

Single Dot Development and Threshold Laser Power on Laser Beam Printer

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Abstract

Latent image formation on electrophotographic Laser beam printer (LBP) which uses Gaussian laser beam and biased voltage development was investigated. As surface voltage of photoreceptor induced by laser exposure must be under the biased voltage, threshold laser power was determined on a simple form. The calculation was compared with experiments of single dot development by 8μm toner with 800dpi and 60ppm LBP. Although toner image of the single dot printing was blurred by the process of development, quantitative agreement was obtained.

1. Introduction

In order to realize high quality printing, the most significant requirement is a fine expression of gray shading which is performed by multi-levels of halftoning, and a suitable relation between the levels and print density. Those are closely related to a reliable shape of one dot printing.

Many kinds of investigation of surface voltage on electrophotographic photoreceptor (EP) due to laser beam exposure have been reported [1,2,3], and an existence of threshold value of laser power (Pc) for development was suggested, implicitly [4]. However, a relation between Pc and the biased voltage (Vb) of development was not clearly shown, and then, the relation for single dot exposure among Pc, Vb, EP properties and a moving speed of the EP (v_p) is obtained here, and that is compared with experimental results.

2. Simple Calculation

The surface voltage (***V***) of EP after laser exposure is represented as [1]

$$V = Vr + (V_o - Vr)\exp(-E/Ea) \quad (1)$$

where ***Vr*** and $\boldsymbol{V_o}$ are residual and initial surface voltage of EP drum, respectively. $\boldsymbol{E(J/mm^2)}$ is exposure energy of laser beam on EP. The laser beam intensity $\boldsymbol{I(W/mm^2)}$ is Gaussian and is expressed[1] by

$$I(x,y)=[P\eta/(2\pi\,\alpha\,\beta)]\ \exp[-(y-y_o/\alpha)^2/2-(x-x_o/\beta)^2/2] \quad (2)$$

where ***P(mW)*** is laser beam power which is experimentally observed quantity, η is the overall optical efficiency, α is the vertical (:sub-scan) spot size parameter and β is the horizontal (:scan) one. (x_o,y_o) is a regular dot position. In this scheme, the widths of laser beams are denoted by 4 α and 4 β, where the intensity ratio $I/I(x_o,y_o)$ becomes $1/e^2$ on each scan direction. Laser beam is scanned by the velocity $\boldsymbol{v}$ to the x-axis, and the EP drum is rotated by $\boldsymbol{v_p}$ to y-axis. Emission of laser is determined by the printing signal, which is expressed by a normalized laser pulse function $\boldsymbol{f(t)}$. Here, *f(t)* is specified approximately as follows, where $\boldsymbol{t_o}$ is the time of one dot printing.

$$-t_o/2 \le t \le t_o/2 \quad : \quad f(t)=1$$

$$t -<-t_o/2, \text{ and } t > t_o/2 \quad : \quad f(t)=0.$$

The exposure energy $E(x_o,y)$ is obtained by time integral of $\boldsymbol{f(t)I(x,y)}$ with a relation of $x - x_o = vt$ (Appendix). It becomes

$$\begin{aligned} E(x_o,y) &= \int_{to/2}^{to/2} I(x,y)dt \\ &= E_o \exp\left[-\left(y-y_o/\alpha\right)^2/2\right] \end{aligned} \quad (3)$$

where,
$$E_o = \left[P\eta(1-\delta)/\left(\alpha v\sqrt{2\pi}\right)\right]. \quad (4)$$

δ gives the difference between Erf (0) and Erf (x), and δ = 0 means integral of ± ∞ in (3). Therefore, the surface voltage of EP is given as

$$V = Vr+(V_o-Vr)\ \exp\{-E_o/Ea\ \exp[-(y-y_o/\alpha)^2/2]\} \quad (5)$$

In the present study, a LBP of 800dpi and 60ppm has been developed with a twin beam laser diode and 8μm toner of dual component developer. For the values of EP drum which is an organic photoconductor (OPC), V_o and Vr are –650V and –40V, respectively. ***Ea*** is obtained to 6.3×10^{-9} J/mm^2, because V changes to the half of V_o at E = 4.8 $\times10^{-9}$ J/mm^2 on the present OPC properties.

4 α = 57μm and 4 β =47μm, and v = 1.85×10^6 mm/sec, t_o=17.2ns for present optical system. From (4), E_o/Ea=2.4 Pη(1 - δ) and the next equation (6) is obtained. This is shown in Fig.1.

$$V= -40 -610\ \exp\{-2.4P\eta\ (1-\delta)\ \exp[-(y-y_o/14.3)^2/2]\} \quad (6)$$

Fig. 1 represents a spatial extension of discharged area of the surface voltage by the laser exposure at y_o= 0, in the case of η = 1 and δ = 0. The horizontal level of Vb = -400V shows a biased voltage of development. When the voltage of the exposed area decreases under Vb, a latent image is formed, because the difference between white and black area is distinguished by the process of development.

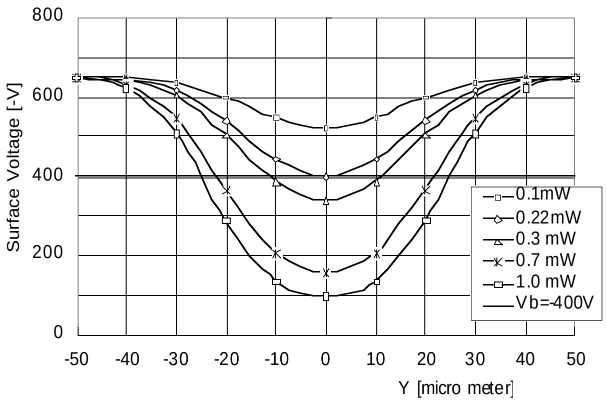

Figure 1. Surface voltage distribution. The values of insert are input power (P) on the photoreceptor at the position y=0 and the biased voltage (Vb) of development.

Using a discharged-area (reversal) development, the area of |Vb| > |V| can be developed by toner[5)] on the OPC, and then the width ***2y*** of the developed area around y_o=0 as a latent image is obtained at V=Vb as follows.

$$\left[P\eta(1-\delta)/\left(\alpha v\sqrt{2\pi}\right)\right]\exp\left[-(y/\alpha)^2/2\right] = Ea\ln\left[(V_o-Vr)/(Vb-Vr)\right] \tag{7}$$

The lowest laser power (threshold, ***Pc***) that is required by the development is given in (8) by the condition of y=0 and V = Vb.

$$Pc=\left[Ea\alpha v\sqrt{2\pi}/\eta(1-\delta)\right]\ln\left[(V_0-Vr)/(Vb-Vr)\right] = P_c^o/(1-\delta)\eta \tag{8}$$

Pc is an output laser power, and $\boldsymbol{Pc^o}$ is an input one of the threshold at the position (x_o,0) on the OPC surface. It is pointed out from (8) that large α,v and low Vb result in large Pc, which is easily observed. Equation (7) is simplified by (8), and 2y is formalized as follows.

$$(P/Pc)=\exp[(y/\alpha)^2/2] \tag{9}$$

$$2y = 2\alpha\cdot\sqrt{2\cdot\ln(P/Pc)} \tag{10}$$

Although the eqs. of (8), (9) and (10) are very simple, those include the properties of the OPC (V_o, Vr, Ea), the optical system(α, v, η, t_o), the biased voltage (Vb) of development and overall system, because the scanning speed v relates to paper feed speed v_p as $\boldsymbol{v\ \ d = v_p\ l}$, where ***d*** is a vertical dot space and ***l*** is a scanning width

3. Comparison with Experiments

The experiments were performed by microscopic observation of toner images of one dot printing on the OPC sheet before transfer station. The images on the OPC are shown in Fig. 2 and here, laser power was varied and Vb was constant (-400V). The laser power described in Fig. 2 was the value on the drum surface.

The image sizes of Fig. 2 are compared with the analytical equation of (10) in Fig. 3 where Pc° was 0.22 mW. In Fig. 3, the observed sizes on the toner image showed a parallel shift of about 30µm above 0.3mW. The toner images of the regular dot position were rapidly spread and disappeared below 0.3mW, and those were not distinguished from background toners on the OPC.

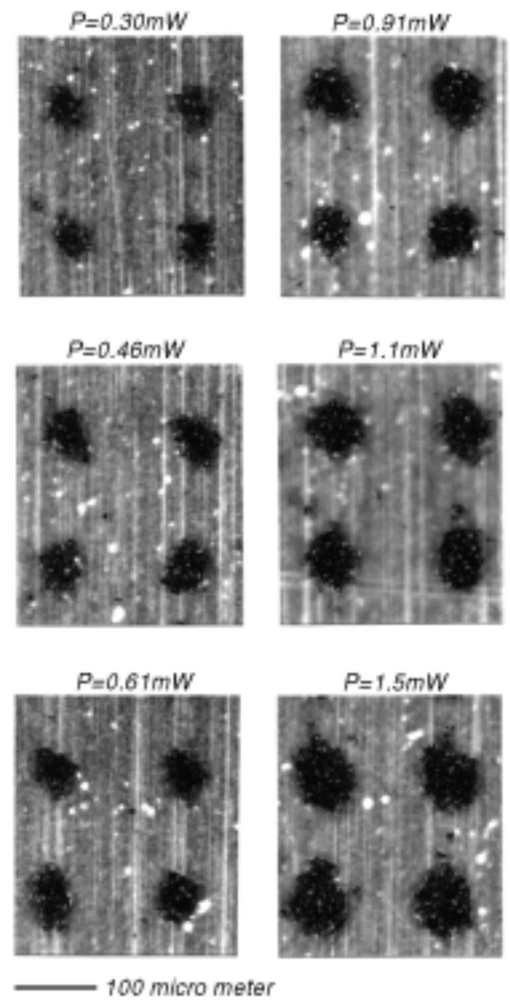

Figure 2. Toner Image of one dot printing on photoreceptor. Horizontal direction is scanning one of laser beam. P is the value of laser power at the photoreceptor.

4. Expansion of Calculation

Present analysis is applied to the 1-On and 1-Off repeated line printing. As a simple case, we consider that *y* = ± *d* are exposed (1-On) line and *y = 0* is a non exposed (1-Off) line. At first, y= -d line is exposed and then, the voltage of y=0 is changed from V_o to V_o'.

On the next exposure of y=d, the voltage of V_o' of y=0 is decayed to V_o''. Final voltage is as following.

$$V_o'' = Vr + (V_o - Vr)\exp(-2A) \tag{11}$$

where, $A = (E_o/Ea) \exp[-(-d/\alpha)^2/2]$
$= (E_o/Ea) \exp[-(+d/\alpha)^2/2]$

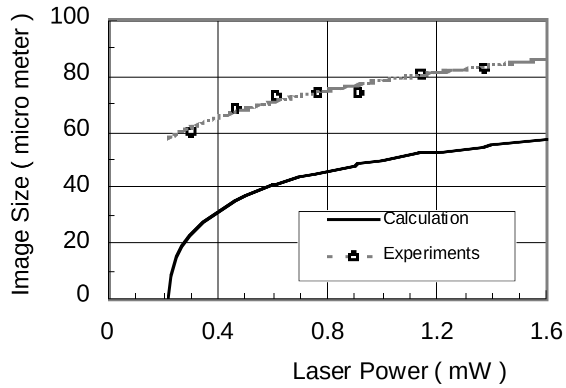

Figure 3. Comparison between calculation and experiments of one dot image size.

For the case of $y \neq 0$, the above equations are modified as follows.

$$V_o'' = Vr + (V_o - Vr) \exp[-(A_1 + A_2)] \quad (12)$$

where, $A_1 = (E_o/Ea) \exp[-(-d-y/\alpha)^2/2]$, and
$A_2 = (E_o/Ea) \exp[-(d-y/\alpha)^2/2]$

This relation is shown in Fig. 4. It can be seen that black-white-black lines merge with one black line on the latent image state above 1.3 mW.

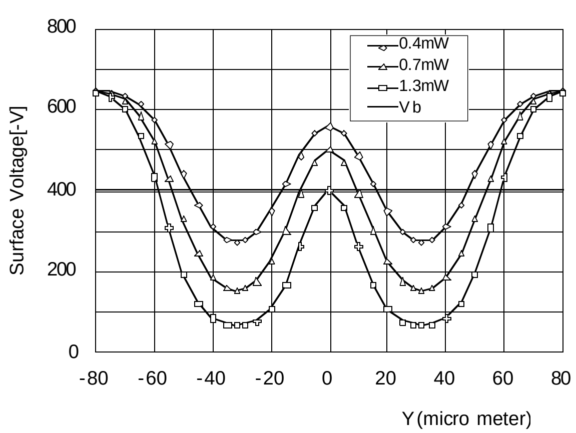

Figure 4. Surface voltage distribution of 1-On/1-Off / 1-On lines.

The width 2y which shows a non printing white line around y=0, is given by V_o''=Vb with use of Pc as follows.

$$(P/Pc)\{\exp[-(d+y/\alpha)^2/2] + \exp[-(d-y/\alpha)^2/2]\} = 1 \quad (13)$$

For an expansion of repeated 1-On/1-Off lines, (13) is modified by

$$(P/Pc)\sum_{n=0}\left\{\exp\left[-(0(2n+1)d - y/\alpha)^2/2\right] + \exp\left[-((2n+1)d - y/\alpha)^2/2\right]\right\} = 1. \quad (14)$$

As the total widths of printing (1-On) and non-printing (1-Off) line are 2d (=63.5μm for 800dpi), a relation between line width and the laser power is obtained in Fig. 5.

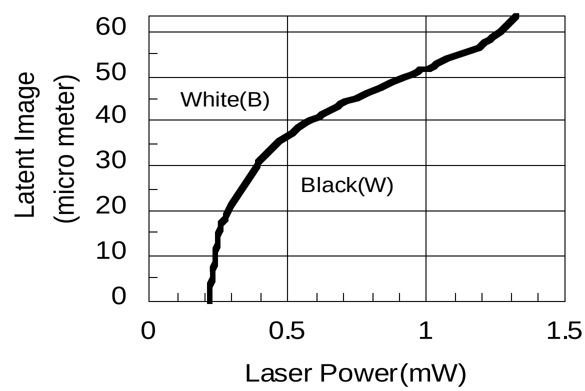

Figure 5. Black and White line width of 1-On/1-Off repeated lines on the reversal development. Parenthesis shows the case of the normal development.

In this diagram which is used in the application of the reversal development, the width of printing black line rapidly increases with laser power. On the other hand, in the case of a charged-area (normal) development, the condition of the development is |Vb| < |V|. Therefore, the width of printing black line in the normal development corresponds to that of the non-printing white line in the reversal development, and the width of black line decreases rapidly with laser power.

5. Conclusion

The width of the latent image which can be developed by toner was obtained by using the expression of threshold laser power in the cases of one dot and 1-On/1-Off repeated line printing. This simple formulation seems to play an essential role in the high resolution printing of LBP.

Experimental results of toner image after fusing showed some spreading of the width compared with the calculation. There are some causes of the spreading; at first, lateral motion of photogenerated carriers[1)] which results from the mutual repulsion of holes on the photoreceptor, and secondly, Paschen's spark in transfer process[6)], and thirdly, jitters due to mechanical vibration of LBP. In near future, Offset like printing seems to be possible by electrophotographic LBP process with some improvements against above items.

Appendix

One dot exposure is obtained by next integral, where

$$k = (vt/\beta\sqrt{2}).$$

$$\int_{-k/2}^{k/2} \exp(-k^2)dk = 2\int_0^\infty \exp(-k^2)dk - 2\int_{k/2}^\infty \exp(-k^2)dk$$

$$= 2[Erf(0) - Erf(k/2)] = (1-\delta)\sqrt{\pi}$$

The second term of right hand on the above integral is well approximated by [7)]

$$2\int_x^\infty \exp(-k^2)dk = (\sqrt{\pi})\ (1 + 0.0705230784x$$

$$+ 0.0422820123x^2 + 0.0092705272x^3 + 0.0001520143x^4$$

$$+ 0.0002765672x^5 + 0.0000430638x^6)^{-16}.$$

In present case, k/2=0.9575, therefore, the second term is $0.176\sqrt{\pi}$. The integral was expressed by $(1-\delta)\sqrt{\pi}$.

Reference

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Biography

Yuji Furuya received his B.S. M.S. and Ph.D. in Physics from Hokkaido University, Japan, in 1968, 1970 and 1977, respectively. Since 1974, he has worked at R&D division of printer in Hitachi Koki Co., Ltd. His research interest is a high resolution and high speed digital printing. He is a member of the Physical Society of Japan, and the Society of Electrophotography of Japan.