An Analysis on both Voltage Sensitivity and High Spatial Resolution with a New Electrostatic Voltmeter Having Extremely High Input Impedance

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Abstract

We investigated the voltage sensitivity and spatial resolution of an electrostatic voltmeter with a high input impedance of 10^{16} *Ω or higher, which was called HZ-ESVM, applied for measuring the electrostatic latent images on a photoconductor in an electro photographic printing system. We report the simulated and experimental results of the output voltage of the HZ-ESVM as a function of probe distance (gap) from the surface of the sample under test, and experimental results of spatial resolution.*

In the simulated results, the simulated output ratio of the voltage between the measurement electrode the sample under test could keep the value higher than 80% at a gap of 50 μm by using a probe with the protruded length of the measurement electrode $L = 100$ *μm. Moreover, the simulated output voltage against sample voltage achieved 95% output at a gap distance of 50 μm using a probe with a shorter length of* $L = 10$ *μm. In the experimental results, the HZ-ESVM with a probe of* $L = 0.32$ *mm and a measurement electrode diameter of 0.55 mm could measure 100% of the input voltage of 600 V up to a gap distance of 65 μm. It is revealed that the voltage without physical contact between the measurement electrode and the sample under test can be measured with this proposed method.*

Introduction

An analysis of electrostatic latent image on photoreceptor is one of the key elements for the quality of electrophotography. The spatial resolution of conventional electrostatic voltmeter is not high enough to do the decent study on electrostatic latent image. Although the demand on high spatial resolution measurement for electrostatic latent image is critically high, there has been no firm solution available yet to date.

We have been doing extensive research on an electric force microscope[1), 2)] with a cantilever method when applying DC and AC bias voltage. We were able to successfully obtain a width spatial resolution less than 10 μm with ability to measure high voltage of greater than 700 V without any arcing. However, the speed of response of the system was not fast enough as it required approximately 860 ms for the measurement with field nullification method with applying bias voltage to the cantilever. We are now trying to use an electrostatic voltmeter having an extremely high input impedance (HZ-ESVM) designed by Trek, INC[3)]. This voltmeter consists of a voltage feedback system to both the measurement electrode and the floating shield which provides an electrostatic shield to the measurement electrode. Since both measurement electrode and floating shield are being driven equal to the voltage to be measured, arcing from the measurement electrode to the surface under test should not be expected.

In this study, we investigated a new method to simulate electrostatic distributions. We also studied the effect of each shape of measurement electrode. The characteristics for voltage detection were studied with using the HZ-ESVM. The results show that this high input impedance electrostatic voltmeter can perform well with high spatial resolution to measure voltage distribution with or without a physical contact between the measurement electrode and the sample under test.

Electrostatic voltmeter with high input impedance

A high input impedance electrostatic voltmeter (HZ-ESVM) Model 800 was designed by Trek, INC. The HZ-ESVM has a feedback system as shown in Figure 1. The input impedance of the HZ-ESVM is 10^{16} Ω or higher. The input voltage range of the system is from 0 V to +/- 2000 V. The speed of response of the system is 3.5 ms for 10% to 90% of 1 kV step input. The voltage on the floating shield is dictated by voltage of the measurement electrode which is identical to the voltage on the sample under test.

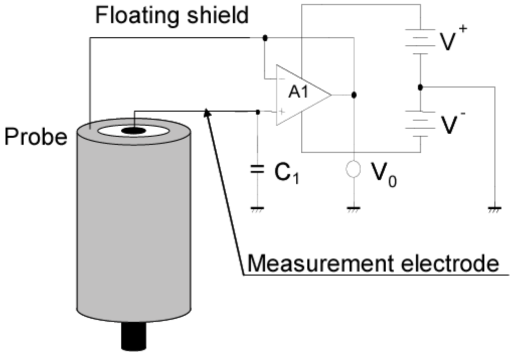

Figure 1. *The equivalent circuit of HZ-ESVM and the connecting diagram to the probe with the measurement electrode and the floating shield.*

Simulation

Process of Simulation

In order to define the effects of the shape of the detector (measurement electrode) with a simulation, we invented a new method for a high spatial resolution electrostatic measurement with using the HZ-ESVM. However, it was not easy to simulate how the HZ-ESVM works with simulation software (J-MAG). In order to plug in the elements needed to simulate how the HZ-ESVM works properly, we firstly simulated the voltage of the measurement electrode (V_{os}) which would be induced by a known charge on the surface under test using the J-MAG designed by JRI Solution Co., Ltd. Secondly, the voltage obtained through the first step for the simulation was set as the feedback voltage to the floating shield (V_{fs}). This simulation process was repeated until the voltage difference ratio ((V_{os} - V_{fs}) / V_{fs} × 100) became to be within +/- 0.5%.

We have confirmed that the relation between (V_{os} - V_{fs}) and V_{fs} was linear when we applied 1 V to the sample under test, which is shown in Figure 2. When the voltage difference (V_{os} - V_{fs}) was zero, we were able to obtain the voltage equilibrium between the V_{os} and V_{fs} and the actual V_{fs} at that time was 0.8 V although we applied 1 V on the sample under test.

The cross sectional view and the top view of the probe (measurement electrode and floating shield) used for the simulation models are shown in Figure 3. The measurement electrode protruded from the shield terminal with a length L. The diameter of the measurement electrode was D = 10 μm. All the simulations were calculated using an infinitely large planer plate underneath the probe which was set with a gap shown in Figure 3.

V_{os} dependency on gap

The V_{os} of the HZ-ESVM was simulated with the same method as explained in the prior paragraph. The results are shown in Figure 4. The conditions for this simulation are (1) the length of the measurement electrode was 10 μm, (2) the insulator thickness was 75 μm, and (3) the metal part of the floating shield thickness was 2 μm, respectively. The measurement electrode protruded from the floating shield terminal with a length L. We have simulated the V_{os} dependency on gap with two lengths of L (10 μm and 100 μm). The voltage of the sample under test (V_{sam}) for the simulation was set at 1 V. The calculation results of the output voltage of HZ-ESVM are shown in Figure 4. The ratio of V_{os} / V_{sam} with L = 100 μm was down to 80% when the gap was set at 50 μm, whereas V_{os} / V_{sam} with L = 10 μm attained more than 95% when we set the gap at 100 μm. Consequently, the V_{os} dependence on the gap was greatly influenced by the length of L.

Experiments

System for Experiments

The block diagram of the experimental system is shown in Figure 5. The sample under test is placed on the stage which can be manipulated by a computer for X, Y, and Z directions independently. The entire HZ-ESVM system, sample under test and the actuators are all placed in an electrostatic shielding box. The voltage applied to the sample under test V_{sam} is monitored by a conventional voltmeter.

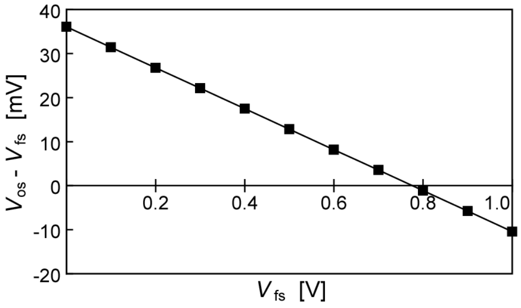

Figure 2. *The dependence of the difference between the voltage of the measurement electrode V_{os} and the voltage of the floating shield V_{fs} in the simulation.*

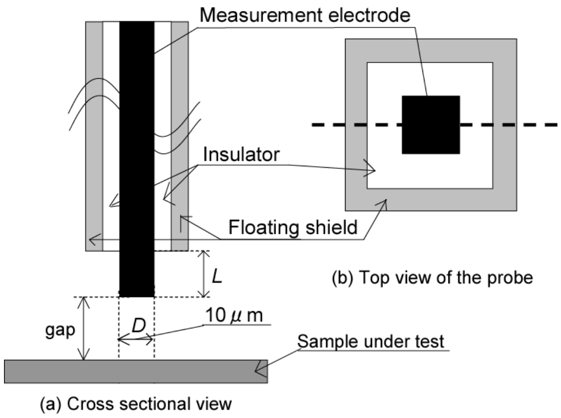

Figure 3. *The schematic diagram in the simulation model of gap dependence (a) is a cross sectional view, and (b) is a top view of the probe.*

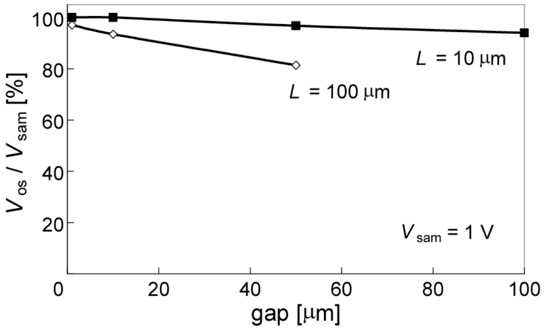

Figure 4. *Gap dependence of V_{os} / V_{sam} of high input impedance electrostatic voltmeter in simulation.*

Output Voltage dependency on diameter of measurement electrode

A shielded cable was used as a sensor cable of the HZ-ESVM. The core of the shielded cable was connected to the measurement electrode whereas the shield of the cable was connected to the floating shield. The measurement electrode made out of a wire protruded from the tip of the shield cable. The wire was covered with an insulator and it was wrapped with an aluminum tape for the electrostatic shielding.

We have tested several different sizes of measurement electrode having the diameter of 3.26 mm, 1.20 mm, 0.55 mm, 0.44 mm, 0.30 mm, and 0.10 mm, respectively. We have taken the data with two different probe lengths using all the measurement electrodes having different diameters. The sample under test was a metal planer plate. We have calibrated the gap to be zero when the measurement electrode touched to the sample under test through checking the contact electrically. To avoid the measurement errors which may occur in Z axis due to the hysteresis of the piezo actuator, the output voltage of HZ-ESVM (V_{om}) was always measured to compensate the error to be minimum.

The V_{sam} of 600 V was applied to the sample under test and measured the V_{sam} with various gap distances, from 0 μm to 72 μm, with two probes having the same diameter 0.55 mm and two different lengths for L (0.32 mm and 1.37 mm). Figure 6 shows the ratio of V_{om} / V_{sam} as a function of the gap using the probe with L = 1.37 mm. The V_{om} / V_{sam} was maintained to be at 100% up to the gap (gap$^{100\%}$) was equal to 3.6 μm. The V_{om} / V_{sam} was decreasing and became unstable whenever the gap became greater than 3.6 μm. The data of the V_{om} / V_{sam} dependency on the gap with L = 0.32 mm is shown in Figure 7. In this case, the V_{om} / V_{sam} was maintained to be at 100% with the gap distances from 0 μm to 65 μm (gap$^{100\%}$ = 65 μm) and then started decreasing steeply to 0% when the gap exceeded 65 μm. These results show that shortening the L is effective for the measurement at a larger gap.

Figure 8 shows the gap$^{100\%}$ with V_{sam} = 600 V as a function of diameter of the measurement electrode with the change of the L. The open square dots in Figure 8 show the test results with L having the length greater than 800 μm, and solid diamond dots also shown in Figure 8 indicated the test results of L shorter than 350 μm. The gap$^{100\%}$ for diameter = 1.20 mm and 3.26 mm were obtained with the gap as large as 72 μm. We have confirmed that larger gap$^{100\%}$ can be obtained with shorter length of L for any diameter of the measurement electrode.

Spatial resolution

To investigate the spatial resolution, a special measurement electrode was made by a stainless steel (SUS). The diameter of the tip of the SUS electrode used was as small as 10 μm. The surface of the SUS electrode was coated with a resin with a coating of approximately 10 μm in thickness. The results were shown in Figure 9. Over the resin coating, we had deposited a Pt-Pd film with a sputtering method which was used as a floating shield layer having an approximate thickness of 200 nm. The resistance between the floating shield and the measurement electrode was greater than 100 MΩ. The floating shield as well as the insulator on the tip of the electrode were removed. The length of the metal portion of the measurement electrode from the floating shield terminal was about 100 μm which is considered to be L in the prior discussions.

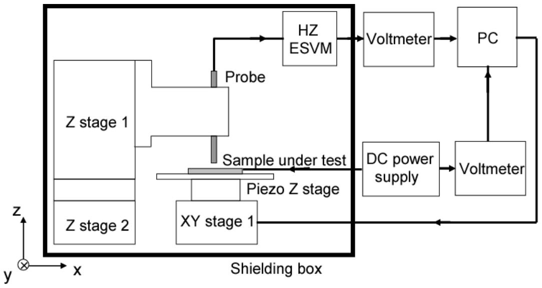

Figure 5. *The block diagram of the experimental system with the HZ–ESVM. The output voltage and the input voltage were monitored by PC. The gap was controlled at Z axis by piezo actuator. XY stage was controlled by a computer for scanning the sample under test.*

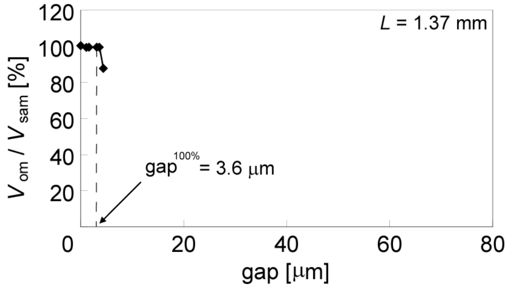

Figure 6. *The ratio of V_{om} / V_{sam} dependency on the gap at L = 1.37 mm with a diameter of the measurement electrode of 0.55 mm.*

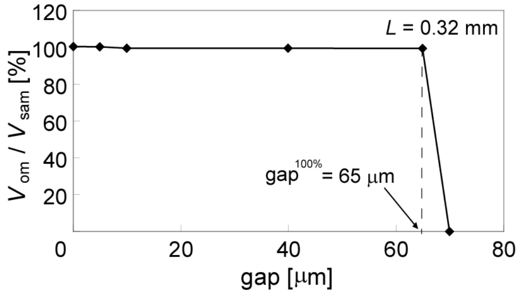

Figure 7. *The ratio of V_{om} / V_{sam} dependency on the gap at L = 0.32 mm with a diameter of the measurement electrode of 0.55 mm.*

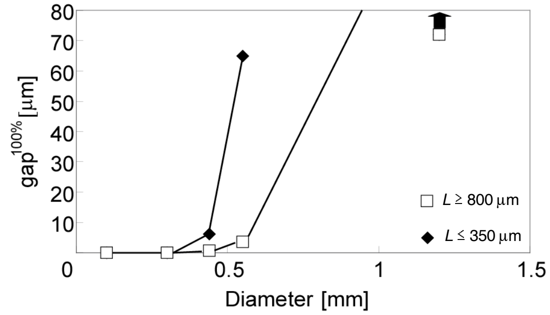

Figure 8. *The dependencies of the gap$^{100\%}$, which maintain the ratio of the voltage of the measurement electrode and the voltage of the sample under test to be at 100%, on the diameter of the measurement electrode.*

The spatial resolution with using aforementioned probe was confirmed with using a comb electrode which has the width as well as the interval length of 100 μm between electrodes. A 600 V was applied to one half set of the comb electrodes, whereas other one half set of the electrodes was grounded so that 600 V and 0 V appeared on the electrodes alternatively. The spatial resolution when a scanning was made over the electrodes is shown in Figure 10. We have confirmed that the probe was able to detect 30% V_{om} / V_{sam} with the said comb electrodes.

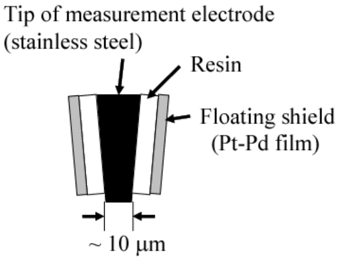

Figure 9. *The diagram of the tip of the probe to measure the spatial resolution in experiment. The diameter of the tip for the measurement electrode was about 10 μm. The floating shield, 200 nm in thickness, was fabricated by a sputtering machine on the coated insulator, 10 μm in thickness.*

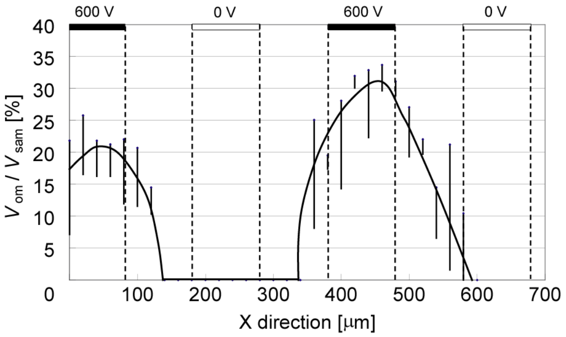

Figure 10. *The measured output V_{om} searching over the comb electrode with the interval length of 100 μm with the HZ–ESVM system. The ratio of the maximum measured output voltage V_{om} and the voltage of the sample under test was 30% of the applied voltage 600 V.*

Summary

For the purpose of obtaining an electrostatic voltage measurement having a high spatial resolution with a wide input voltage range and fast speed of response, we studied a new system through simulating various parameters.

We researched how the voltage ratio (V_{os} / V_{sam}) between the voltage of the measurement electrode and the voltage of the sample under test was influenced in simulation with changing both in length of the protruded measurement electrode and in the gap between them in non-contact measurement. As a result, we found that V_{os} / V_{sam} decreased gradually as the gap increased. And V_{os} / V_{sam} was about 80% when the length of the protruded measurement electrode L was equal to 100 μm, the gap was 50 μm. However, V_{os} / V_{sam} was about 95% at $L = 10$ μm when the gap was 50 μm.

In the experiment, we measured the ratio dependency of the V_{om} / V_{sam} on gap as well as the gap$^{100\%}$, which maintains the ratio of the voltage of the measurement electrode and the voltage of the sample under test to be at 100%. The gap$^{100\%}$ indicates 65 μm when the diameter and the protruded length of the measurement electrode were 0.55 mm and 0.32 mm, respectively. It is revealed that the voltage without physical contact between the measurement electrode and the sample under test can be measured with this proposed method applying the HZ-ESVM. It is also studied that the probe was able to detect 30% V_{om} / V_{sam} with a comb electrode which has the width as well as the interval length of 100 μm between electrodes.

Reference

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Author Biography

Toshio Uehara is CEO of Trek, Inc. and President of Trek Japan KK. He graduated from Nihon University College of Science & Technology. He has been involved in the measurements on electrophotography for more than 25 years and is currently doing joint research on electrostatic microscope with Nihon University. He received President’s Award of the Electrostatic Institute of Japan in 2002 and President’s Special Award of Imaging Society of Japan in 2005.