discharge testing. Pink meshed region means the IEC specified climate range. Absolute humidity curves in the figure were calculated from temperature and the resultant saturated water vapor amount [7]. Closed and open circles show our measurement points in the IEC specified and non-specified climate range, respectively. At these points, measurements of air discharge currents were conducted in a thermo-humidistat, or constant temperature and humidity chamber, where the atmospheric pressure at the time of measurement was 1013 to

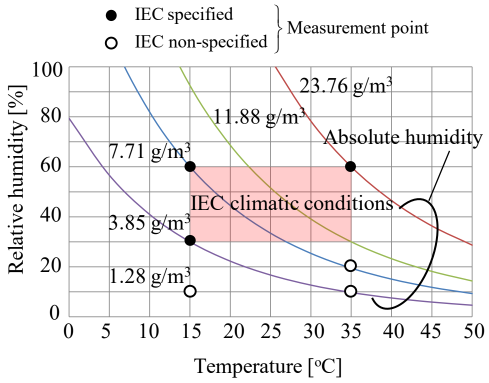


Fig. 1 Climatic range of relative humidity and temperature under the IEC specified and non-specified conditions for air discharge testing.

1022 hPa. The chamber is located inside the Tokyo metropolitan industrial technology research institute, which allows changing relative humidity and temperature from 10 to 95 % and from -40 to 80 degrees Celsius, respectively. The chamber dimensions are 3020 mm width by 4000 mm depth by 2100 mm height.

Fig. 2 shows a setup for measuring air discharge currents in the constant temperature and humidity chamber. A vertical uniaxial actuator (Noiseken ZAP-1A) was used for air discharges of an ESD generator. As indicated in Fig. 2, the ESD generator (Noiseken TC-815R with ESS-2000AX) was mounted on the actuator. It was placed on a horizontal ground plane to which attaches an IEC required current target (Noiseken 06-00067A). A small metal sphere with a diameter of 6 mm was mounted on the target for stable spark discharges [8]. A 20 dB attenuator was connected directly to the current target and a 6 dB attenuator was also connected to an oscilloscope to attenuate the input amplitude. The ground connection of the ESD generator was arranged to meet the IEC standard calibration requirements. The waveforms of air discharge currents were measured outside the chamber with a 4 GHz oscilloscope (Tektronix TDS7404B).

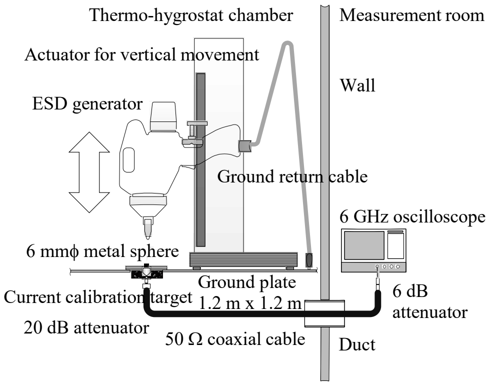


Fig. 2 Measurement setup for air discharge currents.

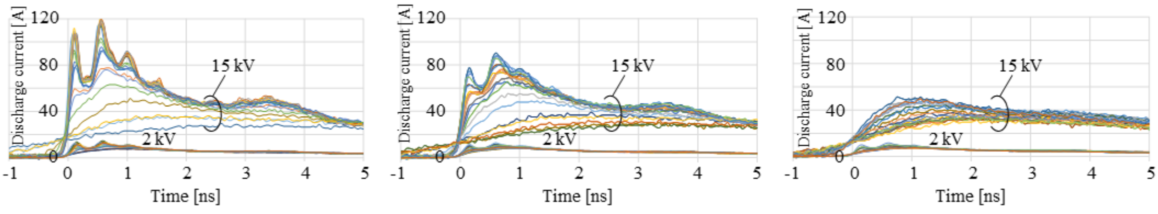
B. Measurement conditions

As shown in Fig. 1, 6 combinations of the climatic conditions were set to three border points in the IEC requirement range and three lower relative humidity points in the IEC non-specified range with closed and open circles, respectively. As indicated in Fig. 2, the uniaxial actuator goes down from a distance of 50 mm vertically to the current target electrode with two different speeds of 80 mm/s and 20 mm/s. These speeds were determined since less than 100 mm/s does not almost affect the peaks of discharge currents according to [3]. Just before the electrode of the ESD generator collides with the current target electrode, a spark occurs between the both electrodes, and the oscilloscope records the air discharge waveform. This operation is repeated more than 20 times under each of the climatic conditions.

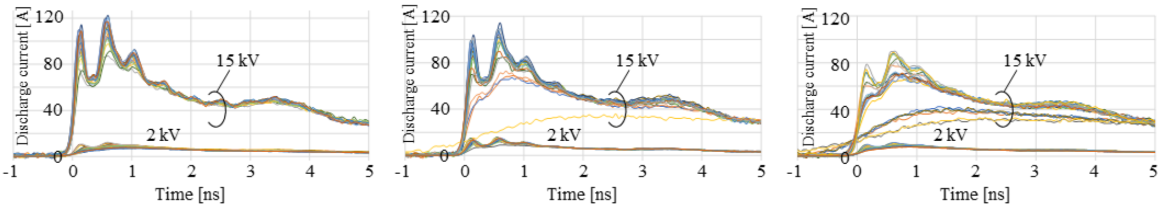
III. RESULTS AND DISCUSSION

Fig. 3 shows 20 measured waveforms of 2 kV and 15 kV air discharge currents at an approach speed of 80 mm/s under various conditions of relative humidity and temperature. Figs. 3 (a) to (c) and Figs. 3 (d) to (f) show the measured results under the IEC specified and non-specified climate conditions, respectively.

These results, which are almost identical to our previous

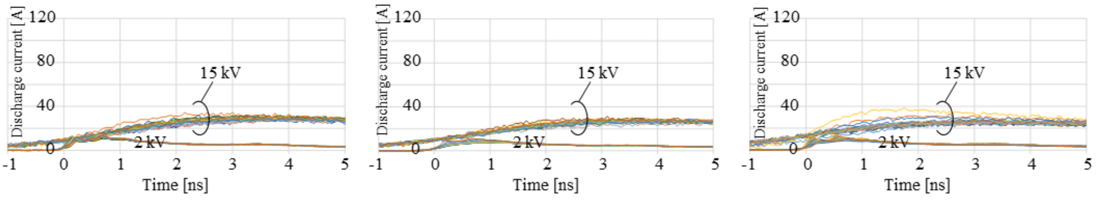


(a) 15°C RH 30 % AH3.85 g/m³ (b) 15°C RH 60 % AH7.71 g/m³ (c) 35°C RH 60 % AH23.76 g/m³

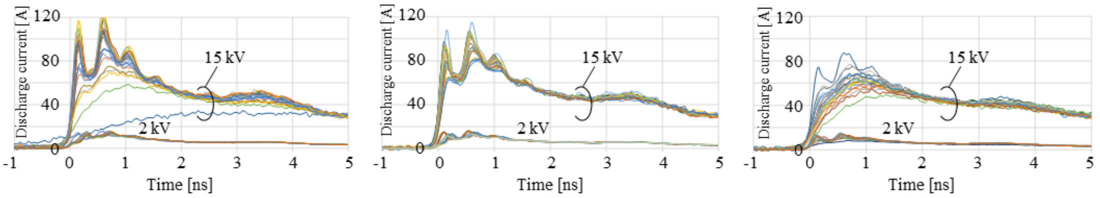


(d) 15°C RH 10 % AH1.28 g/m³ (e) 35°C RH 10 % AH3.96 g/m³ (f) 35°C RH 20 % AH7.92 g/m³

Fig. 3 Measured waveforms of discharge currents at an approach speed of 80 mm/s under different climatic conditions inside IEC standard of (a), (b) and (c) and outside IEC standard of (d), (e) and (f). RH and AH mean relative humidity and absolute humidity, respectively.



(a) 15°C RH 30 % AH3.85 g/m^3 (b) 15°C RH 60 % AH7.71 g/m^3 (c) 35°C RH 60 % AH23.76 g/m^3

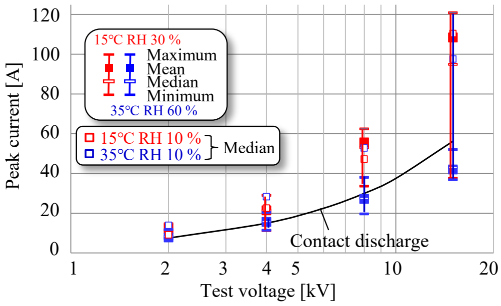


(d) 15°C RH 10 % AH1.28 g/m^3 (e) 35°C RH 10 % AH3.96 g/m^3 (f) 35°C RH 20 % AH7.92 g/m^3

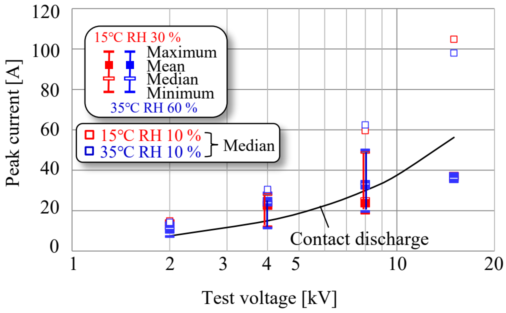
Fig. 4 Measured waveforms of discharge currents at an approach speed of 20 mm/s under different climatic conditions inside IEC standard of (a), (b) and (c) and outside IEC standard of (d), (e) and (f). RH and AH mean relative humidity and absolute humidity, respectively.

ones [6], confirm that the 15 kV peak currents decrease as the absolute humidity increases despite different temperature and relative humidity, whereas the 2 kV current waveforms seem to be not affected by the climatic conditions, as shown in Fig. 3. Figs. 3(a) and (c) show the results under the lowest and highest relative humidity conditions, respectively, that the IEC standard requires. Figs. 3 (a) (e) and Figs. 3(b) (f) are the results measured under almost the same conditions of absolute humidity, as seen in Fig. 1. These waveforms are similar despite different relative humidity and temperature. They also exhibit rise time of less than 200 ps except the case of 15 kV in Fig. 3(c), which is very fast in comparison with 800 ps of contact discharges [1]. Note that variations in the 15 kV current waveforms in the IEC specified climate range reduce with increasing the absolute humidity, however, in the IEC non-specified case they seem to reduce as the absolute humidity decreases.

Fig. 4 shows 20 measured waveforms of 2 kV and 15 kV air discharge currents at an approach speed of 20 mm/s under the same climate conditions as those in Fig. 3. Differently from in Fig. 3, it indicates that the 15 kV current waveforms are not affected by the absolute humidity in the IEC specified climate range, whereas these current waveforms under the IEC non-specified relative humidity and temperature seem to be identical to those in Figs. 3(d) to (f). This exhibits that the same absolute humidity does not always provide the identical waveforms of the discharge currents, in which the decisive factors that affect the discharge current waveforms are unknown at present. Note, however, that 2 kV current waveforms are not almost affected by the climate conditions.



(a) Test voltage versus peak current at 80 mm/s

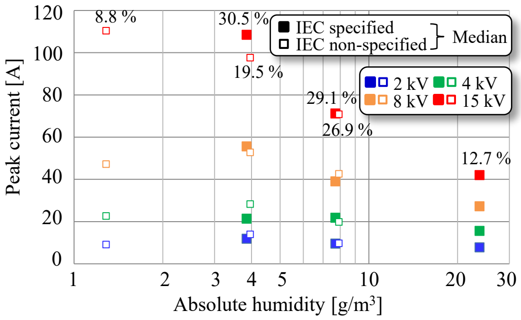


(b) Test voltage versus peak current at 20 mm/s

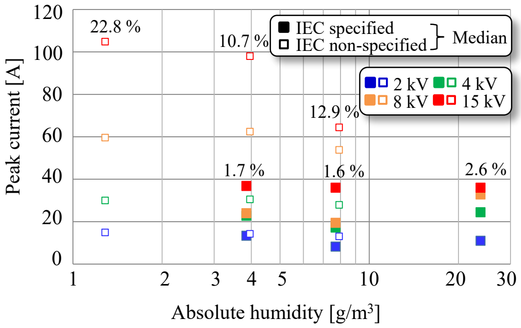
Fig. 5 Dependence of peak currents on test voltages.

Figs. 5(a) and (b) show the dependence on test voltages of current peak statistics at approach speeds of 80 mm/s and 20 mm/s, respectively. Red and blue closed squares indicate the results under relative humidity of 30 % and 60 %, respectively, and temperature of 15 and 35 degrees Celsius, respectively. Open squares indicate the test voltage dependence of median current peaks measured in the IEC non-specified climate range. Solid curve indicates the current peaks for contact discharges, which are not affected by the climatic conditions [1]. As indicated in Fig. 5, in comparison with the current peaks for contact discharges, at 80 mm/s the median peaks are larger at any test voltages under 30 % relative humidity condition, and they are close to those for contact discharges at test voltages of 2 kV and 4 kV under 60 % relative humidity condition, while at 20 mm/s the peaks are larger at test voltages of 2 kV and 4 kV under relative humidity conditions of 30 % and 60 %. It should be noted, however, that the median peaks in the IEC non-specified climate range are always larger compared to those for contact discharges regardless of the approach speeds and test voltages.

Figs. 6(a) and (b) show the dependence of median current peaks on absolute humidity at approach speeds of 80 mm/s and 20 mm/s, respectively. Numbers in the figures represent variations of 15kV current peaks that were obtained in % from dividing the standard deviations by the mean values. As shown in Fig. 6, at 80 mm/s, regardless of the IEC specified and non-



(a) Absolute humidity versus median peak at 80 mm/s



(b) Absolute humidity versus median peak at 20 mm/s

Fig. 6 Dependence of peak currents on absolute humidity.

specified climate conditions, the current peaks at test voltages of 2 kV and 4 kV that are not almost affected by the absolute humidity, while 8 kV and 15 kV current peaks decrease as the absolute humidity increases. At 20 mm/s, on the other hand, the peaks are not affected by the absolute humidity regardless of test voltages under the IEC specified climate conditions, whereas the 8 kV and 15 kV peaks in the IEC non-specified climate range decrease with increasing the absolute humidity likewise the case at 80 mm/s.

Concerning the variations of the 15 kV peaks, at 80 mm/s, they decrease under the IEC specified conditions as the absolute humidity increases, but under the IEC non-specified conditions they have the opposite tendencies. At 20 mm/s, however, the variations do not have definite dependence on the absolute humidity at both the IEC climate conditions, but under the IEC specified conditions they are significantly smaller than those at 80 mm/s.

The above findings suggest that the higher absolute humidity and lower approaching speed are likely to increase the reproducibility in immunity testing and also to decrease the current peak variations, which supports the results of [3].

IV. CONCLUSION

The dependence of air discharges on test voltages, relative humidity and temperature was examined in conjunction with two different approach speeds of 80 mm/s and 20 mm/s. As a result, we found that differently from the previous result [6], the same absolute humidity does not always provide the identical waveforms of air discharge currents. At higher test voltages with an approach speed of 80 mm/s current peaks decreased as the absolute humidity increased, likewise in [6], while at any test voltages with 20 mm/s the current peaks were not almost affected by the absolute humidity under the IEC specified climate conditions, however, in the IEC non-specified climate range they had tendencies similar to those at 80 mm/s. Such differences in air discharges that an approach speed causes are likely to be provided by surface roughness of the tip electrode of the ESD generator and metal sphere attached to the target, which is generated by the collision every measurement, whereas the mechanism remains unknown even at present.

The future task is to investigate the dependence of air discharges on the very low approach speed of ESD generators at higher test voltages under various climate conditions.

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REFERENCES

[1] IEC 61000-4-2: Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test," Edition 2.0, December 2008.

[2] D. Pommerenke : “ESD:transient fields, arc simulation and rise time limit,” Journal of Electrostatics, Vol. 36, pp. 31-54 (1995).

[3] S. Frei, M. Senghaas, R. Jobava, W. Kalkner: “The Influence of speed of Approach and Humidity on The Intensity of ESD,” Proc. 13th international Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility, Zurich (1999).

[4] Ikuko Mori and Osamu Fujiwara: “Sevrity Evaluation of the IEC Immunity Test against ESD based on Wideband Measurement of Discharge Current Waveforms,” IEEJ Trans. FM, Vol.130, No.5 pp.457-461 (2010) (in Japanese).

[5] Qingyun Yuan, Shanghe Liu, Xijun Zhang, Zhancheng Wu, and Ming Wei: “The Effect of Approach Speed and Charge Voltage on an Air Discharge,” IEEE Transactions on Electromagnetic Compatibility, Vol. 52, No. 4, pp.985-993 (November 2010).

[6] Takeshi Ishida, Hiroaki Okajima, Kiyoshi Endo, Masamichi Kinoshita, Osamu Fujiwara, Shuichi Nitta: “Combined Effects of Relative Humidity and Temperature on Air discharges of Electrostatic Discharge Generator,” Proc. 2017 IEEE International Symposium on Electromagnetic Compatibility, Signal and Power Integrity, Washington, DC, Abstract Reviewed, pp. 135-139 (August 2017).

[7] http://biomet.ucdavis.edu/conversions/HumCon.pdf (accessed August 1, 2018).

[8] Takeshi Ishida, Fengchao Xiao, Yoshio Kami, Osamu Fujiwara, and Shuichi Nitta, “An Alternative Air Discharge Test in Contact Discharge of ESD Generator Through Fixed Gap,” Proc. IEEE International Symposium on Electromagnetic Compatibility, pp.46-50 (August 2016)