Parametric analysis with micro jitter generation for a direct current charging roller based electrophotographic device

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To realize high quality electrophotography, it is important to clarify the influence of the design parameters in a charging roller (CR) system on the output image on the paper. We first analyzed the parameters related to the direct current (dc) bias CR system, and consequently confirmed micro jitter generation as a printing quality indicator for varying CR resistance and the surface roughness of the CR elastic layer. It turned out that the micro jitters were correspondingly generated for the chosen representative parameters, and therefore, the analyses can be used as a design platform to prepare an optimum dc CR system.

I. INTRODUCTION

The information technology industry is rapidly progressing and subsequently, with the advent of imaging technology,1–4 electrophotographic systems became popular as digital printing devices because the systems have been the technology of choice for high speed printing.5,6 Specifically, the systems have been applied and studied widely for office appliances to obtain a visible image fused on papers or transparencies.4,7 In order to realize high-resolution electrophotographic systems such as laser beam printers, copying machines, and fax machines, it is important to clarify the influence of design parameters for a charging process consisting of gas discharge tools on the quality of the output image on the paper.8–10

The phenomenon of electrophotography is extensively used in applications based on static electricity, and is therefore particularly important.11 A charging roller (CR) system is a kind of contact electrostatic charger for electrophotographic imaging devices. The system consists of a CR, an organic photocconductor (OPC), and a direct current (dc) power supply. The electrostatic charging happens between the CR and OPC, and thus the surface of the OPC is charged. The CR is made from graphite containing an elastic layer on a conductive shaft. The primary image-capturing element in an electrophotographic system, the OPC, is a thin layer of a dark-insulating, photoconductive material on a conductive cylinder.12,13 Recently, this system has become popular because of greatly reduced ozone emissions compared with corona chargers.14,15 Ozone is rarely generated by a dc bias CR system with the improvement of the charging performance in a laser beam printer. In this paper, design parameters were chosen for the CR system, which were numerically represented as charging maintenance and electric field distribution. Consequently, a selection of the analyzed results was compared with the experimental evidence (i.e., micro jitter on halftone printing image) to clarify their applicability in the design of a dc CR system.

II. EXPERIMENTAL DETAILS

Figures 1(a) and 1(b) show a schematic of the CR system with a DC bias voltage and the corresponding actual picture, respectively. The schematic consists of the CR, OPC (Mitsubishi Chemical Corporation), and dc power supply. The electrical discharge happens between the CR and OPC, and thus the surface of the OPC is electrostatically charged. From the dc CR schematic (Fig. 1(a)), the OPC surface potential \( V_{\text{OPC}} \) can be derived based on a Zener diode as follows:17

\[
V_{\text{OPC}}(t) = \frac{Q_{\text{OPC}}}{C_{\text{OPC}}} = e^{-t/\tau} \left[ \int_0^t e^{\tau t} (V_a - V_F) \, dt \right]^{1/\tau}
\]

\[
V_{\text{OPC}} = V_a - V_0 - S_F \cdot d_{\text{min}} - V_I \ln \frac{V_a - V_0 - S_F \cdot d_{\text{min}} + V_F}{V_F}
\]

where \( Q_{\text{OPC}} \) is the charge amount on the OPC local surface, \( C_{\text{OPC}} \) is the capacitance of OPC, \( t_0 \) and \( t \) are the initial and
specific charging times respectively, and $\tau$ is the time constant (sec, $C_{OPC}$ (F) $\times$ $R_{CR}$ (Ω); where $R_{CR}$ is the resistance of CR).$^{18}$ $V_a$ is the applied voltage to the CR core shaft, $V_P$ is the Paschen breakdown voltage in air, and $V_o$, $S_p$, and $d_{\text{min}}$ are the minimum voltage ($\sim$230 V), curve slope ($\sim$$10^4$ V mm$^{-1}$), and minimum gap distance ($\sim$7.5 μm) for the Paschen breakdown in air, respectively. $V_s$ is the systematic voltage, defined as follows:

$$V_s = \frac{S_p}{V_o} + \frac{V_s}{V_o} + \frac{d_{\text{min}}}{V_o} + \frac{V_0}{V_o} + \frac{SP_\text{d}}{V_o} + \frac{V_0}{V_o}$$

where $U_p$ is the process speed (mm sec$^{-1}$), $W_{\text{nip}}$ is the width (mm) of the CR-OPC contact (or nip), and $r_{CR}$ and $r_{OPC}$ are the radii (mm) of the CR and OPC, respectively. The charging maintenance time ($t_c$) is derived by converting Eq. (1) as follows:

$$t_c = t_o - t_u = \tau \ln \frac{V_a - V_0 - S_p \cdot d_{\text{min}} + V_s}{V_0}$$

where $t_o$ is the overall time (sec) of a charging cycle, and $t_u$ is the uncharging time in the cycle. The $t_u$ term can be written as follows:

$$t_u = \frac{S_p \cdot d_{\text{min}}}{V_0} \cdot \tau$$

Finally, the charging maintenance length ($L_c$) can be expressed as the product of the process speed and the charging maintenance time as follows:

$$L_c = U_p \cdot t_c$$

The end gap distance ($d_o$) of the charging roller can be expressed as follows:

$$d_o = \frac{V_0 \cdot \tau}{S_p \cdot \tau}$$

The specifications of the experiments at normal temperature-normal humidity (denoted as ‘NN’: 22°C, 55% relative humidity (RH)) environment are as follows: single-layer CR length of 230 mm; applied voltage of −1364 V; CR and OPC radii of 4.25 and 12 mm, respectively; nip width of 0.5 mm; process speed of 155 mm sec$^{-1}$; and OPC dielectric constant and thickness of 3 and 20 μm, respectively.

III. RESULTS AND DISCUSSION

Figures 2(a)–2(c) show the trends of the OPC surface potential ($V_{OPC}$), charging maintenance length ($L_c$), and specific charging gap distance ($d_i$) for varying parameters of the CR resistance ($R_{CR}$), CR-OPC nip width ($W_{\text{nip}}$), and CR radius ($r_{CR}$). Within the chosen range of the parameters, the change in $V_{OPC}$, $L_c$, and $d_i$ for varying $R_{CR}$ and $W_{\text{nip}}$ is rather larger than those for varying $r_{CR}$. The resistance was varied, $L_c$, and $d_i$ remarkably increased from about 0.6 MΩ of $R_{CR}$ while $V_{OPC}$ was inversely proportional to $R_{CR}$. Here, the $L_c$ increase can be represented as a charging stability, and thus the experimental results (i.e., micro jitter generation on halftone printing image) correspondingly followed. For example, the results (Fig. 2(d)) clearly reveal that the $R_{CR}$ has a large effect on the printing image quality; where micro jitter on the print image is enhanced by increasing the $R_{CR}$ from 0.6 to 4.0 MΩ when −1364 V was applied to the CR core shaft.

The micro jitter generation is also verified with the surface roughness of the CR elastic layer; analytic (Figs. 3(a) and 3(b)) and experimental (Fig. 3(c)) results are depicted. In order to calculate the field ($E$) distribution between the CR and OPC surfaces, which is important for correlating between the surface roughness of the elastic layer and micro jitter generation, the field amplification factor ($\beta$) is used to account for the micro geometry of the surface of the elastic layer$^{19}$:

$$E = \frac{\beta \cdot V_b}{d}$$

where $\beta$ depends on the surface geometry, such as roughness. One way to calculate $\beta$ is by using the simple approximation:
where $R_z$ and $R_a$ are the ten-point and arithmetic mean heights (μm) relating to the surface irregularity, respectively. $V_b$ is the Paschen breakdown voltage, and is calculated as follows:

$$V_b = A \cdot \frac{p \cdot d}{B + \ln(p \cdot d)}$$

(10)

where $p$ is the gas pressure (Pa), $d$ is the gap distance (m), and $A$ and $B$ are the gas-dependent coefficients ($A = 279.6 \text{ V m}^{-1} \text{ Pa}^{-1}$, $B = 0.9$ for air). The uniformity of the field distribution is enhanced by decreasing the values of $R_z$ (Fig. 3(a)) and $R_a$ (Fig. 3(b)). Moreover, for varying $R_a$, the field magnification is also varied as well as the field distribution uniformity. Micro jitter generation is experimentally evaluated by the roughness variations, and the results including CR surface images are shown in Fig. 3(c). Regarding the analyses, the micro jitter generation is weak in accordance with decreasing $R_z$ and $R_a$.

Additionally, we tested the micro jitter generation while varying the experimental environment for an identical CR-OPC specification ($V_a$ of $-1364 \text{ V}$, $R_{CR}$ of $0.6 \text{ MΩ}$, $W_{nip}$ of $0.5 \text{ mm}$, and $r_{CR}$ of $4.25 \text{ mm}$), hence, the measured current ($I$)-voltage ($V$) characteristics including the approximation from Eq. (11) have been compared with the printing image quality.¹⁰

$$E_o \approx C \cdot \delta + D \cdot \sqrt{\frac{\delta}{R_z}}$$

(11)

where $E_o$ is the discharge onset field ($\text{V m}^{-1}$), $C$ ($32.3 \times 10^5 \text{ V m}^{-1} \text{ in air}$) and $D$ ($0.846 \times 10^5 \text{ V (m}^{-1})^{1/2} \text{ in air}$) are the uncertainty values, and $\delta$ is the relative air density. As shown in Fig. 4, the onset voltage (or onset field) for current generation decreased from the low temperature-low humidity (denoted as ‘LL’: $10 \text{ °C}$, 12% RH) to the high temperature-high humidity (denoted as ‘HH’: $32 \text{ °C}$, 85% RH) environment, and thus the linearity between $V$ and $I$ is rather
More linear correlation can represent more stable charging (due to an enhanced charge flux onto the OPC), and thus the suppression of micro jitter generation is rather preferred for the HH environment than the others (see the insets of Fig. 4).

IV. CONCLUSIONS

In summary, the parameters related to the DC bias CR system ($V_{OPC}$, $L_c$, and $d_i$ versus $R_{CR}$, $W_{nip}$, and $r_{CR}$) and the surface roughness of the CR elastic layer ($E$ distribution versus $R_z$ and $R_a$) were numerically analyzed, and subsequently confirmed micro jitter generation on the printing image for varying CR resistance and for surface roughness of the CR elastic layer. Results from the analysis and experiment clearly revealed that the $R_{CR}$ has a large effect on the printing image quality; where micro jitter on the printing image is enhanced by increasing the $R_{CR}$ from 0.6 to 4.0 MΩ. Regarding the surface roughness of the CR elastic layer, the micro jitter generation is weak in accordance with decreasing $R_z$ and $R_a$ (inducing uniformity of the $E$ distribution). Additionally, micro jitter generation while varying the experimental environment for an identical CR-OPC specification is enhanced for HH. More linear correlation can represent more stable charging (due to an enhanced charge flux onto the OPC), and thus the suppression of micro jitter generation is rather preferred for the HH environment than the others (see the insets of Fig. 4).
verified, and the generation is affected by the environment in accordance with the $I-V$ characteristics. Our strategy of parametric analyses along with gathering evidence through experiments is attractive because of its simple and distinctive features, and it may contribute to appropriately designing dc bias CR systems in electrophotographic devices.