Voltage and Indentation Development

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Electrostatic detection devices (EDDs) utilize charging to visualize indentations on documents. In this study, a voltage probe was used to measure the characteristics of the voltage at the surface of the film covering the document to better understand this electrostatic phenomenon. The ultimate objective of this research was to enable document examiners to obtain better development of indentations. This initial work demonstrated that such measurements are useful for controlling the extent of charging the film.

(Any mention of trade and/or commercial names does not represent endorsement by the author, the Canada Border Services Agency, or the Government of Canada.)

Introduction

One of the steps in the development of indented impressions is the charging of the film on which the toner will be applied. A high voltage corona is used for such purposes. Generally, examiners are aware of some of the difficulties that may be encountered with the charging process and how to counteract some of them. These include moving the corona in random directions to minimize "streaking" effects during toner development.

Seward (1999) suggested 9 steps for optimal development of indentations. One unconventional recommendation included waiting for 30 minutes after charging before toner application. A 2nd suggestion involved a charging time of 2 minutes, a time longer than most examiners use in practice. Previous experiments by the author following these practices found no significant difference in the development on the same document when surface discharge was allowed versus when development took place immediately. Additionally, Seward suggested the use of a voltage monitor to measure the voltage at the film surface. He advocated charging the film until a specified voltage was reached and then applying the toner to the film. According to Seward, the only option available for this would be an electrostatic high-voltage probe that is relatively costly. He listed Monroe Electronics Inc. and Trek Inc. as 2 manufacturers of such instrumentation. IISI Corporation was mentioned as a possible manufacturer of an economical voltage measurement system for the Electrostatic Detection Apparatus (ESDA) by Foster + Freeman. However, to date, the author knows of no economical voltage device available for the ESDA or any other EDD.

Methods and Materials

Motivated by the suggestion of using an electrostatic high-voltage probe and from discussions with scientists at the Society for Imaging Science and Technology's Non-Impact Printing conferences, the author's laboratory acquired a high-speed electrostatic voltmeter, Trek Model 370, for approximately $5,000 (US). This device, with an end viewing probe, was used to measure the voltage at the surface of the film. The electrostatic voltmeter has a measurement range between -3000V and +3000V and a response time of less than 50 microseconds for a 1000V step. A digital display on the front panel provides a reading of the current voltage. For high-speed measurements, the display at the front of the controller will not respond as fast as measurements can be made, as the voltage display is updated 2.5 times per second. To record such brief duration events the Data Acquisition Module was used, which stores the voltage and time values in an internal memory buffer before writing them to a file in a computer.

The Trek Model 370 uses a noncontact probe connected to a controller box. An electrostatic field-nulling technique is used to ensure that a high-accuracy voltage measurement is made of the surface being measured, even if the probe-to-surface distance changes or the probe is moved. The manual for the Model 370 suggests that the separation between the probe and surface be 2 mm ± 1 mm.

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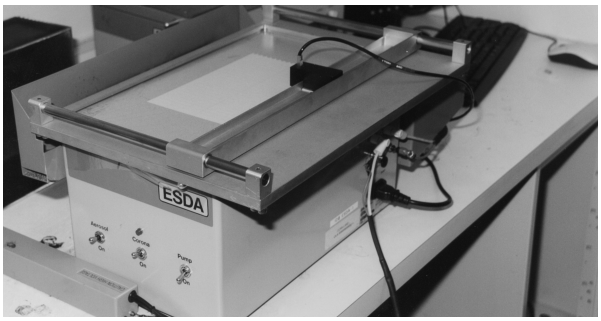

Figure 1. An ESDA showing the rail system with a voltage probe.

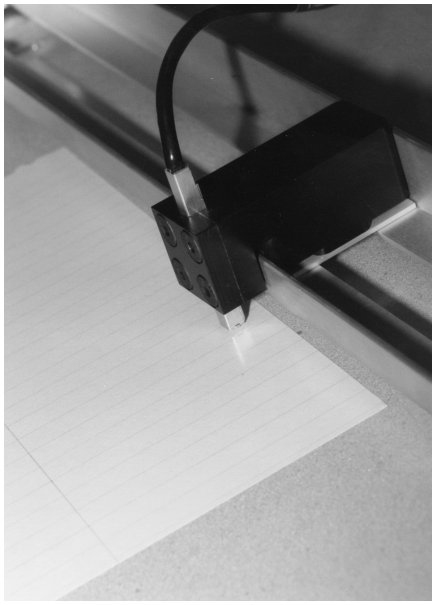

Figure 2. Close-up of the voltage probe.

To keep the probe at approximately the same distance from the film, a metallic sliding rail system was custom made. This rail system was made from aluminum with a nonconducting holder that allowed the voltage probe to be moved over the whole surface of the ESDA (original design). During operation, the voltage probe is electrified and cannot be handled directly by human hands during measurements. Adjustments can be made to the holder to allow for different probe-to-surface distances. The probe was not positioned near sites on the document known to have indentations (Figures 1, 2, 3).

Although a high-speed voltmeter with data-saving capability was used, the measurements



Figure 3. The computer with the Trek Model 370 electrostatic voltmeter used to measure and record voltage.

for voltage before development did not require a high-speed voltmeter. This is due to the slowly changing voltage that the film surface has after a period of charging. Handheld units are available at a much lower cost and require much less space in the laboratory. The other equipment used for this study included an environmental chamber where temperature and relative humidity can be controlled, an original model ESDA, and cascade developer compatible with the original model ESDA.

Basic Corona Physics

The theory of dielectric (electrical insulator) charging has been investigated by scientists working in the electrophotographic (EP) fields. There are many similar processes used by EP and indentation development that include charging mechanisms and the application of toner. When the film surface is charged with a negative corona as it is with the ESDA, negative ions are generated. Approximately 90% of the ions are CO_3^- (Williams 1993). Other negative ions which stream towards the film surface include $CO_3^-(H_2O)$, $O^-(H_2O)$ and $O_3^-(H_2O)$. The process of charging is complicated by atmospheric conditions such as humidity, altitude above sea level, air composition, and corrosion of the corona wire. Although not part of this study, the effects of corrosion may be minimized by using corrosion-resistant wires such as platinum. The movement of the corona wire may also influence the charging process.

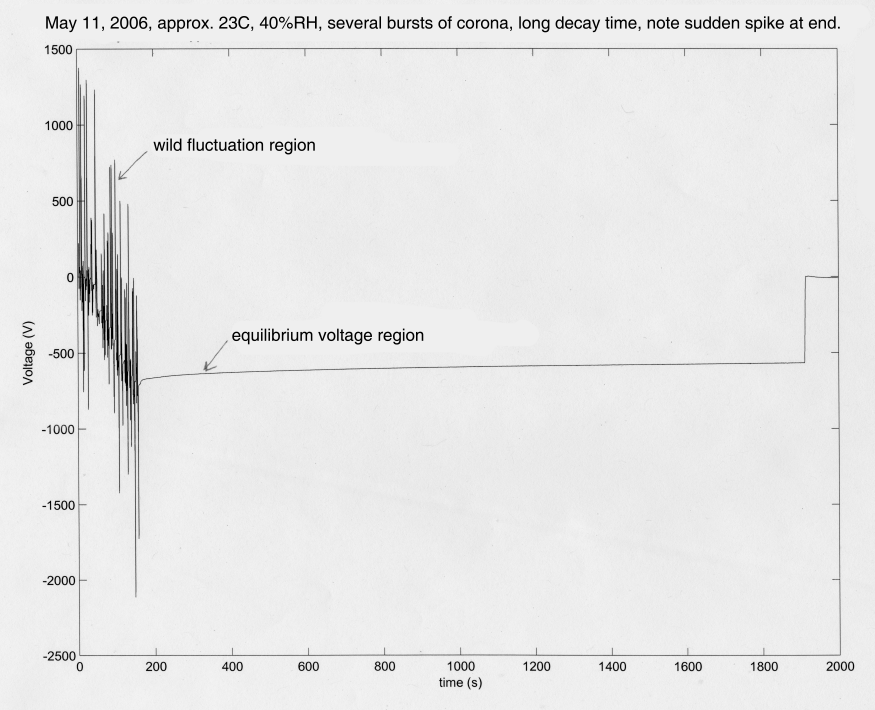

Figure 4. Example of voltage at film surface vs. time, initial portion showing wild fluctuations in voltage during charging followed by slow decay in equilibrium voltage region.

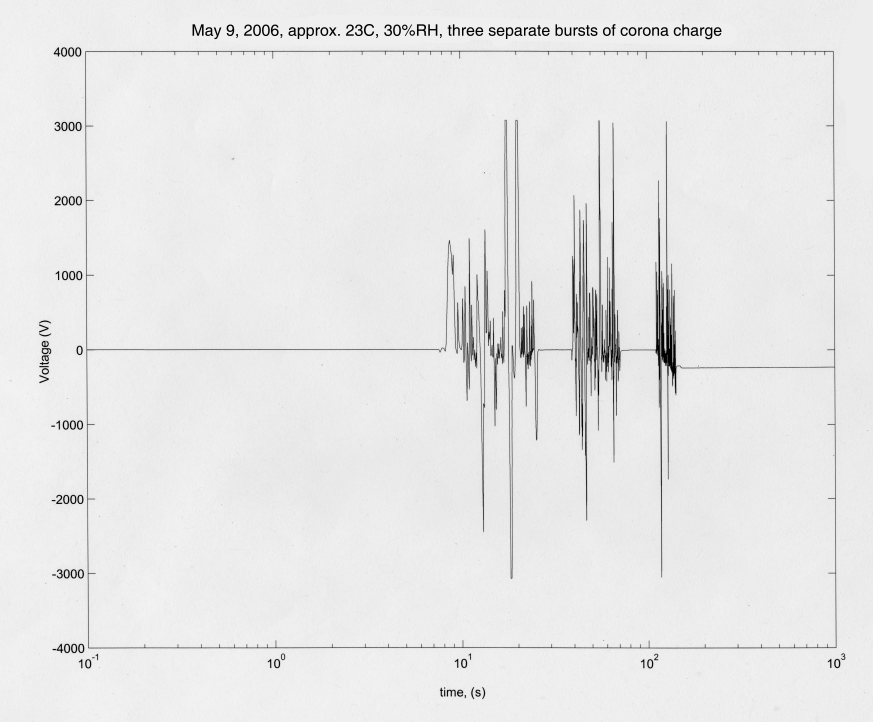

Figure 5. Example of voltage at film surface vs. time (logarithmic) for 3 bursts of corona charge.

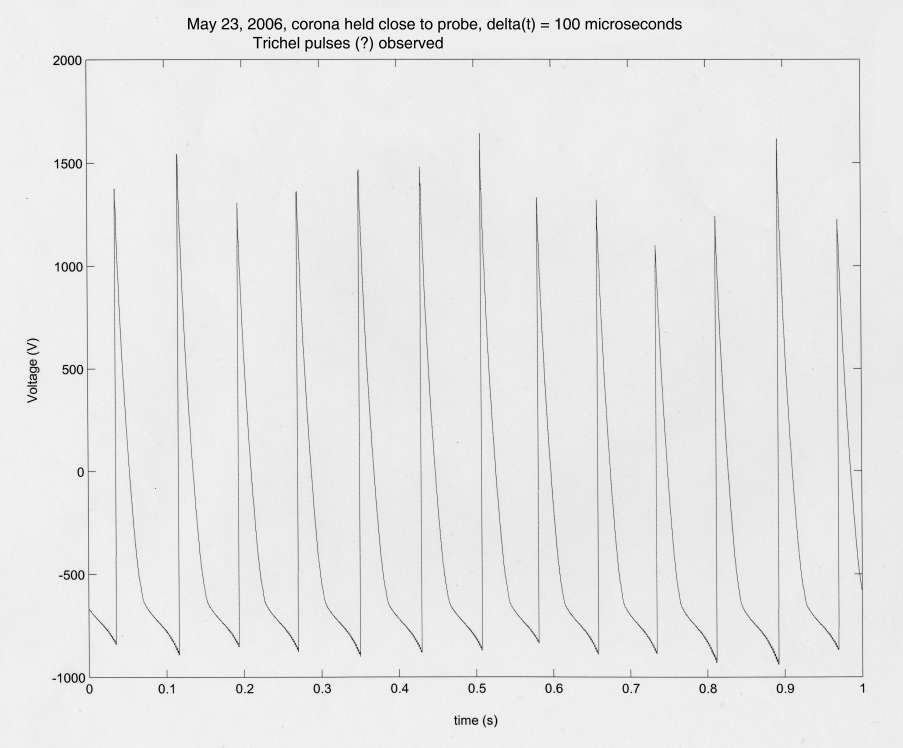

Figure 6. Voltage at film surface vs. time with sampling frequency of 100 microseconds.

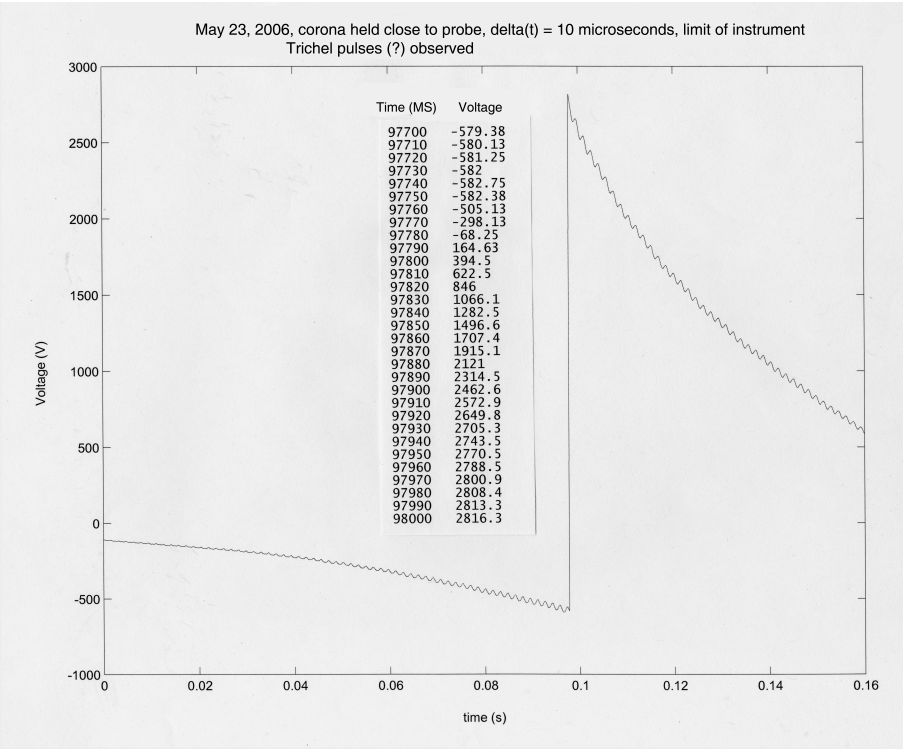

Figure 7. Voltage vs. time plot with sampling frequency of 10 microseconds, showing the very short duration behavior of voltage at the film surface during charging.

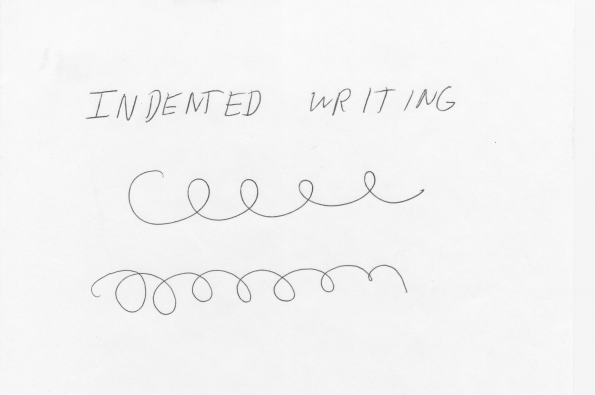

Figure 8. Hammermill original writing.

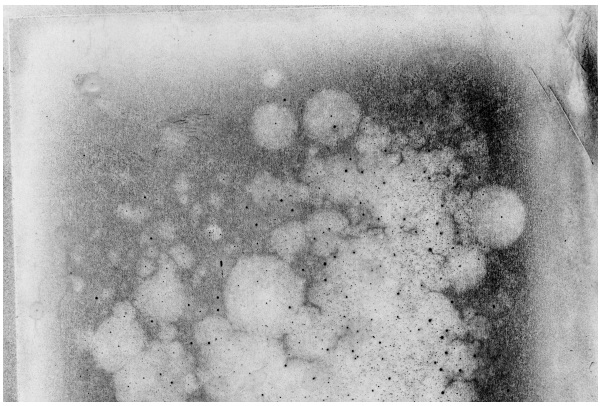

Figure 9. Hammermill, -800V development.

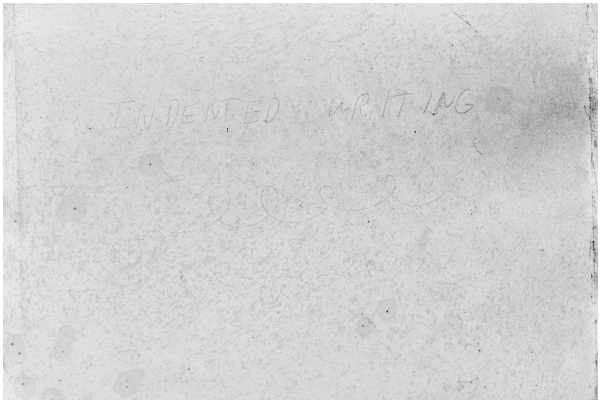

Figure 10. Hammermill, -400V development.

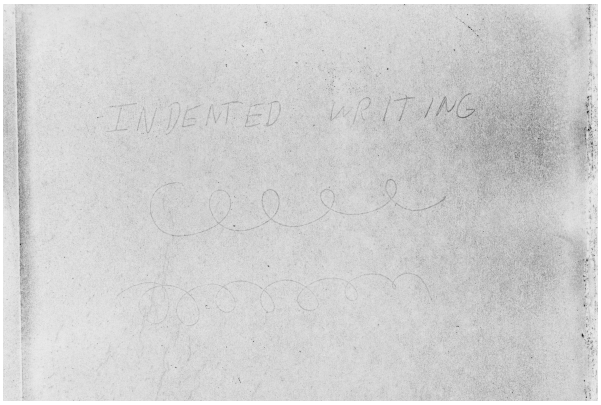

Figure 11. Hammermill, -200V development.



Figure 12. Hammermill, -100V development.



Figure 13. Hammermill, - 50V development.

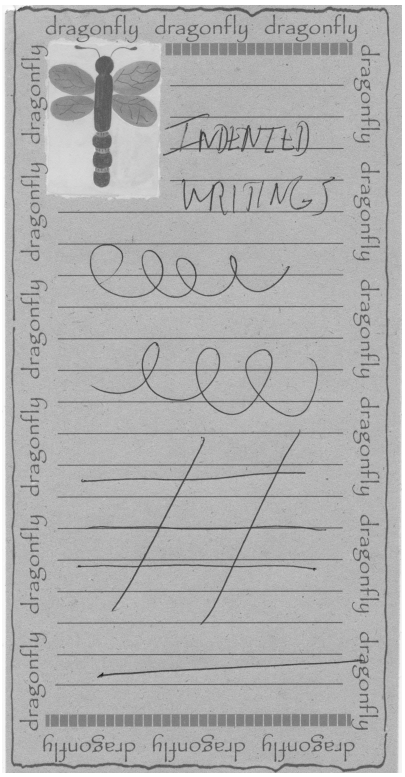

Figure 14. Dragonfly, original writing.

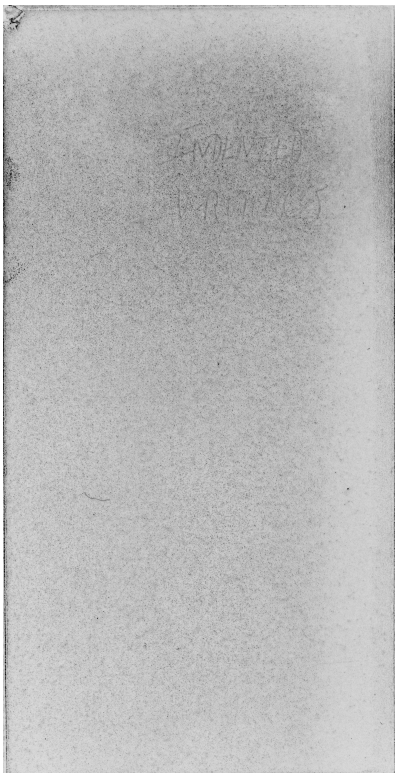

Figure 15. Dragonfly, -800V development.

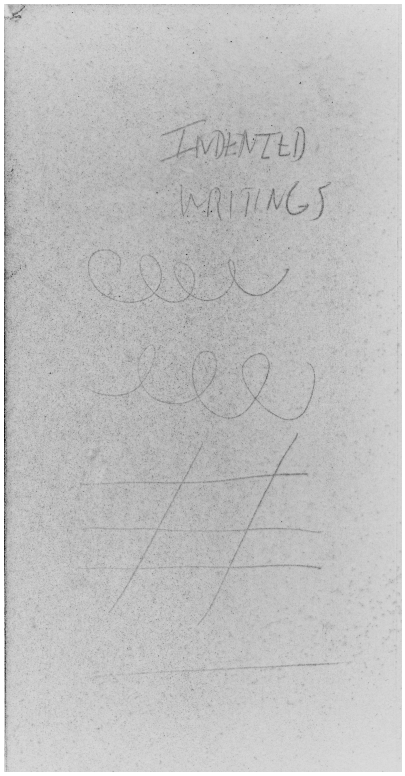

Figure 16. Dragonfly, -400V development.

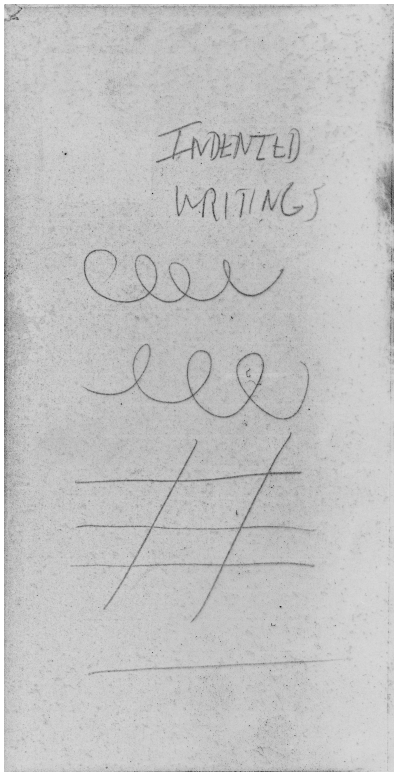

Figure 17. Dragonfly, -200V development.

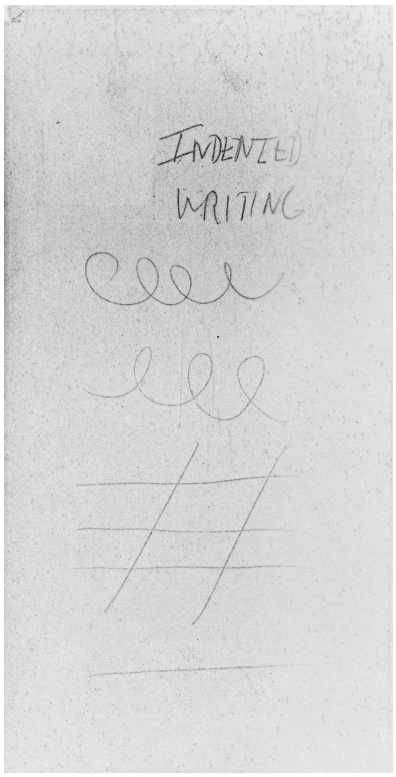

Figure 18. Dragonfly, -100V development.

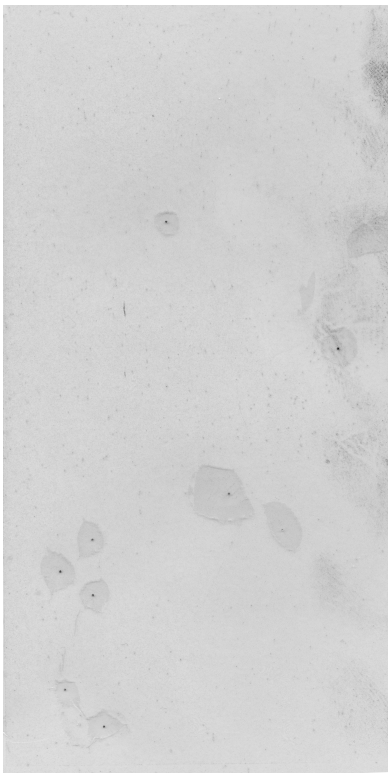

Figure 19. Dragonfly, -50V development.

Charging the Film

The first measurements of voltage were to determine the range of voltages of the development film covering the document. Charging of the film was conducted after the usual steps of humidifying the document, activating the vacuum pump, placing the document on the ESDA plate, and drawing the development film over top. The corona wire used by the ESDA has an approximate voltage of -8000V, but the voltage at the surface of the film will be much less than -8000V due to the mechanism of charging (Williams 1993).

The film voltage was observed to be in the range of -400V in 15 seconds, and extreme potentials of -800V were achieved within 2 to 3 minutes of charging (Figures 4, 5, 6, 7). During the charging process (i.e., when the corona was moved in proximity of the probe), wild oscillations in measured voltage were observed. During corona operation, negative and positive ions are driven towards the film. The phenomenon of "corona wind" is likely the cause of these wild oscillations. This phenomenon has been known since the late 1600s where an electrified probe was observed to be able to generate a wind powerful enough to extinguish a candle flame (Williams 1993). Very high frequency data collection of the film voltage, with the corona held about 3 cm away from the probe, disclosed evidence of such random movement of the ions. Sample periods of 10^{-5} s and 10^{-4} s demonstrate fine sinusoidal-like fluctuations in the decay in voltage with unexpected large spikes where the voltage would surge over 1000V in 50 microseconds (Figure 7). The irregular fluctuations observed may be from Trichel pulses, which are short bursts of negative ions researched by Loeb in the 1950s.

The lower frequency measurements disclosed the wildly fluctuating voltage during charging. However, after the corona is powered off or moved away, a much more stable voltage was observed. This region of voltage stability shall be referred to as the "equilibrium voltage" (Figure 4). Observations were made of the voltage stability in the equilibrium region. The long-term behavior of the voltage was recorded, and a slow decay taking approximately 30 minutes was observed. After 30 minutes an unexpected spike occurred, the cause of which would need further investigation beyond the scope of this paper.

Surface Voltage and Optimized Development

Three different paper types were used in this study, the goal being to narrow the range of equilibrium voltages for optimized development for a particular document. Indentations were made on the documents by taking 2 sheets of the same type of paper and writing/drawing entries on the top sheet. The indented lower sheet was then removed and developed as normal except for the measurement of equilibrium voltage before application of toner via the cascade method. The 3 paper types were:

1. Hammermill International Paper Great White Copy North American, letter size, 20 lb. weight, designed for office equipment (Figures 8 through 13);
2. Note pad paper with Dragonfly graphics, BT's Paper Company (Figures 14 through 19); and
3. Grand & Toy easel notebook paper (Figures 20 through 25).

Development was done at 5 equilibrium voltages for each paper type: -800V, -400V, -200V, -100V and -50V. Note that these are approximate voltages due to drift and small sampling area. Approximately 100 mL of cascade developer was used for each development. New cascade developer from an unopened bottle was used, with some replenishment as required between developments. All developments were conducted in approximately the same conditions, with a room temperature of about 25°C and a relative humidity of 40%.

It was observed that for the 3 paper types, a better development was obtained for voltages of -200V (Figures 11, 17, 23). This series of tests suggests that an equilibrium voltage of approximately -200V will provide a level of charging for optimal development with the cascade developer that was used. The physical properties of the cascade developer were not measured; e.g., the charge-to-mass ratio (Q/m) that is commonly measured in the EP industry is known to play an important role in obtaining a quality development. It should be cautioned that these results do not imply that -200V will give optimal development in all circumstances where different paper types and/or different developer is used.

Several variables were not controlled in these experiments. However, it is important to note that even when attempting to conduct controlled experiments with electrostatic phenomena,

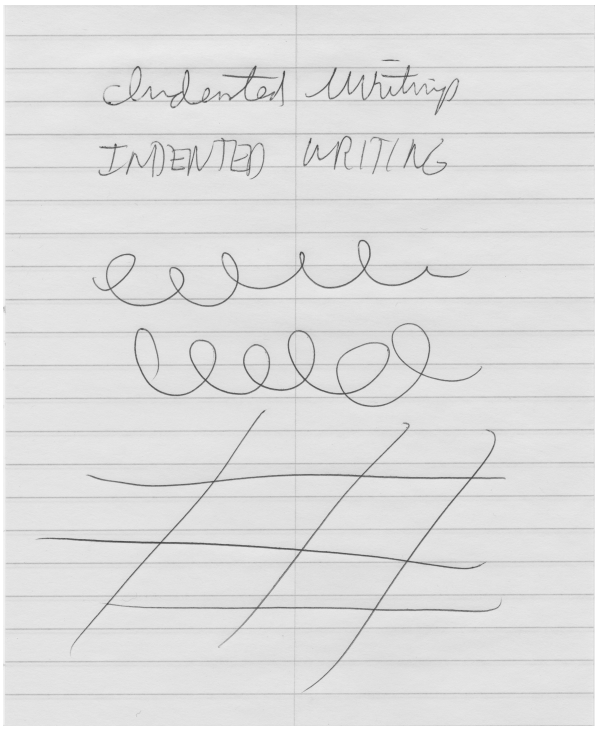

Figure 20. Grand & Toy original writing.

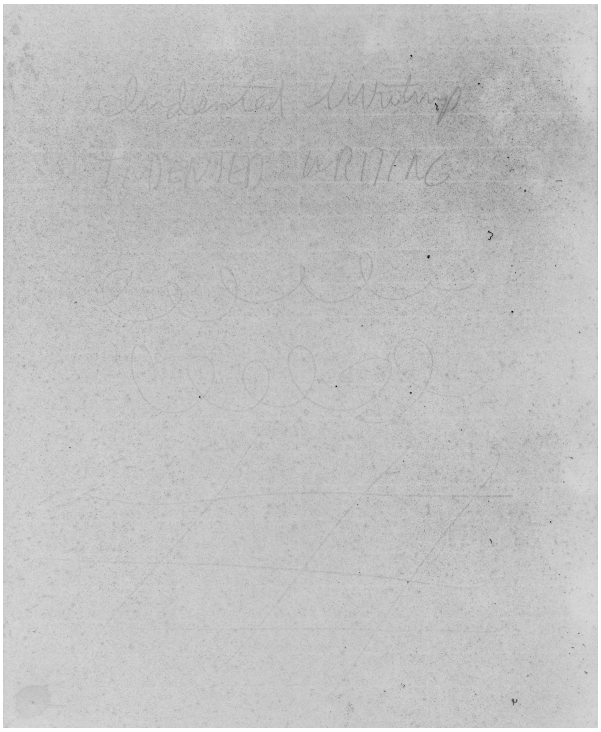

Figure 21. Grand & Toy, -800V development.

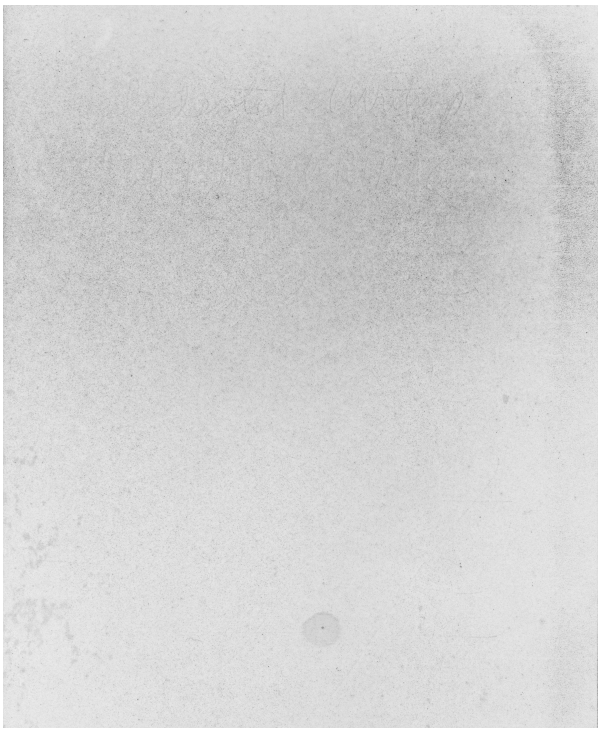

Figure 22. Grand & Toy, -400V development.

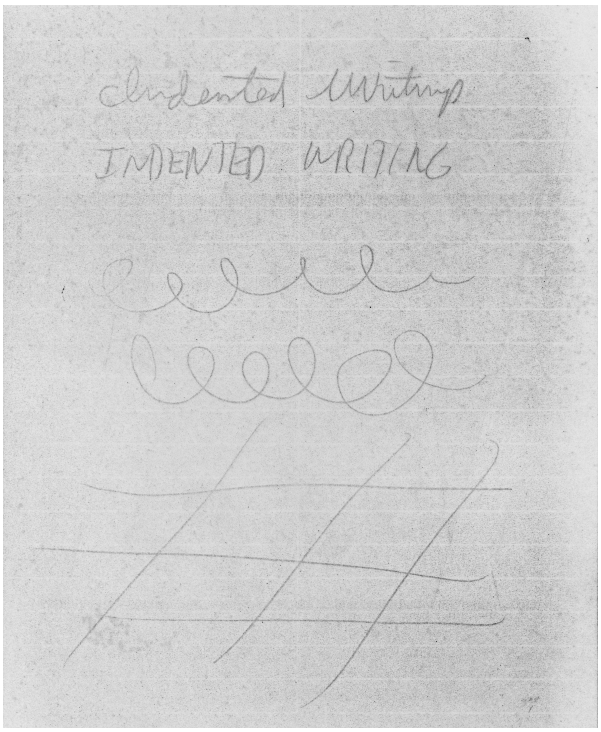

Figure 23. Grand & Toy, -200V development.

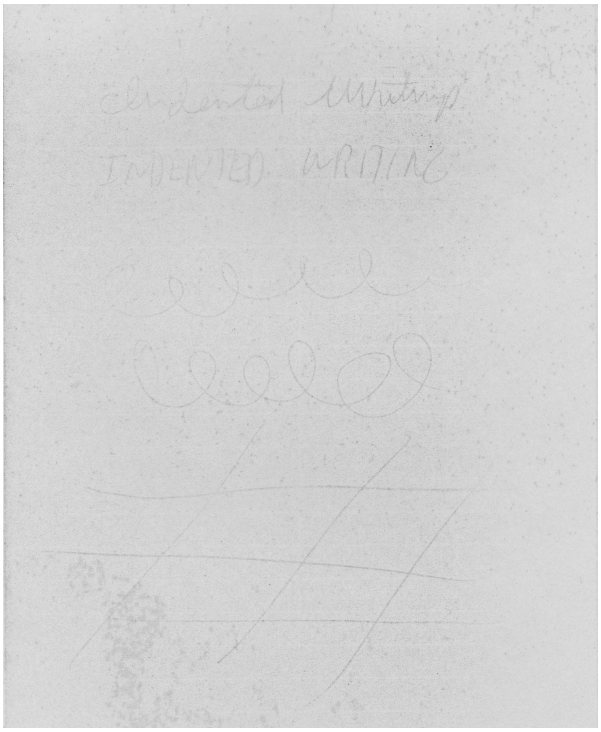

Figure 24. Grand & Toy, -100V development.

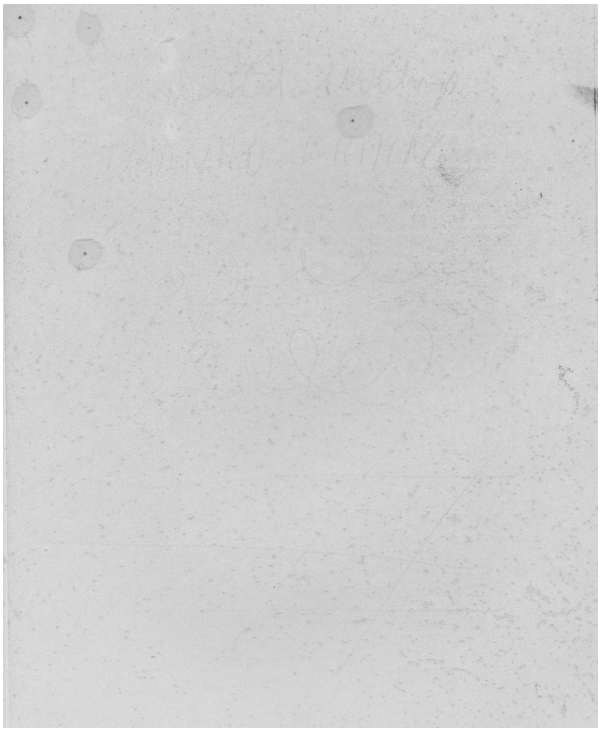

Figure 25. Grand & Toy, -50V development.

several difficulties will be encountered (Harper 1967).

Discussion

The initial tests conducted for this research indicate that the use of electrostatic probes may be useful in the charging step of indentation development. By charging the film to different voltages, the development may be improved; it is analogous to "bracketing the exposure" in photography.

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