Prediction of Deposit Toner Mass by Improved Toner Flow Model for Dual Component Magnetic Brush Development

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Abstract

Toner deposition on latent electrostatic images is a function of the toner flow rate in the development region of a dual component magnetic brush development system. we had previously proposed an improved toner flow model as mean of solving the deposition rate.

This paper describes toner deposit mass predicted by the model in the case of some different development devices adopted such as a double pole magnetic development brush or multiple development rollers taking the dynamic electric resistance of developers and development threshold values into account. The good correspondences were obtained between calculations and experiments for toner deposit mass and dynamic electric resistivity of developer.

Introduction

Magnetic brush development with a dual component developer is the most common method of development of electrostatic latent images in electrophotography or electrostatic recording. Although the development process and the behavior of developing toner are complicated, they are important since the development characteristics and image quality are influenced by them. In this development process, toner flows to the development region, where a part of it deposits on the surface of electrostatic latent images of the recording medium. Many studies have been carried out in analysis, experiments, and models concerning this development process 1)2)3)4).

We proposed an improved toner flow model 5)6). Also we considered the development efficiency in dynamic conditions by this model at IS&T 13th International Congress on Advances in Non-Impact Printing Technologies 8). This paper describes toner deposit mass predicted by the model in the case of some different development devices having a special development magnetic pole or multiple development rollers. In this study we considered the dynamic electric resistance of developer. Experimental results were compared with calculated values.

Improved Toner Flow Model

1) Toner Flow Mass for Solid Images 5)6)

Fig.1 shows the development schemes for a dual component magnetic brush development. Toner particles are transported by carrier beads into the development region. The developer brush contacts the surface of a recording medium having electrostatic latent images with the brush nip width W. Toner particles deposits on the surface through a balance of electrostatic and kinetic force. The change of the brush shape during transportation of developer, the collision force by the rising carrier bead chains of the brush, and the shear force by the brush speed difference make the beads move or rotate as shown in figure 1. This perturbation or agitation causes the toner flow mass to increase. Therefore the toner flow mass in solid area development is determined by the product of the brush speed ratio and the perturbation of the developer.

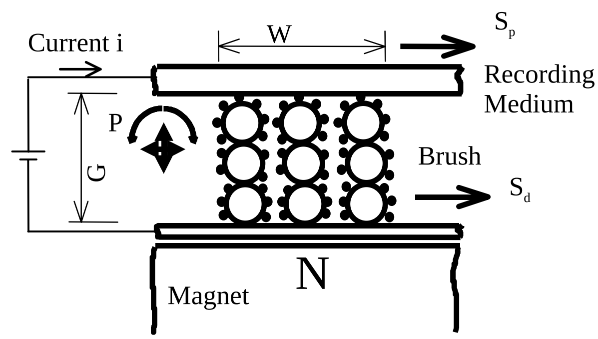

Figure 1. Development scheme for a dual component magnetic development system. The movement of carrier bead chains gives perturbation P to developer.

As the developer perturbation is increased by an increase in the speed difference between the brush and latent image, it is thought that the differential of perturbation with respect to brush speed difference is in proportion to the perturbation difference from the saturation value. Thus

$$p_o - p = \eta \cdot dp/dJ \quad (1)$$

where p_o=saturation value of perturbation, p=perturbation per unit brush nip width, η=coefficient, $J=|S_d-S_p|$=brush speed difference, S_d=brush speed, S_p=recording medium speed, and where S_d is positive for the with-mode operation. Solving this, the perturbation is given by

$$p=p_1+(p_o-p_1)\{1-exp(-J/\eta)\},$$
$$=p_1[1+\lambda\{1-exp(-J/\eta)\}] \qquad (2)$$

for p_1=perturbation at J=0 and λ=perturbation coefficient. Rewritten as a function of the speed ratio between the brush and the latent surface

$$P=P_1[1+\lambda\{1-exp(-|S-1|/\nu)\}] \qquad (3)$$

for P=pW,magnitude of perturbation, $P_1=p_1W$, perturbation at S=1, W=brush nip width, $\nu=\eta/|S_p|$ and $S=S_d/S_p$, Speed ratio.

The toner flow mass by this perturbation is added to the original. Eventually the total toner flow mass H is

$$H=(a+puW)|S|, \qquad (4)$$

where H= toner flow mass, a= toner weight per unit area of the top surface of the brush, u=toner weight per unit volume of the developer. When puW is large or “a” is treated including in perturbation, equation (4) gives

$$H=puW|S|=Pu|S| =A[1+\lambda\{1-exp(-|S-1|/\nu)\}]|S|. \qquad (5)$$

$$=A[1+\lambda\{1-exp(-|S-1|S_p/\nu_oS_{po})\}]\,|S| \qquad (6)$$

where $A=P_1u$, ν_o is ν at $S_p=S_{po}$.

(2) Deposit Toner Mass for Solid Images

Toner deposition progresses through a balance of electrostatic and kinetic force. Therefore the differential of the deposited toner mass with respect to toner flow mass is proportional to toner-depositing potential. Thus,

$$M_o-M=\varphi\cdot dM/dH \qquad (7)$$

where M_o=saturation value of deposit toner mass, M=deposit toner mass, φ= coefficient. This gives

$$M=M_o\{1-exp(-H/\varphi)\}. \qquad (8)$$

M_0 is represented as follows,

$$M_o=\kappa E_e/q \qquad (9)$$

with E_e as effective electrostatic field strength of a latent image 5)6), q as toner charge deposited and κ as coefficient.

If the development region consists of electric condensers, E_e is given approximately by

$$E_e=E_1+E_2\{1-exp(-t/\tau_1)\}-E_3exp(-t/\tau_2)-E_4 \qquad (10)$$

where E_1 is for the electrostatic field strength at t=0, E_2 is for the saturation value of the increased electrostatic field strength by the charge injection into the carrier beads for development time t, E_3 is for the counter charge, E_4 is for the development threshold value by image force, van der Waals force and scavenging force, and τ_1 and τ_2 are time constants. When $\tau_1=\tau_2=\tau$,

$$E_e=E_2\{E_1/E_2+(1-E_4/E_2)-(1+E_3/E_2)exp(-t/\tau)\}. \qquad (11)$$

Thinking of the average field strength during development period, E_e is given by

$$E_e=E_2[E_1/E_2+(1-E_4/E_2)-(1+E_3/E_2)\{1-exp(-t/\tau)\}\tau/t], \qquad (12)$$

where $t=W/S_pS$, $\tau=\varepsilon_o\varepsilon_s\rho$, ε_o=dielectric constant of vacuum, ε_s=dielectric constant of developer and ρ=dynamic resistivity of developer.

(3) Dynamic Electric Resistivity of Developer

The electric resistance depends on the movement of developer in the nip region. we call this dynamic electric resistance. The stronger movement causes the lower resistance. This contributes much deposit toner mass, because of the increasing of charging speed for forming the electrostatic field of latent images and the discharging speed of counter charge on the carriers.

Dynamic electric resistivity ρ is dominated by the movement of developer in development region. The movement which relates to the charge conveyance is so complicate that it is difficult to analyze and formalize ρ exactly. We thought that charge current which goes through developer at development nip consists of two components. One is independent of the movement, another is a function of the movement. Charges are conveyed by the movement of carrier beads adding the charges streaming through the beads. Then the current by the movement is analogous to toner deposit mass for toner flow, that is the differential of current with respect to movement difference is in proportion to current difference. And the movement is analogous to the perturbation of developer in the nip. Thus, ρ will be given as

$$R=V/i=R_o/[1+i_2/i_1\cdot\{1-exp(-F/\alpha)\}] \qquad (13)$$

$$\rho=\rho_o/[1+i_2/i_1\cdot\{1-exp(-F/\alpha)\}] \qquad (14)$$

where R=dynamic resistance measured, V=applied voltage, i=current, R_o=dynamic resistance for movement F=0, ρ_o=resistivity for movement F=0, i_1=current at F=0, and i_2=maximum current by movement. Then, movement F is

$$F=F_1[1+\beta\{1-exp(-|S-1|/\gamma)\}]S_d$$
$$=F_1[1+\beta\{1-exp(-|S-1|S_p/\gamma_oS_{po})\}]SS_p \qquad (15)$$

where F_1,α,β,γ=coefficient, and $\gamma_o=\gamma$ at $S_p=S_{po}$.

(4) Development Threshold

Toner particles flowed into development area do not deposit on latent images if the electrostatic field strength is under a level. we named this level ‘development threshold’. It is also difficult to formalize because it is influenced by many parameter such as image force, scavenging force, van der Waals force. Particularly the movement of developer seems to affect it because of the decreasing of such adhesion forces by the perturbation of developer. According to experiments in middle speed print range, it is approximately represented by a saturation function of brush speed difference 8),

$$E_4=E_5exp(-|S_d-S_p|/\delta)$$
$$=E_5exp(-|S-1|S_p/\delta_oS_{po}), \qquad (16)$$

where E_5 is the electric field strength of development threshold at S=1 and δ is coefficient and δ_o is δ at $S_p=S_{po}$.

However it is thought that scavenging force might increase in high speed print range and development threshold have the minimum value for some movement or a process speed.

Calculations and Experiments

We can know what factor influences toner deposit mass by calculating equations above-mentioned with changing the values of parameters and comparison between calculated and experimental data. In the calculations, the parameters used were determined by fitting the calculated values to the experimental values and the maximum value of deposit toner mass was assumed as $1 mg/cm^2$ when toner flow mass was large enough. In our experiments, the optical image density and the developed toner mass on the photoreceptor were investigated by reversal development using high and low speed laser beam printers. Each condition was selected for experimental objectives and convenience. Dynamic resistance was measured using aluminum drum electrode.

Fig. 2 shows some examples of dynamic electric resistivity by calculations and experiments. The good correspondence between measured and calculated values was obtained. IMB has high resistivity and big peak value at S=1. However SCMB or CMB does not have a big peak value. The dip of toner deposit mass at S=1 will be big for high electric resistance. Type B, C and D were used for printing experiments.

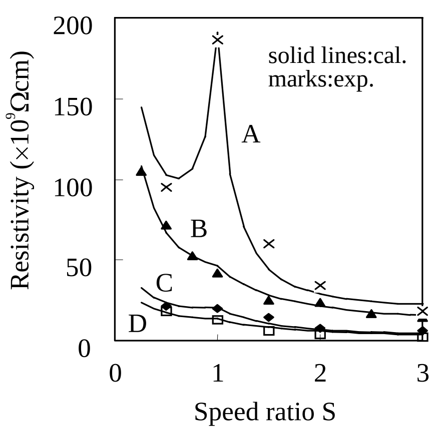

Figure 2. Dynamic resistivity of developers. Calculation conditions; $F_1/\alpha=0.33$, $\beta=15$, $\gamma=2$, $\rho_o=1100(\times 10^9 \Omega cm)$, $i_2/i_1=50$, $S_p=0.3m/s$, for A, $F_1/\alpha=0.8$, $\beta=0.5$, $\gamma=0.7$, $\rho_o=400(\times 10^9 \Omega cm)$, $i_2/i_1=42$, $S_p=0.25m/s$ for B, $F_1/\alpha=0.33$, $\beta=3$, $\gamma=2$, $\rho_o=80(\times 10^9 \Omega cm)$, $i_2/i_1=30$, $S_p=0.3m/s$ for C, $F_1/\alpha=0.33$, $\beta=1.5$, $\gamma=2$, $i_2/i_1=25$, $\rho_o=45(\times 10^9 \Omega cm)$, $S_p=0.3m/s$ for D.

Fig. 3 shows a typical result of the toner deposit mass for solid images. In the calculation, the dynamic resistivity and development threshold were taken into account by using equation (12), (14) and (16). The experimental values corresponds well with the calculated values.

Fig. 4 shows the deposit toner mass as a function of process speed. The solid line for IMB and dot line for SCMB are by calculations in consideration of t/τ and E_4. The decrease for lower speeds depends on the speed difference between S_d and S_p, and the decrease for higher speeds depends on the development time.

Unfortunately we do not have the experimental data of consistent conditions with calculations for the devices and materials. For reference of relative comparison, experimental data are plotted. The calculations and experiments are relatively in low speed range, but the decrease in calculations for high speed range is smaller than this experimental result. we guess the reason for this difference to be the increasing of scavenging force or decreasing of developer mass transported.

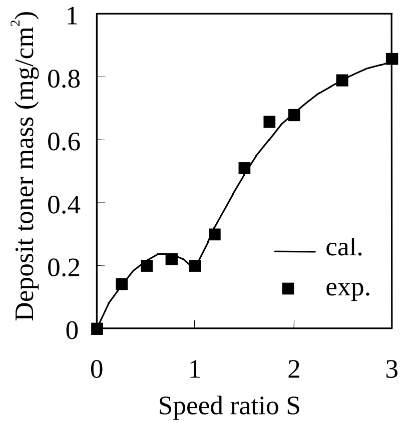

Figure 3. Characteristics of deposit toner mass for solid images in middle speed range. Calculation and experiment conditions; developer=B, $S_p=0.25m/s$, $\delta_o=0.7$, $E_1/E_2=0.9$, $E_5/E_2=0.1$, $E_3/E_2=0.2$, $W=0.007m$, $\varepsilon_s=5$, $A/\varphi=0.23$, $\lambda=2$, $\nu=0.7$.

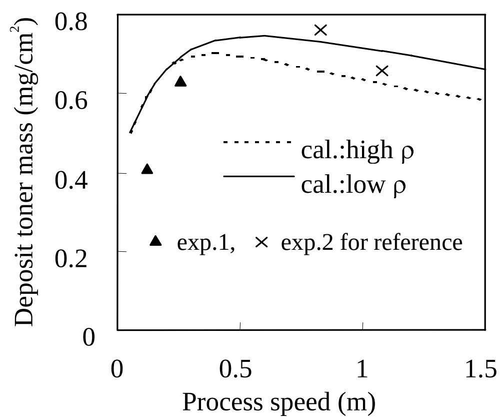

Figure 4. Deposit toner mass as a function of process speed. Calculation conditions; $\delta_o=0.7$, $E_1/E_2=0.9$, $E_5/E_2=0.1$, $E_3/E_2=0.2$, $W=0.007m$, $\varepsilon_s=5$, $A/\varphi=0.23$, $\lambda=2$, $\nu=0.7$ for high resistivity developer, $S_{po}=0.25m/s$, $\delta_o=0.7$, $E_1/E_2=0.3$, $E_5/E_2=0.1$, $E_3/E_2=0.1$, $W=0.007m$, $\varepsilon_s=5$, $A/\varphi=0.23$, $\lambda=2$, $\nu=0.7$ for low resistivity developer. Experimental conditions; exp.1=single development roller, exp.2=multiple development rollers.

Fig. 5 shows deposit toner mass calculated with M_0=constant which corresponds to the condition of large t/τ and small E_4. From this, it is necessary to be the development devices having large A/φ or P_1, in order to get much toner deposit mass, for example using a double-pole magnet development roller, multiple development rollers or/and supplying AC voltage as additional biasing.

Fig. 6 shows the result by a special development device which has double pole magnet for forming development brush. It has several times of development ability compared with a single pole type. Fig. 7 shows the result by another special device adopted multiple development rollers. In those calculations, t/τ and E_4 were taken into account. It seems that large S is inadvisable for high speed range.

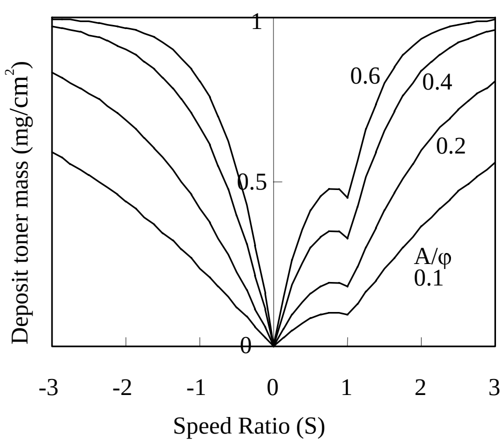

Figure 5. Calculated result with Ee=constant, λ=2, and ν=1.

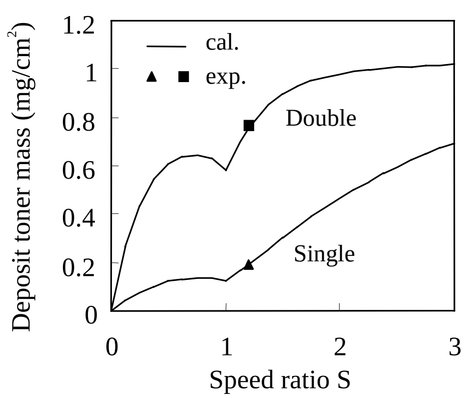

Figure 6. The effect of a double pole magnetic development brush for deposit toner mass. Calculation and experiment conditions; developer=D, S_p=0.18m/s, δ_o=0.7, E_1/E_2=0.3, E_5/E_2=0.1, E_3/E_2=0.1, W=0.007m, ε_s=5, A/φ=0.15 for single, A/φ=1 for double, λ=2, ν=0.7.

Conclusions

In support of some consideration on the prediction of toner deposit mass by an improved toner flow model for dual component magnetic brush development, the following results were obtained:

(1) Deposit toner mass can be predicted by toner flow mass and effective electric field strength.

(2) The dynamic resistivity of developer is represented by a saturation function of developer movement in the development region.

(3) The effective toner flow mass of a double pole magnetic development brush has several times compared to a single magnetic pole development brush.

(4) The good correspondences were obtained between calculations and experiments for toner deposit mass and dynamic resistivity of developer.

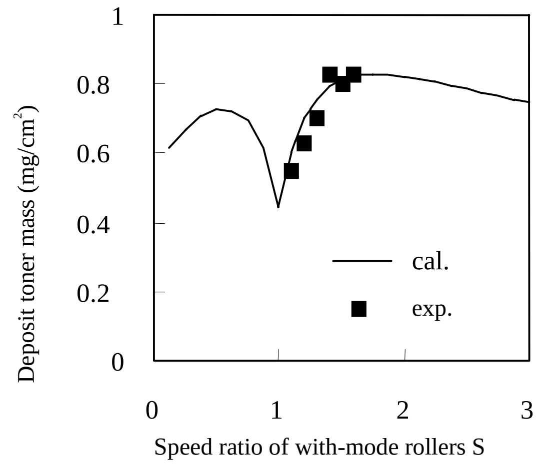

Figure 7. Deposit toner mass by a multiple roller development device. Calculation and experiment conditions; developer=C, S_p=1.07m/s, δ_o=0.7, E_1/E_2=0.5, E_5/E_2=0.2, E_3/E_2=0.2, W=0.007m, ε_s=5, A/φ=0.28, λ=1.5, ν=1, develpment rollers=one counter-mode development roller(S=1) and two with-mode development rollers.

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Biography

Masayasu Anzai was born in 1939 Japan. He received the B. Eng. Degree in electrical engineering in 1962 and the Dr. Eng. in 1989 both from the Shizuoka University, Japan. He worked on development of color electrophotographic systems and laser beam printers. He is now chief engineer of the printer division of Hitachi koki Co., Ltd.