DSP Measurement of Dielectric Property of Polymeric Materials Using Interdigital Electrodes

H. Shindou, T. Tokoro and M. Kosaki
Department of Electrical and Computer Engineering, Gifu National College of Technology
Shinsei-cho, Motosu-gun, Gifu 501-0495, Japan

Abstract

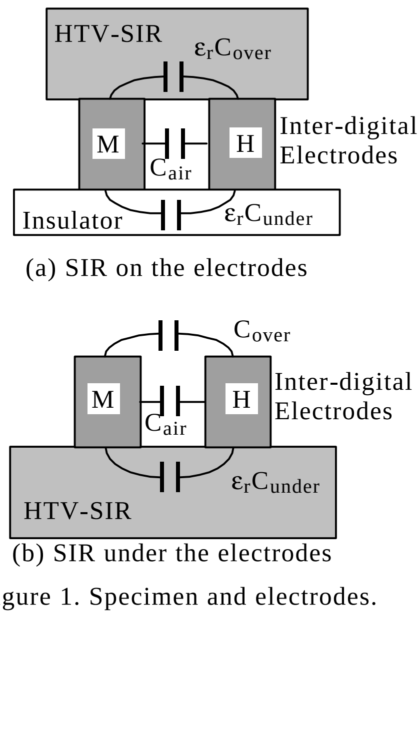
Generally, dielectric property of insulating material is evaluated as loss tangent and capacitance by using thin samples. These bulk properties are measured by the application of electric field from one side to another side of the sample film surface. Three terminal parallel plane electrodes are usually used for this measurement. In this paper, a pair of inter-digital electrodes is set only on one side of sample surface, such as silicone and EPDM rubber insulators. Then, we evaluate the dielectric property by using the leakage of the electric field lines from the edge of interdigital finger electrode to the bulk of the sample [1]. Digital signal processor (DSP) is used for data processing. We can successfully measure the degradation and recovery process of the surface of polymer insulating materials.

Our DSP measuring system of dielectric materials can detect the change in dielectric properties of polymer surface during absorption and evaporation of the moisture for every one cycle of 50 Hz electric field applications [2]. Both capacitive and loss currents of the polymer increase during aging of the sample by the adhesion of water droplets. They decrease during recovery by the evaporation of moisture. These changes of dielectric properties can measure not only from bulk direction but also from surface direction of electric field application by using a pair of interdigital electrodes on the sample surface.

Introduction

Usually, it has been evaluated the dielectric property of insulating material by using three terminal parallel plane electrodes. In this paper, we have used interdigital electrodes to measure and to evaluate dielectric property from one side of the sample surface. For the measuring method by using three terminal parallel plane electrodes, it is important to reduce the leakage of the electric field lines from electrode edge. However, for the measuring method by using a pair of interdigital electrodes, this leakage of electric field line is very important [1]. Conventional measuring method for bulk direction by using three terminal parallel plane electrodes sometimes evaluates comparatively larger leakage and capacitive current. However, a pair of interdigital electrodes for surface direction has to measure very small capacitive and leakage current of a sample on the electrodes. Figure 1 (a) shows the schematic view of a sample on the electrodes. This pair of interdigital electrodes not only measures the leakage current through the sample on the electrodes but also measures the one through the insulating substrate under the electrodes. Therefore, it is required to measure both with and without the sample on the electrodes. Thereafter, the difference of two measurements is calculated to evaluate the dielectric property of the sample.

DSP measuring system [2] can measure the dielectric properties with averaging of the detected signals. Therefore, this system can detect the minute signal by reduce the influence of the random noise from environmental. It can also measure the



(a) SIR on the electrodes

(b) SIR under the electrodes

Figure 1. Specimen and electrodes.

real-time change of dielectric properties of the sample. To combine the interdigital electrodes with DSP measuring system, it can measure dynamic changes of dielectric property during aging and recovery of the sample by the environmental factors.

In this paper, we try to measure the dynamic change of dielectric property by the spraying of distilled water on the sample surface. Therefore, the electrodes are on the SIR sample shown in Fig. 1 (b).

Interdigital Electrodes and Samples

A pair of interdigital electrodes is made from stainless steel. Both the electrode's width and interval are 2 mm. Thickness of the finger electrode is 3 mm. Schematic view of a pair of interdigital electrodes is shown in Fig. 2. In this measurement, three finger electrodes of inside are high voltage electrodes and four finger electrodes of outside are main electrodes, respectively.

The tip of each finger electrode was rounded in order to prevent the concentration of electric field more than necessary. HTV silicone rubber (HTV-SIR) was used for measurement specimen. The size of HTV-SIR plate was 60 x 50 and 6 mm in thickness. Before the measurement sample was dried naturally in air at room temperature.

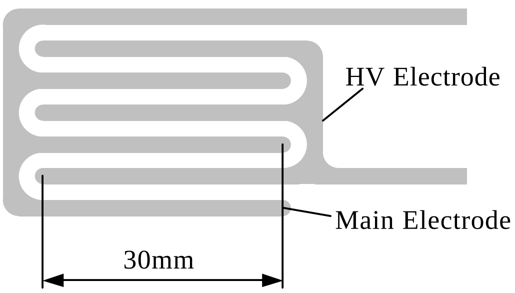


Figure 2. A pair of Interdigital Electrodes

Experimental Method

In this study, interdigital electrodes are put on an HTV-SIR sample on the insulating board. Therefore, finger electrodes can measure the capacitive current of air between and above the electrodes and the leakage current through the surface and bulk of the sample under the electrodes. If the air has little loss compared to the sample, this measurement can detect the change in dielectric property of the sample.

Specimen was placed in the thermostatic bath. Before the measurement, transfer function of the total measurement system is evaluated. The schematic view of DSP measuring system is shown in Fig. 3. DSP system has both two channels of A/D and D/A converters to measure and to make the signals, respectively. To evaluate the transfer function of this system, we remove the high voltage power amplifier from the circuit and set the standard resistance instead of the sample with interdigital electrodes. Then the evaluation program of transfer function of the system calculates the function by DSP, automatically.

After evaluating the transfer function of the measuring system, restructure the circuit to origin. Then impress the high voltage to the sample and adjust the Capacitance Bridge to be balanced. After the bridge is balanced, put tanδ dials back to zero, which can provide the loss current response from the balance-detecting amplifier of the bridge.

After digitizing the data, we can evaluate the high field dielectric property of sample by analyze the measurement result with using transfer function of this system.

Results and Discussions

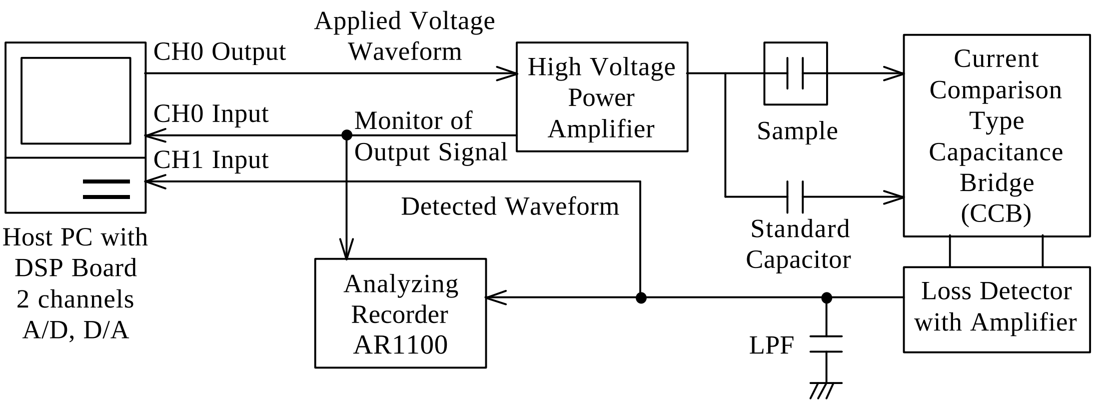


Figure 3. Schematic view of DSP measuring system.

Averaging Effect of the Signal

Figure 4 shows the effect of averaging of the signal. It shows the evaluated loss current of the sample during the application of ac ramp voltage. This figure shows the results both with and without the averaging. For each step of the electric field, 100 times of averaging is done by DSP system.

This figure shows that the result from no averaging is not related to the shape of applied voltage, but the one from averaging is related to the shape of ac ramp voltage. It also shows that even the signal is smaller than environmental noise, this system can detect the dielectric property by using averaging method. All other measurements in this paper are carried out with averaging of 100 times.

Change of Dielectric Property after Spraying of Water

The change in dielectric property when the water was sprayed on the sample was measured. Figure 5 shows the result during the application of constant voltage. Distilled water was sprayed on the HTV-SIR at the time shown in the figure. From Fig. 5, it is found that unbalanced component of capacitive current (Ixc) increases a little after the spraying of water. But dissipation current (Ixr) increases more when distilled water is sprayed. Therefore, the interdigital electrodes system on the sample can detect the change in loss current component more compared to capacitive component. Whereas, for the bulk direction measurement, capacitive component is better than loss component of the detected current that evaluate the absorption of water [3].

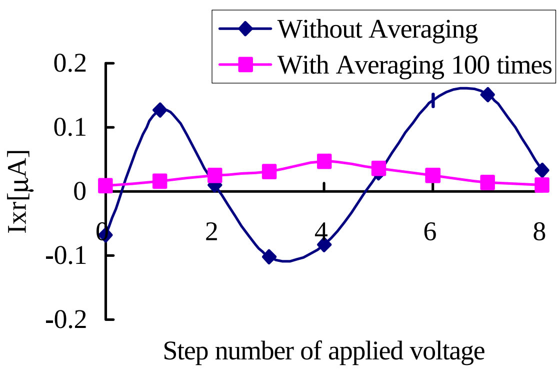


Figure 4. Evaluated result by DSP system of dissipation current with and without averaging of detected signals. Conditions: Room temperature, maximum applied voltage is 50 Hz, 1,000 V. All magnitudes of voltage and current are zero to peek values. Each voltage step is 200 V. Averaging is carried out 100 times for each step.

Figure 6 shows the waveforms of both the applied voltage and detected unbalanced current response of the system. Two times of ac ramp voltages were applied. Figure 7 shows the same one but 5 times of ac ramp voltages. Distilled water was sprayed on the sample at the time shown in these figures. These figure's upper sides show applied voltage waveform and undersides show detected unbalanced loss current waveform with larger noise signals. After spraying the water, amplitude of detected unbalanced loss current becomes larger. This effect of the spraying on the sample remains and shows some time dependency during the experimental period of this study.

Figures 8 and 9 show the evaluated ac loss current magnitude from Figures6 and 7, respectively, by using the transfer function of the system. After spraying the water, the maximum values of dissipation current increase 6.5 and 14.5 times, respectively. After spraying distilled water on the sample, tanδ and capacitance are also increased.

From these results, nonlinear electric field dependence of loss current and time dependent increase during constant voltage application may be resulted to the absorption of moisture of the sample from its surface to the bulk.

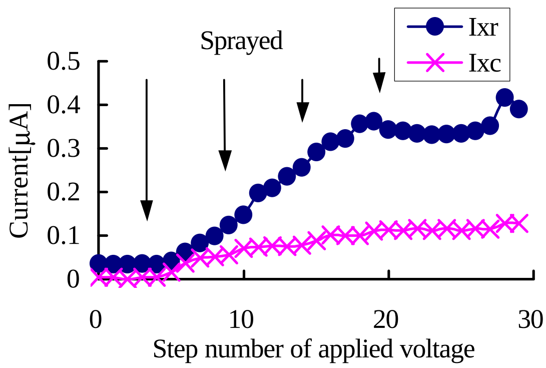


Figure 5. Change of dielectric property after the spraying of distilled water on HTV-SIR during the application of constant ac voltage. Conditions: Room temperature, amplitude of applied voltage is 50 Hz, 1,000 V (zero to peek). Averaging 100 times each point. Distilled water was sprayed on the HTV-SIR at the times shown in this figure.

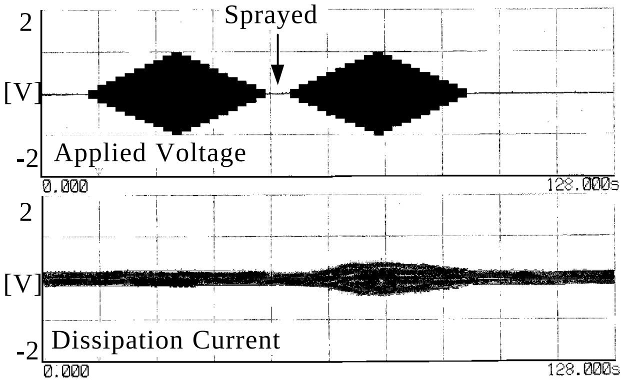


Figure 6. Applied voltage and unbalanced detected current waveform digitized by DSP system. Conditions: Room temperature, ac ramp voltage is applied two times sequentially. Maximum amplitude of applied voltage is 50 Hz, 1,000 V (zero to peek). Each step of applied voltage is constant during 100 cycles to carry out 100 times of averaging. Distilled water was sprayed on HTV-SIR before the second application of ac ramp voltage.

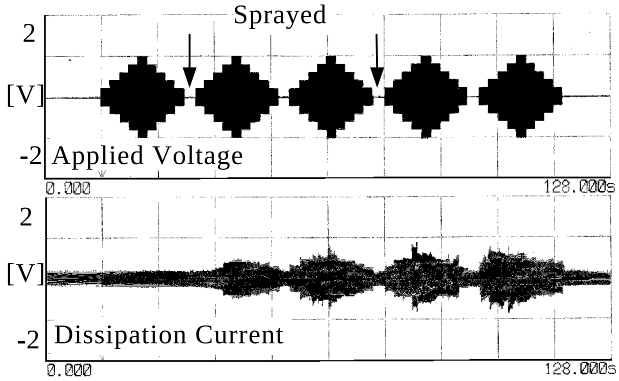


Figure 7. Applied voltage and unbalanced detected current waveform digitized by DSP system. Conditions are same as Fig.6 except the numbers of ac ramp voltages are 5 times.

Summary

1. Using averaging procedure, DSP measurement system of dielectric properties can evaluate the signal smaller than random noise caused by the environment.

2. Interdigital electrodes on the one side of specimen surface can detect the change in surface condition during spraying of distilled water on the surface.

3. Both capacitive and loss component of leakage current are increased.

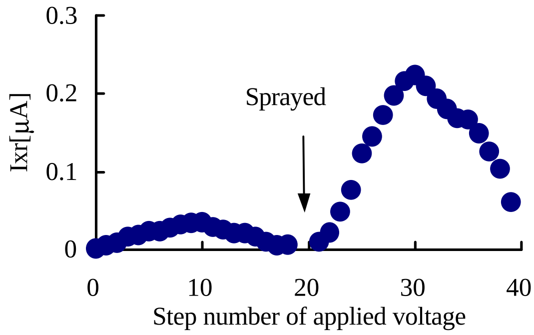


Figure 8. Change in dissipation current after the spraying of distilled water on HTV-SIR evaluated from Fig. 6.

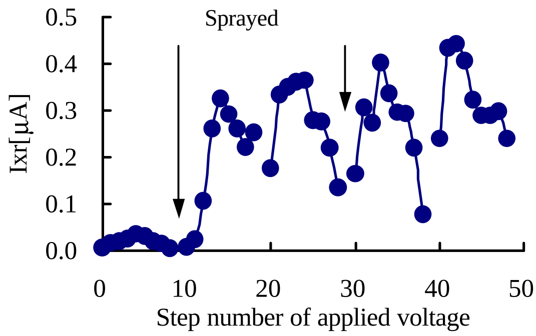


Figure 9. Same as Fig. 8 except for evaluated from Fig. 7.

4. For the surface measurement, loss current is more sensitive compared to capacitive current.

5. Nonlinear electric field dependence of loss current and its time dependent increase during constant voltage application may be resulted by the absorption of moisture of the samples.

References

[1]. M. Zahn, "Optical, Electrical, and Electro-Mechanical Measurement Methodologies of Electric Field, Charge, and Polarization in Dielectrics", IEEE CEIDP Vol. 1, pp. 1-14, 1998.

[2]. Y. Fujii, T. Tokoro, M. Nagao, and M. Kosaki, "Development of DSP Measuring System of High-field Dielectric Property of Silicone Rubber Sheets", IEEE ISEIM, pp.603-606, 1998.

[3]. T.Tokoro, M.Nagao and M.Kosaki, “Effect of Water Absorption on the High-field Dielectric Property of Silicone Rubber” ", IEEE ISEIM, pp.461-464, 1998.