A Study of High Resolution Latent Image Forming and Development

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Abstract

In recent years, the resolution in digital printing has been becoming higher, in response to the need for high image quality. However, since there is a cost disadvantage to using a smaller exposing beam, methods like PWM control only used, and real high resolution has not been achieved. For this reason, high-resolution stable single dots and single lines cannot be formed. To improve the sharpness and halftone of images and to achieve a photo-quality image, the high-resolution image forming technology is required.

To help allow for the employment of smaller exposing beams, for example using blue lasers, we have conducted the study reported in the present paper in which we have investigated the necessary conditions for the high-resolution latent image forming and development process. In this paper, we first discuss our frequency analysis of the latent electric field, through which we have determined an OPC thickness that can give single and periodic lines simultaneously between 600 and 2400 dpi. Next, we discuss the test-bed we constructed and our experimental examination of the characteristics of single line and periodic line image forming at 1200 dpi. Finally, we consider the effect of several methods on high-resolution image forming.

Introduction

Schaffert[1] and Schmidlin[2~4] made detailed studies of the electric field of the periodic latent image in the development area and made calculations using the three dielectric layers model. Scharfe[5] simplified the model to two dielectric layers and analyzed the characteristics of the electric field with regard to solid and line image development.

In the case of non-magnetic mono-component contact development, the thickness of the toner layer is thin, so the frequency characteristics of the latent electric field at the toner layer is monotonic no maximum. We calculated the frequency characteristics of the OPC surface potential at the development area, and analyzed the single line and periodic line compatibility. So doing, we confirmed the effectiveness of a thin OPC for high-resolution image forming.

Next, we constructed the test-bed, which consisted of a charging component, a high-resolution exposing component, and a developing component, and we verified the effect of thin OPC on the compatibility.

Theory

Solution of the Equation for the Electric Field at the Periodic Line Latent Image

Figure 1 depicts the model used for calculation of the electric field in the development area. The dielectric constants are ε_a and ε_b. The thickness of the layers are l and m. There is a periodic charge density σ at the boundary between the OPC layer and the toner layer.

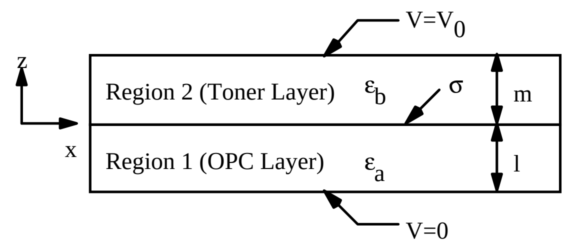

Figure 1. Schematic of calculation model

The charge density σ is given by Eq. 1, and Laplace's equation is applied to the toner layer according to Eq. 2. The DC and AC components of potential function ϕ_2 are defined by Eq. 3. Solving Eq. 4 and 5, the potential function ϕ_{2ac} and ϕ_{2dc} are given by Eq. 6 and 7, respectively.

$$\sigma = \frac{\sigma_0}{2}(1+\cos\omega x)\ ,\ \omega = \frac{2\pi}{\lambda} \qquad (1)$$

$$\frac{\partial^2\phi_2}{\partial x^2} + \frac{\partial^2\phi_2}{\partial z^2} = 0 \qquad (2)$$

$$\phi_2 = \phi_{2dc} + \phi_{2ac} \qquad (3)$$

$$\phi_{2dc}[x,z] = b_b + b_0 z \qquad (4)$$

$$\phi_{2ac}[x,z] = \{b_1 \cdot e^{\omega z} + b_2 \cdot e^{-\omega z}\}\cos(\omega x) \qquad (5)$$

$$\phi_{2ac} = -\frac{\dfrac{\sigma_0}{\varepsilon_a}\dfrac{\sinh\{\omega(z-m)\}}{\cosh(\omega m)}\cos(\omega x)}{2\omega\left(\dfrac{\varepsilon_b}{\varepsilon_a}+\dfrac{\tanh(\omega m)}{\tanh(\omega l)}\right)} \quad (6)$$

$$\phi_{2dc} = \frac{2V_0\left(\dfrac{z}{\varepsilon_b}+\dfrac{l}{\varepsilon_a}\right)+\dfrac{l}{\varepsilon_a}\dfrac{(m-z)}{\varepsilon_b}\sigma_0}{2\left(\dfrac{m}{\varepsilon_b}+\dfrac{l}{\varepsilon_a}\right)} \quad (7)$$

The Electric Field Strength at the Toner Layer

For analyzing the frequency characteristics, only the AC component should be treated. The electric field strength at the position where the potential amplitude is maximal is obtained from Eq.8 by substituting x=0 into Eq.6 and differentiate by z:

$$E_{2ac0} = -\frac{\dfrac{\sigma_0}{\varepsilon_a}\dfrac{\cosh\{\omega(z-m)\}}{\cosh(\omega m)}}{2\omega\left(\dfrac{\varepsilon_b}{\varepsilon_a}+\dfrac{\tanh(\omega m)}{\tanh(\omega l)}\right)} \quad (8)$$

Figure 2 shows the relation obtained from Eq.8 between the latent spatial frequency and the electric field strength for several values of the parameter m (toner thickness). These are the characteristics at a distance of 10 μm from the OPC surface (z=10 μm). Table 1 gives the standard values of parameters. In the case of a thin toner layer, represented as mono-component contact development, the frequency of the latent electric field is monotonic no maximum. This is shown by the m=20 curve in Fig. 2.

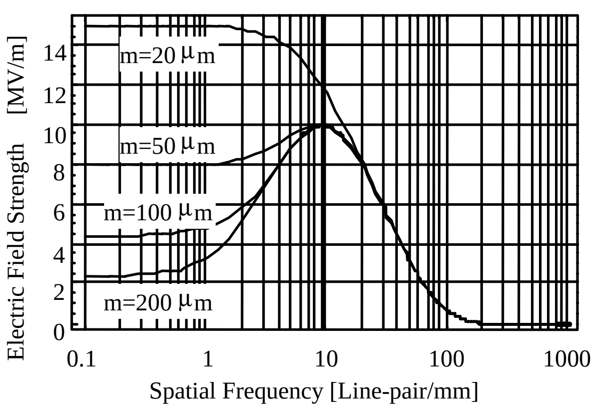

Figure 2. Spatial frequency of the toner layer electric field

Table 1. Standard Values of Parameters

Photoreceptor Layer		
Thickness	l	20 μm
Dielectric Constant	ε_a	3
Charge Density	σ_0	1.33 mC/m^2
Toner Layer		
Thickness	m	20 μm
Dielectric Constant	εb	2
Electric potential	V_0	0 V

The Frequency Characteristics of the Latent Potential

The frequency characteristics of the OPC surface potential are analyzed as follows, following Eq.6. In this case, we treat the OPC thickness l as a parameter, and thus we set the constraint that the charge density σ_0 is constant, independent of the thickness l. Then, the electric field strength at charging is kept constant and the allowance for dielectric breakdown is kept the same. The standard value of σ_0 is 1.33[mC/m^2] as shown in Table 1, calculated for the conditions where the OPC thickness is 20μm and the charging is 1kV.

Figure 3 shows the relation between the latent spatial frequency and the amplitude of the latent potential for several values of the parameter l (OPC thickness). As the frequency increases, the potential amplitude decreases. This corresponds to a decrease in the development volume. In the case of a thin OPC, the potential amplitude is small, but the frequency is flat. This indicates the stability of the development volume and the image density with respect to changes in the latent frequency.

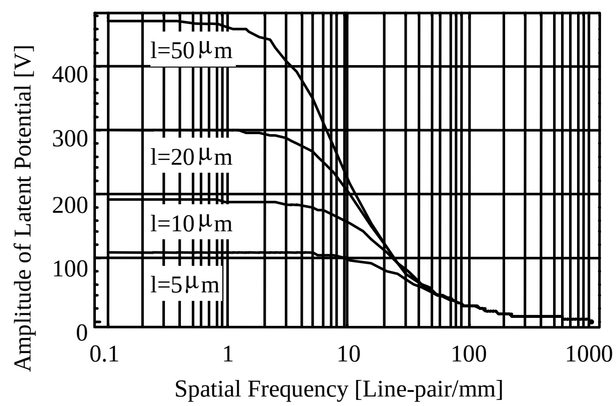

Figure 3. Effect of OPC thickness on frequency of the latent potential

Single Line and Periodic Line Compatibility

We used the function G(θ) to calculate the electric field of single line latent image. This rectangular wave function G(θ), which has period 2π, width 2θ and height 1 is given by Eq. 9 as a Fourier series. The amplitude of the AC potential Amp_{ac} is given by Eq. 10 by substituting x=0, z=0 and ω=nω into ϕ_{ac}. For the low frequency, ω≅0, the amplitude of the AC potential $Amp_{ac\omega o}$ is obtained from Eq. 11 by substituting x=0 and z=0 into ϕ_{ac} and taking the limit ω→0. Then, the MTF_{ltnt} function, which represents the frequency dependence of the potential amplitude, is defined by Eq. 12. Next, to apply a periodic line image pattern that has a white width X_w and black width X_b to the MTF_{ltnt} function, the relation in Eq.13 should be substituted into Eq. 9. Consequently, the response function RF is found from Eq. 14 by multiplying the AC component of G(θ) by the MTF_{ltnt} corresponding to the frequency. This response function RF is normalized, so the actual latent potential profile PR is found from Eq. 15 by multiplying the function RF by the total amplitude 2 $Amp_{ac\omega o}$:

$$G(\theta) = \frac{\alpha}{\pi} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin(n \cdot \alpha)}{n}\cos(n \cdot \theta) \tag{9}$$

$$Amp_{ac} = \frac{\sigma_0}{2}\left[\left(\frac{\tanh(n\omega l)}{\varepsilon_a n\omega}\right)^{-1} + \left(\frac{\tanh(n\omega m)}{\varepsilon_b n\omega}\right)^{-1}\right]^{-1} \tag{10}$$

$$Amp_{ac\omega 0} = \underset{\omega \to 0}{Limit}\,\phi_{2\,ac} = \frac{\sigma_0}{2}\left[\left(\frac{l}{\varepsilon_a}\right)^{-1} + \left(\frac{m}{\varepsilon_b}\right)^{-1}\right]^{-1} \tag{11}$$

$$MTF_{ltnt} = \frac{\left(\frac{l}{\varepsilon_a}\right)^{-1} + \left(\frac{m}{\varepsilon_b}\right)^{-1}}{\left(\frac{\tanh(n\omega l)}{\varepsilon_a n\omega}\right)^{-1} + \left(\frac{\tanh(n\omega m)}{\varepsilon_b n\omega}\right)^{-1}} \tag{12}$$

$$\alpha = \frac{X_w}{X_w + X_b}\pi\ ,\ \theta = \omega x \tag{13}$$

$$RF = \frac{X_w}{X_w + X_b} + \frac{2}{\pi}\sum_{n=1}^{\infty} MTF_{ltnt}\frac{\sin\left(n\pi\frac{X_w}{X_w + X_b}\right)}{n}\cos(n\omega x) \tag{14}$$

$$PR = 2Amp_{ac\omega 0} \cdot RF \tag{15}$$

Figure 4 displays a result of the calculation for the latent potential, where a single white line, a periodic line, and a single black line are defined as indicated in Table 2. The latent period in Fig.4 is 20µm, which corresponds approximately to 2400 dpi. Figure 4 indicates that the image density of the single white line is larger than the image density of the single black line or the black part of the periodic line. Under these conditions, the single line is not compatible with the periodic line.

Through the detailed simulation, we can determine the frequency quantitatively, this shows that the potential amplitude decreases and the compatibility becomes worse when the frequency increases. For example, when the OPC thickness is changed to 10µm from 20µm, the compatibility is improved. Figure 5 describes this improvement.

Table 2. Definition of single and periodic lines

		X_w	X_b
Single White Line	SWL	λ/2	5 λ/2
Periodic Line	PL	λ/2	λ/2
Single Black Line	SBL	5 λ/2	λ/2

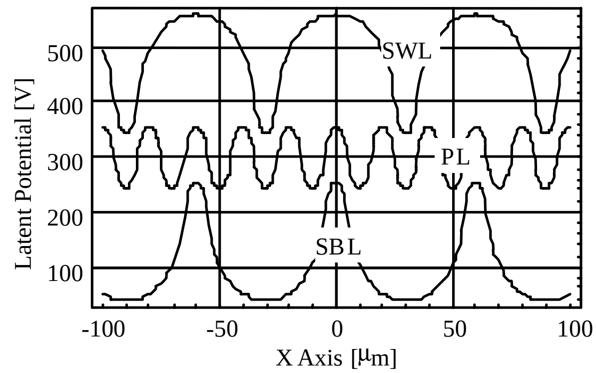

Figure 4. Compatibility of a single white line, a periodic line, and a single black line when l=20µm..

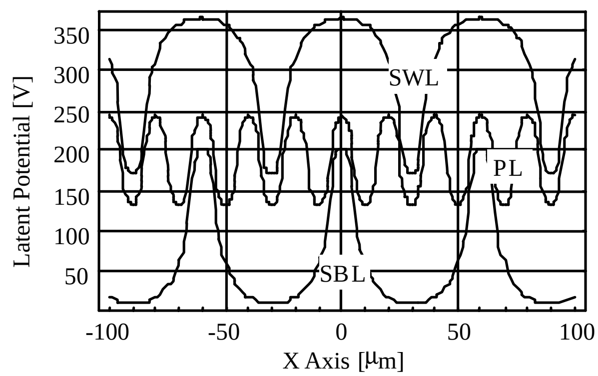

Figure 5. Compatibility of a single white line, a periodic line, and a single black line when l=10µm

Experiment

Experimental Equipment

Our test-bed for examining the development of high resolution latent images is as follows. The test-bed consists of a charging component, a exposing component, and a developing component, which are controlled by a computer. The OPC film is arranged flat. The half decay exposure is 0.08µJ/cm^2. The optical system for exposing can control the beam diameter from 300 to 6000dpi and set the position with a resolution of 1µm. The exposing beam diameter was set to 3λ/2 in the experiment. The development system uses non-magnetic mono-component contact development. The toner average diameter is 5µm.

Effect of OPC thickness

Figure 6 displays developed images obtained at 600dpi. The OPC thickness on the left side is 20µm and that on the right side is 15µm. By using a thin OPC, a single line and a single dot can be developed more stably. At 1200dpi, there was no substantial difference between the images obtained using the 20 and 15 µm OPC. We consider this is due to carrier diffusion in the OPC layer and other causes.

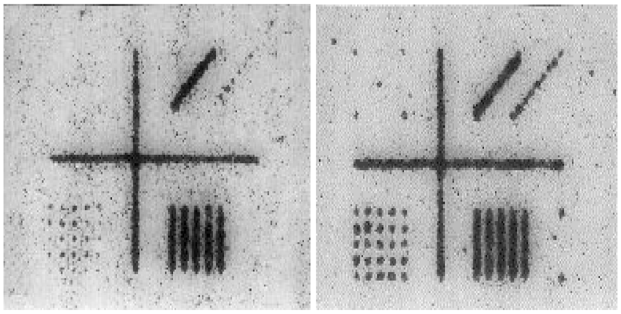

Figure 6. Effect of OPC thickness on the developed image. The OPC thickness in the left picture is 20μm and that in the right one is 15μm.

Discussion

About the Simulation

Figure 7 shows a schematic of the electric potential obtained from Eq.6. The electric field strength that generates the toner driving force decreases markedly with an increase in the distance to the OPC surface. This phenomenon becomes remarkable as the frequency increases. In accordance with the higher frequency, the electric field strength that is necessary to drive the toner is only large near the OPC surface. Thus, we can see the efficiency of using smaller diameter toner for stable development of a high-resolution latent image.

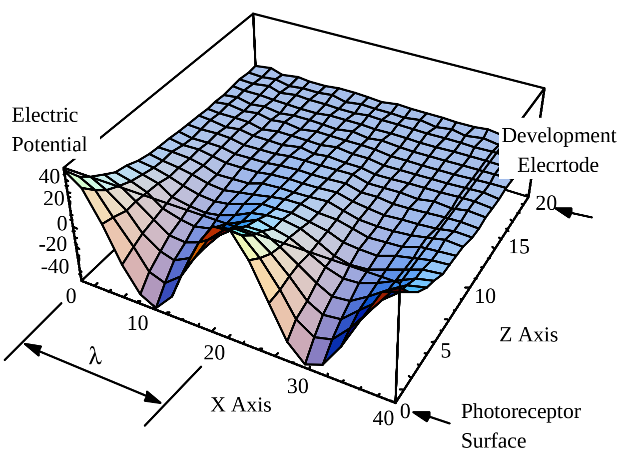

Figure 7. Electric field of the toner layer

For more accurate calculations, it is necessary to consider the volume charge density of the toner layer and other factors. However, the purpose of this simulation is to determine the compatibility of a single line and a periodic line. Therefor, we calculated the frequency at the OPC surface. In the case of poor compatibility at the OPC surface, the compatibility of the developed image should also be poor.

About the Experiment

A prerequisite for the calculation is an ideal charge distribution, but actually the deterioration of the charge distribution occurs for some reasons, such as an inappropriate exposing beam diameter and the carrier diffusion in the OPC layer. Therefor, it is important to use a beam with the appropriate exposing diameter. However, the actual 1200dpi printers use a large diameter beam because making smaller beams is costly. We expect to realize a low price and smaller exposing beam with a blue laser in the near future.

Conclusion

1. We demonstrated the advantage of the frequency calculation using a Fourier series to study the compatibility of a single line and a periodic line.
2. We theoretically showed that the thin OPC is effective to improve the compatibility.
3. We constructed a test-bed which can test high-resolution exposure and development, and we verified the efficiency of a thin OPC in improving the compatibility.

Acknowledgement

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Biography

Tadashi Iwamatsu received his B.S. degree in mechanical engineering from Kyoto University in 1986. After graduation, he joined the Sharp Corporation in 1986. He has been engaged in the design of servomechanisms, the optical design of hologram scanners, and the research of electrophotography. He belongs to the Precision Technology Development Center. His current research interests include the simulation of electrophotography. He is a member of the IS&T.