The Mechanism of Ghost Formation in a Nonmagnetic Single-Component Process*

Katsuhiro Aoki, Hiroyuki Matsushiro and Koji Sakamoto

Imaging Technology Development Center, Ricoh Co., Ltd., Tokyo, Japan

In a contact single-component (CSC) development system, uniformity of development ability for halftone images is quite significant. In the use of a development roller having relatively high resistance (over 10^{12} Ω cm) a significant "ghost" phenomenon is observed. In a four-step color printing process for pictorial full-color images, this phenomenon will emphasize fluctuation of the image density and spoil its quality. We have studied the transition and the control of the charge distribution on the surface of the development roller. We obtained the optimal condition for stabilizing the surface potential of the development roller by contacting it with a biased conductive brush, with the bias voltage applied to the conductive brush being far higher than that of the development roller. In this study the ghost mechanism and solutions for the above system are reviewed.

Journal of Imaging Science and Technology 40: 359–363 (1996)

Introduction

The "ghost" phenomenon, or residual image, is observed in a certain pattern. For example, if we use an image pattern that has a series of parallel slits and a uniform halftone whose direction is the same as the rotation direction of the development roller, the ghost phenomenon typically occurs. Our definition of "ghost" is based on the image density (ID) difference in a halftone area (2 × 2 dot pixel pattern of 600 dpi) after drawing a solid pattern and a nonimage. The halftone ID of the solid area part is ID_1, the other part is ID_2, their ratio is calculated by the formula[1]

$$\text{Residual ratio (RR)} = [(ID_1 - ID_2)/(ID_1 + ID_2)]*100\%.$$

If RR > 0 we call the residual image a positive ghost, and if RR < 0 we call it a negative ghost. In our system, we have observed the negative ghost. The typical negative ghost has under –10% of the RR. The causes are outlined in Table I.

One of the most reliable ways to cope with this phenomenon is, after the development step, to attach a roller or other part and to scrape all residual toners to make the surface potential of the development roller uniform. However, in this system it is necessary to use many parts and power supply units, so that it would be a very expensive and complicated solution. Therefore, we tried to search for a simpler way to make the system ghost free.

Original manuscript received February 21, 1996. Revised May 1, 1996.

* Presented in part at IS&T 's 11th International Congress on Advances in Non-Impact Printing Technologies, October 29 – November 3, 1995, Hilton Head, SC.

TABLE I. Cause of the Ghost

Phenomenon	Cause	Note (this system)
Positive ghost	Excess of toner supply	—
	Insufficiency of toner *q/m*	—
Negative ghost	Insufficiency of the toner supply	m/a increased (Fig. 4)
	Excess of toner *q/m*	q/m is stable (Fig. 3)
	Charge accumulation on the development roller	Increase of the surface potential development roller; 140 V

In the Experimental section, we show the structure of an experimental unit and describe the relation between toner charge, toner charge-to-mass ratio, and the condition of applied bias voltage. Under Results, we show the measurement of the time dependence on the surface potential of the development roller and the effect of a biased brush. In the Discussion section, we present some fundamental considerations of the mechanism, using the model of the equivalent circuit, and show why optimum usage of a conductive biased brush is able to overcome the "ghost" phenomenon.

Experimental

Experimental Unit. Figure 1 shows a schematic of the development unit. The development roller has a 3×10^{-5} m thick layer of silicone resin with charge control agent (CCA) around the metal roller, which has a 16-mm diameter. The supply roller is made of polyurethane foam and its resistance is controlled by the carbon black content. The regulating blade is made of a metal plate that is 0.1 mm thick. All of them are biased. The bias voltages to the development roller, the supply roller, and the regulating blade are expressed as V_B, V_{Sp}, and V_{Bl} respectively. For convenience, we use ΔV_{Sp} and ΔV_{Bl}, which are potential differences from V_B, such that $\Delta V_{Sp} = V_{Sp} - V_B$ and $\Delta V_{Bl} = V_{Bl} - V_B$. The toner is put into the toner cartridge, which is attached to the side of the unit. The toner supply screw originates in this cartridge and extends out into the body of the unit parallel to the toner supply roller, where it rotates so that the toner is uniformly fed to the supply roller. The development roller rotates at a velocity of 140 mm/s and the ratio of its velocity to the speed of the photoconductor, ν_{Dr}/ν_{Pc}, is 1.5/1. The supply roller rotates at a velocity of 120 mm/s and the ratio of its velocity to the speed of the photoconductor, ν_{Dr}/ν_{Sp}, is 1/0.86. The toner-collecting screw collects the toner that has fallen from the surface of the development roller and returns it to the toner cartridge. We used a cyan toner in this experiment. This toner was composed of a binder resin (polyol), a pigment (phthalocyanine), a CCA, and silica. The average diameter of the toner particle was 7.5 μm.[2]

Procedure. To characterize the time dependence, we measured the properties of the surface potential of the

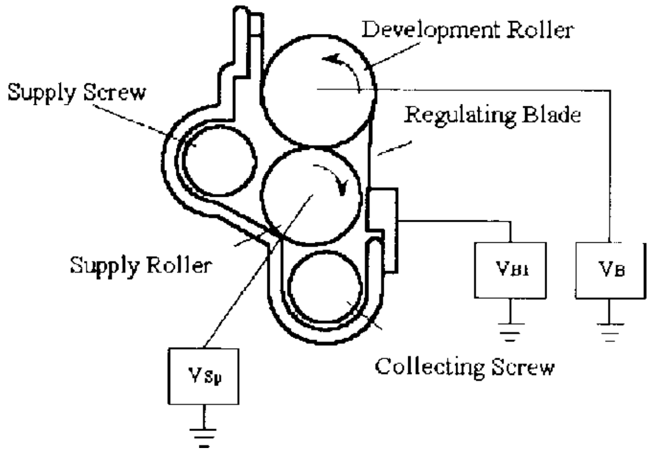

Figure 1. Schematic of the experimental unit.

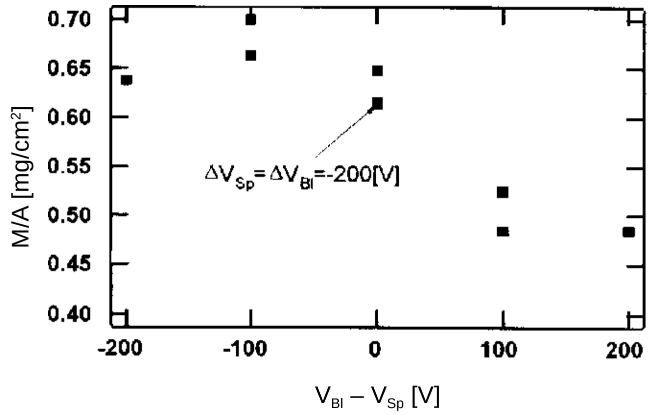

Figure 2. M/A versus $(V_{Bl} - V_{Sp})$.

development roller, toner mass, and toner charge-to-mass ratio in three situations, as follows: (1) saturated condition (before development), (2) just after the solid development for one rotation of the development roller (0.35 s), and (3) just after the continued solid development for nine rotations of the development roller (3.15 s), the dimensional equivalent of a full-size sheet of A4 paper.

We define the term V_{Dr} as the surface potential of the development roller. However, when we want to distinguish a position on the development roller we use V_{mn}. The subscript *mn* represents each measuring position, where *m* represents the rotation of the development roller (0 represents the saturated condition; 1 represents just after one rotation of the development roller); *n* represents the position in which *b* has just passed the regulating blade, and *s* is just past the supply roller.

Before measurement we saturate the toner layers on the development roller. We operate the development unit for 30 s without development to form stable toner layers.

Measurement. Just after the unit is stopped, the voltages applied to the development roller, the supply roller, and the regulating blade are turned off. (1) In the position past the regulating blade we measure the surface potential, including the toner layers. (2) After removing the toner layers in one portion by applying the nozzle that connects to the vacuum equipment, we measure the surface potential of the development roller. (3) We measure the toner mass and the charge-to-mass ratio on the surface of the development roller in another portion. The technique for measuring the toner mass and the charge-to-mass ratio involves removal of toner particles from the surface on the development roller by vacuum. The removed toner particles are caught in the glass filter, which serves as a coulomb gauge. It is connected to a programmable electrometer (Keithley Model 617). The mass is measured as the weight of the coulomb gauge before and after absorption, using an electric analytical balance (Sartorius Model R-200D). The bare surface of the development roller is 3.3 cm². (4) The solid development continues for one rotation, nine rotations, and just after one rotation drive to form the toner layers.

Results

1. **The Appropriate Applied Voltage to the Supply Roller and the Regulating Blade.** Figure 2 shows the toner mass on the surface of the development roller versus the difference between the voltages applied to the supply roller and the regulating blade at saturation. The toner mass, which depends on ΔV_{Sp}, is well known, as is ΔV_{Bl}, because it also determined the quantity of toner particles by the electric field between the doctor blade and the development roller.[3] In the area of $V_{Bl} - V_{Sp} > 100$ V the toner mass was insufficient. Giving consideration to continuing solid development, we chose the condition $\Delta V_{Sp} = \Delta V_{Bl} = -200$ V by way of experiment.
2. **The Toner Mass and the Toner Charge-to-Mass Ratio Dependence on the Surface Potential of the Development Roller.** Figures 3 and 4 show the toner mass and the charge-to-mass ratio versus the surface potential of the development roller. Also included are points representing multiple rotations, as for making a solid image. In this result the toner mass increased a little bit but the toner charge-to-mass ratio was quite stable.
3. **The Residual Ratio Dependence on the Surface Potential of the Development Roller.** Figure 5 shows the relation between the residual ratio and the surface potential of the development roller. We obtained the RR as described in the Introduction. Because our target for the residual ratio is less than 2%, the surface potential of the development roller should be less than 30 V.
4. **The Time Dependence of the Potential of the Development Roller's Surface.** Figure 6 shows the time dependence of V_{Dr} as the solid development continues. The plotted points show, respectively, saturated condition, condition after development for one rotation, for nine rotations, and for 86 rotations. We confirmed the charge accumulation on the surface of the development roller.

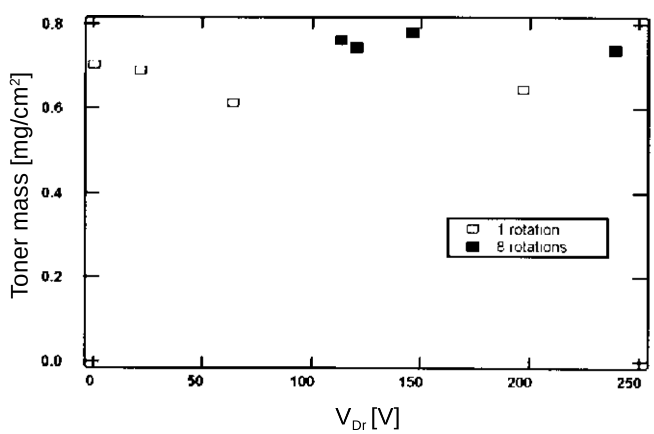

Figure 3. Toner mass versus V_{Dr}.

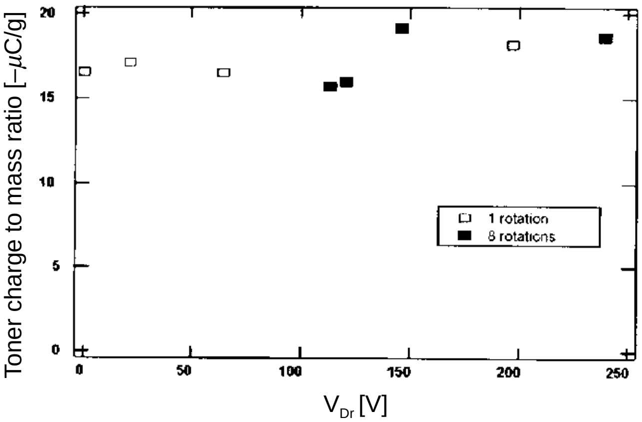

Figure 4. Toner charge-to-mass ratio versus V_{Dr}.

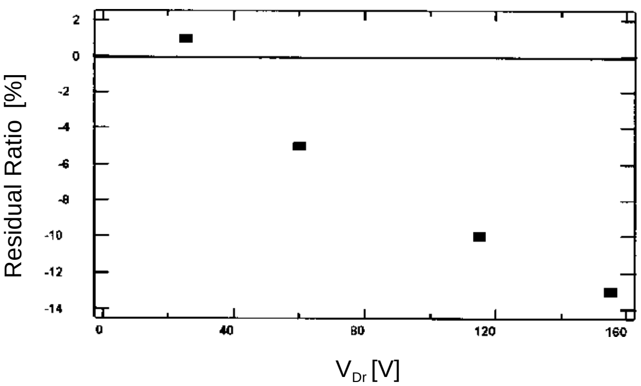

Figure 5. Residual ratio versus V_{Dr}.

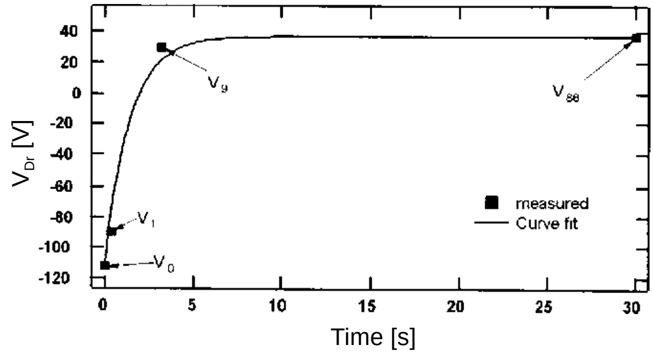

Figure 6. Time dependence of V_{Dr}.

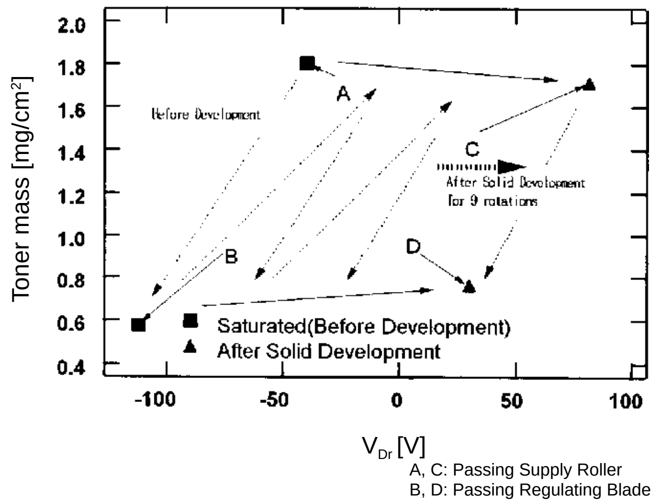

Figure 7. The charge accumulation on the surface of the development roller.

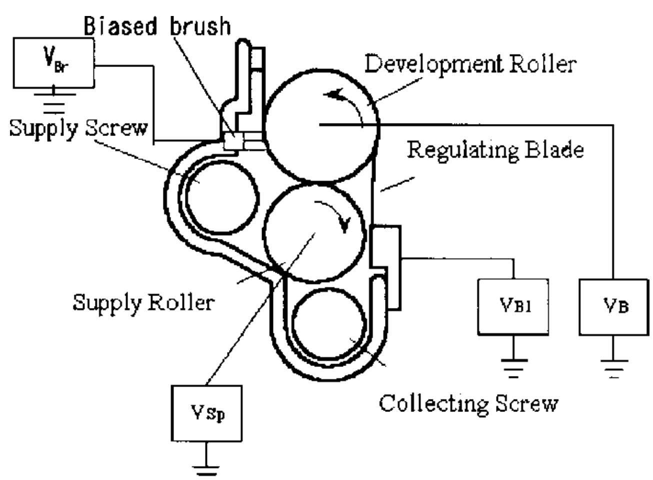

Figure 8. Revised schematic of the experimental unit.

5. **The Charge Accumulation on the Surface of the Development Roller.** To determine the charge accumulation on the development roller's surface, we measured not only the surface potential, but also the toner mass and the toner charge-to-mass ratio. Just after stopping the drive we disassembled the development unit and took out the development roller. We calculated the time constant, and it was over 200 s because the resistance was over 10^{12} Ω cm and the capacitance of the resin layer of the development roller was 9.7×10^{-9} F. Figure 7 shows the result for the toner mass. After passing the supply roller it has a certain surface potential and the excess mass (Point A) but just after passing the regulating blade, its surface potential decreases (Point B). After nine rotations of continual solid development, the surface potential of the development roller increases (Points C and D). It seems that the translation of the line depends on V_{Dr}. That change is caused by the charge accumulation with each rotation of the development roller after contacting the supply roller. From this analysis we judged that the charge accumulation on the surface of the development roller was caused by the contact between toner and the development roller as a result of the friction of the supply roller.
6. **Confirmation of the Effect of the Solution.** As a result of the cause analysis, we chose to initialize the charge distribution on the surface of the development roller. This approach was also investigated by other researchers.[4,5] To contact the surface of the development roller we arranged a conductive brush, which is biased with two components, dc and ac (peak-to-peak voltage is 1200 V, frequency is 2500 Hz) voltages. The revised schematic is shown in Fig. 8. The effect of the biased brush is shown in Fig. 9. In the negative area of the applied voltage, there is a difference of the surface potential on the development roller between one rotation and nine rotations. On the contrary, the surface potentials are nearly the same in the positive area of the applied voltage.

Applying the above conditions, we obtained an increase of nearly 30 V in the surface potential of the development roller, as compared with the previous measurement of 140 V without the contact brush.

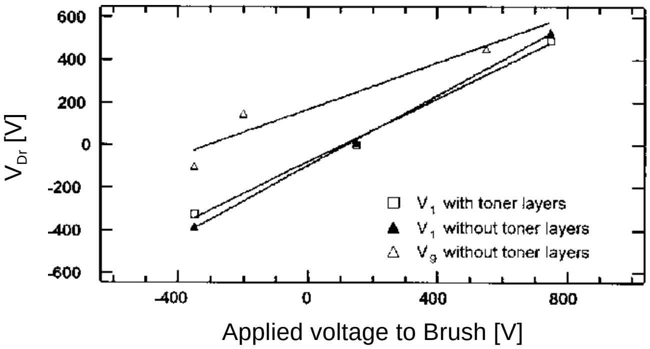

Figure 9. V_{Dr} versus applied voltage to brush.

Discussion

Charge Accumulation Model. As the solid development continues, the surface of the development roller receives a tribo charge by the contact of new noncharged toners one after another. Some researchers have put forward the charge accumulation of the repeat contact, and it is shown as follows:

$$q(n) = q_{\max}\left\{1 - \exp\left(-\frac{n}{\tau}\right)\right\}, \qquad (1)$$

where $q_{\max}$ is a saturated charge on the surface of the substance A, τ is the time constant of the substance A, and n is the number of times contact occurs between Substance A and Substance B. On the other hand, we consider the case of a charge accumulation model for a resistance–condenser direct junction circuit. Its equation is as follows:

$$R \cdot \frac{dq}{dt} + \frac{q}{C} = E \text{(initial condition: } q = 0 \text{ at } t = 0;$$

$$E \text{ is initial applied voltage),}$$

where R is the electric resistance and C is the capacitance of the total circuit. The solution is as follows:

$$q(t) = CE \cdot \left\{1 - \exp\left(-\frac{t}{RC}\right)\right\}. \qquad (2)$$

If the initial condition is $q = Q_0$ at $t = 0$ and Eq. 2 is converted as follows:

$$q(t) = CE \cdot \left\{1 - \exp\left(-\frac{t}{RC}\right)\right\} + Q_0 \cdot \exp\left(-\frac{t}{RC}\right), \qquad (3)$$

where $CE = q_{\max}$, from the relation $V = \dfrac{Q}{C}$, then

$$V(t) = V_{\max} \cdot \left\{1 - \exp\left(-\frac{t}{RC}\right)\right\} + V_0 \cdot \exp\left(-\frac{t}{RC}\right). \qquad (4)$$

By curve-fit calculations we determined that the time constant is 1.67 to 2.5 s, though the R^*C of the resin layer of the development roller is more than 200 s. Therefore, we consider the contribution of the supply roller and the regulating blade. As we mentioned before, the resistance of the supply roller is 10^5 Ω cm, that of the toner is 10^{11} Ω cm, and the regulating blade is conductive. So we estimated the effect of this time constant on the total electric circuit including the effects of the supply roller and the regulating blade.

From Fig. 7 we estimated the area that influenced the surface of the development roller. We concluded that the domain just after contact of the supply roller with the toner had a major influence on the charge accumulation on the surface of the development roller. As a result of these analyses we can define several steps of the mechanism of the "ghost" phenomenon: (1) V_{Dr} increases with the supply of new toner on the surface of the development roller. (2) The change in V_{Dr} influences the development's bias shift. (3) The development efficiency decreases. (4) The image density of the developed area decreases. However, there is a change of toner mass on the development roller according to the increase on the surface potential of the development roller, and the influence of the development roller's surface potential exceeds the influence of the increase of toner mass. These steps lead to the "ghost" phenomenon.

Atmospheric Discharge. One reason that we should add the relatively high voltage to the conductive brush is given by the analysis of the effects on the stability of the development roller's surface potential. The other reason is that each part must be regulated within certain conditions. For the regulating blade, a positive high voltage will increase background density. For the supply roller at 0 or greater than 0 positive voltage the absolute quantity of toner supply on the development roller will decrease. For this reason we have to consider another place to add relatively high positive voltage. That is the conductive brush just after the development.

As with the measurement shown in Fig. 7, we have several successive points to observe the surface potential. These points are just after contact with the brush, with the supply roller, and with the regulating blade. They are P_{Br}, P_{Sp}, and P_{Bl}, respectively. In the case of noncontact with the brush, the surface potential of the development roller decreased negatively according to the bias voltage on the regulating blade, as already shown. Further, it was shown that after contacting the supply roller, the surface potential increased because of the tribo charge of the toner. By addition of the biased brush we made the surface potential positive relatively high. The measured data at each point are shown in Fig. 10. When any point on the surface of the development roller contacted the supply roller, the surface potential increased positively and that potential difference between the two parts led to the atmospheric discharge and decreased potential.

We considered the transition of the surface potential at each point referred to in Figs. 10 and 11. After development the biased brush was contacted and the surface potential of the development roller rose to more than 500 V. Further bias voltage to the supply roller added another 200 V to the potential difference. The surface potential increased by the contact with the supply roller because of the tribo charge of the toner. We compared the potential difference between the surface of the development roller and the supply roller, by a calculation using the surface potential, the bias voltages ($V_{Dr} + \Delta V_{Sp}$) and the dielectric constant of the development roller in the consideration of the discharge of peeling. Further we compared these results with the modified Paschen curve.[6] In Fig. 11, we found that atmospheric discharge occurred between the development roller, the supply roller, and the regulating blade when two of them were approaching each other with the gap estimated at 20 to 40 μm with over 700 V of potential difference. As we can see, the line for 700 V total voltage lies over the modified Paschen curve. This gap is based on

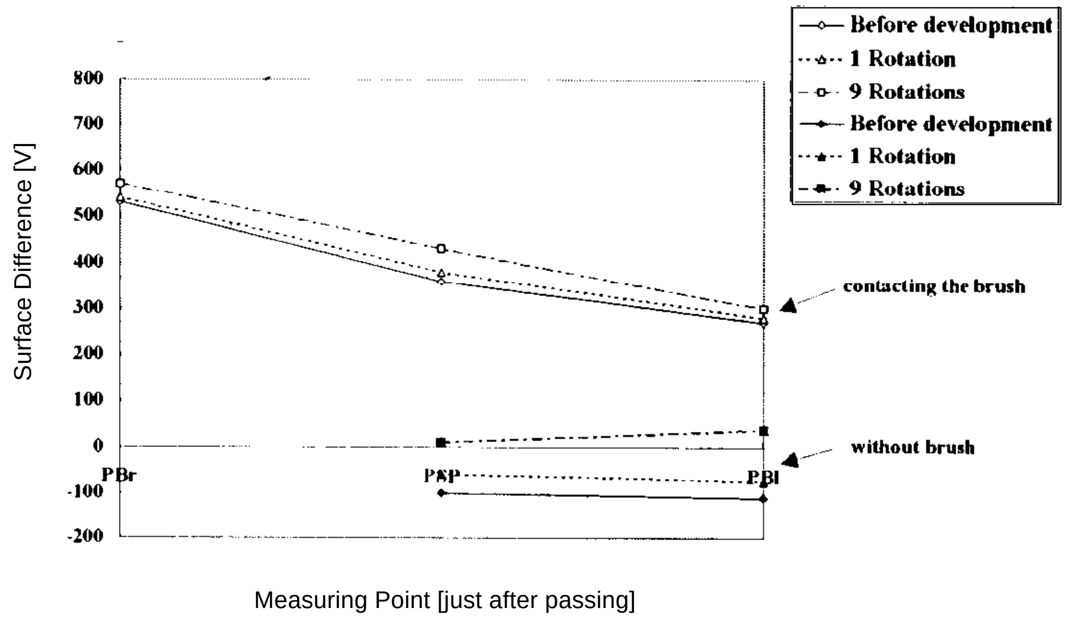

Figure 10. Transition of the surface potential.

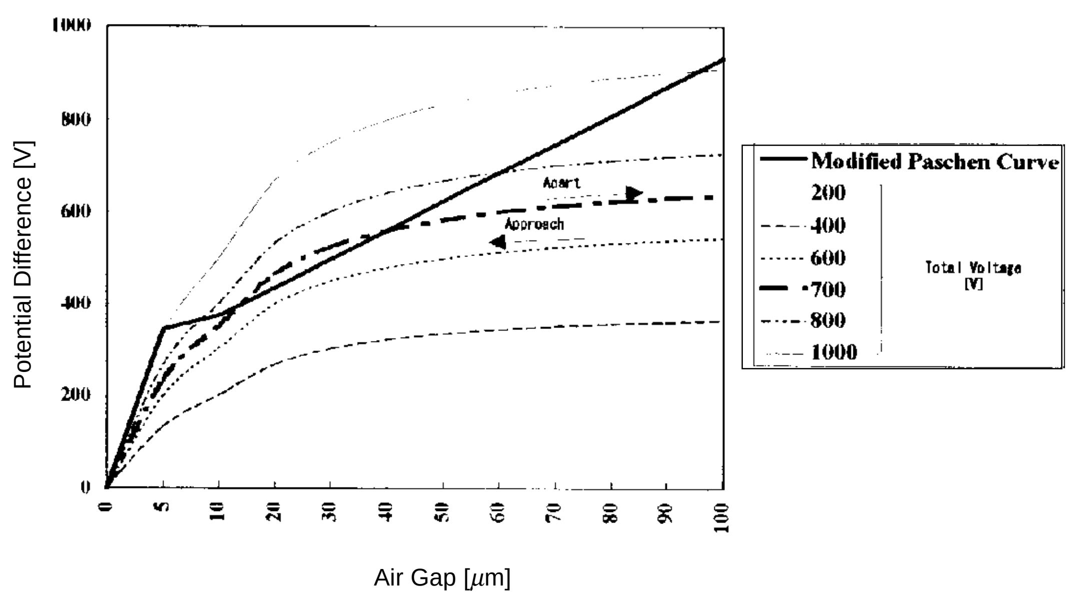

Figure 11. Modified Paschen curve and potential difference.

the existence of the toner or the mesh net of the supply roller. The plot suggests occurrence of atmospheric discharge because that potential difference is greater than that of the modified Paschen curve shown in Fig. 11. In terms of this effect, it is easy to maintain the surface potential of the development roller.

Conclusions

1. In using a development roller which has relatively high resistance (over 10^{12} Ω cm) the main cause of the "ghost" is identified as the charge accumulation on the surface of the development roller by tribo charge with toner through the friction of the supply roller.
2. We have obtained an optimal condition that is able to decrease the charge accumulation by contacting the biased brush. Because this condition (dc component of ΔV_{Br} = 750 V) is quite high compared with the development bias voltage, we are able to maintain the high surface potential of the development roller by the effect of atmospheric discharge.

References

1. K. Hirakura, et al., *Proceedings of IS&T's Tenth International Congress on Advances in Non-Impact Printing Technologies*, pp. 53–54 (1994).
2. Y. Ueno, et al., *Proceedings of IS&T's Ninth International Congress on Advances in Non-Impact Printing Technologies*, 1993, pp. 45–48.
3. C. Yamaguchi, et al. *Proceedings of IS&T's Eighth International Congress on Advances in Non-Impact Printing Technologies*, 1992, pp. 72–74.
4. M. Hosoya, et al., *IEEE Trans. on Industry Appl.*, **24** (2) (1988).
5. M. Hosoya, et al., *Proceedings of IS&T's Eighth International Congress on Advances in Non-Impact Printing Technologies*, 1992, pp. 66–71.
6. R. M. Schaffert, *Electrophotography,* John Wiley & Sons, New York, 1975.