Latent Image Measurement for Dot Pattern Formed by Scanning Laser Beam

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Abstract

A method that enables the measurement of an electrostatic latent image equipped with a laser scanning unit is proposed. One of the features of this method is that the laser scanning unit is arranged outside the vacuum chamber. The vibration and the electromagnetic field interference of a polygon motor do not affect the orbit of the electron beam because the polygon motor is kept away from the electron optics system. A pair of laser diodes (LDs) is used as the light source of the laser scanning unit. The measurement results obtained by the proposed method provide valuable new information on latent image characteristics for exposure conditions.

Introduction

The demand for high-quality, color output from digital copy machines and laser printers has been rising significantly, thus prompting the development of achieving fine dot reproducibility. In the electrophotographic process, the electrostatic latent image formed on the photoconductor directly affects the behavior of toner particles. Since the mechanism of the latent image formation is not fully understood theoretically, we cannot optimize the diameter or profile of an exposure beam. Under such circumstances, it is necessary to perform high-resolution measurements of the electrostatic latent image on the order of several micrometers. However, the spatial resolution of commercial electrostatic voltmeters is on the order of several millimeters at best.

Measurement methods that use a head sensor, such as a cantilever, and detect an electrostatic attractive force and a dielectric current have been reported [1]. However, it is difficult to set them up in the allowed time because the head sensor must be moved closer to the sample. These methods also come with additional problems related to natural discharge, absorption, and absolute distance measurement. Voltage contrast observations for conductors or insulators have been reported [2]. However, since the resistance of an organic photoconductor (OPC) is not infinite, dark decay occurs, and the electric charge decreases with time. Measurements must be taken within a short time after the formation of the electrostatic latent image. We previously proposed a method of measuring an electrostatic latent image by detecting primary electrons or secondary electrons with high-resolution on the order of several micrometers [3,4]. In this method, since a static laser beam was exposed, our system was not able to measure the electrostatic latent image of the dot or line pattern formed on the photoconductor in the actual electrophotographic printing. We have therefore developed a new measuring device equipped with a laser scanning unit.

In this paper, we report the evaluation results of the latent image formed when changing various parameters of the laser scanning unit.

Measurement Principle

The measurement principle of the proposed method is shown in Fig. 1. When a charged photoconductor is exposed to light, electron-hole pairs are generated at the charge generation layer (CGL). Holes move through the charge transport layer (CTL), combine with electrons on the photoconductor surface, and disappear. As a result, an electrostatic latent image is formed on the photoconductor. When a primary electron beam hits the photoconductor, secondary electrons are generated. Secondary electrons generated in a charged area travel to the detector through an accelerating electric field. In contrast, secondary electrons generated in the exposed area are pulled back to the photoconductor. The exposed and charged areas are determined in this way. However, the photoconductor has dark decay, requiring measurements to be performed within a short time following the formation of the electrostatic latent image.

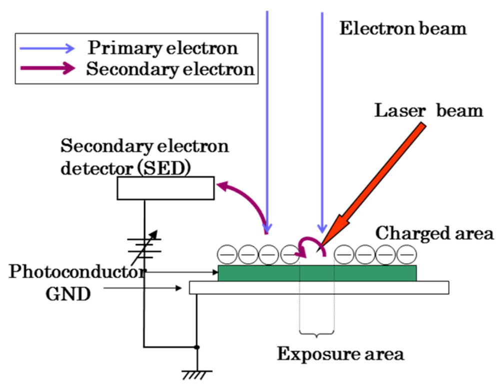


Figure 1. Measurement principle.

The feature of our method is that the charging, exposure, and detection devices are all incorporated in the same system, making real-time measurement possible. Moreover, we have developed the measuring device equipped with the laser scanning optical unit in order to measure the electrostatic latent image of the dot or line pattern formed on the photoconductor in the actual electrophotographic printing.

Scanning Exposure Method

Figure 2 shows the layout of the laser scanning unit (LSU). A pair of LDs is used as the light source of the LSU. The LSU is composed of this light source unit, a collimator, an aperture, a cylinder lens, scanning lenses, a mirror, a synchronization detection means, and polygonal mirrors that acts as an optical deflector. The LSU also includes a shutter, which shields against the offset emission by the bias current of the LD.

The light flux emitted from the LD is converted into a parallel laser beam by a collimator lens. Next, the laser beam passes through an aperture and is deflected by the rotating polygonal mirror. It is then focused on a photoconductor by condensing lenses.

Each of the scanning lenses has an *f-θ* property, and is configured to move the laser light at a substantially constant speed relative to an image plane on the photoconductor while rotating the polygonal mirror at a constant speed. The LSU makes the beam spot diameter substantially constant in the image plane.

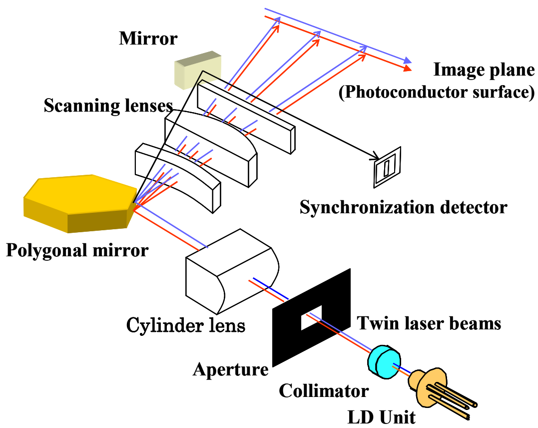


Figure 2. Laser scanning unit (LSU).

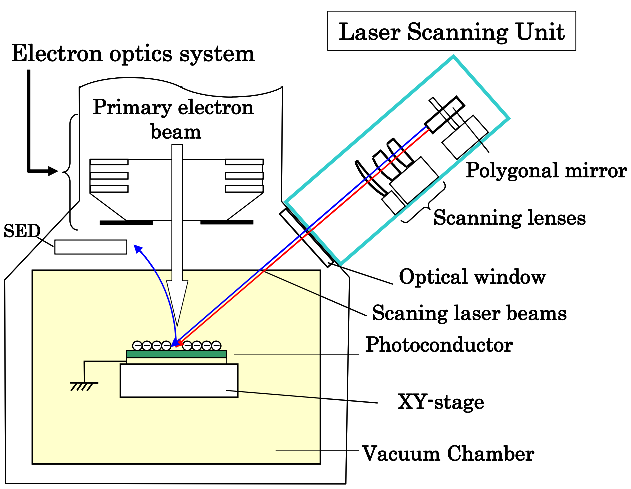


Figure 3. Electrostatic Latent Image Measuring System (ELIMS) equipped with LSU.

A sectional view of the Electrostatic Latent Image Measuring System (ELIMS) equipped with the LSU is shown in Fig. 3. The key feature of this method is that the laser scanning unit is arranged outside the vacuum chamber. The vibration and the electromagnetic field interference of a polygon motor do not affect the orbit of the electron beam because the polygon motor is kept away from the electron optics system. An entrance window functions as both an optical high precision plane and as vacuum shielding.

The laser beam enters at an incident angle of approximately 45 degrees relative to the sample in order to prevent interference between the electron beam path and the optical components. As a result, the beam diameter of the sub-scanning direction is the square root of 2 times as large as that of vertical image plane. The desired beam spot diameter can be determined by adjusting the aperture size in order to correct the tilt of the image surface.

This system makes it possible to form the latent image of arbitrary picture patterns with a maximum of two lines in the sub-scanning direction by use of twin beam.

The main specifications of the LSU are listed in Table 1. This LSU can set exposure parameters—exposure energy, duty, a starting position, a side-lobe peak and a dot-pattern, etc. —via computer control of the LD driver. The line spacing of a twin beam can be changed to the equivalent of 600 or 1200 dpi or even higher density.

Table 1 Specifications of laser scanning unit.

Wavelength	655 nm
Beam number	2
Image density	600, 1200 dpi
Exposure energy	Maximum 10 mJ/m^2
Duty	1/32 pixel step
Starting position to draw	1/16 pixel step
Side-lobe peak	4.8 to 20 %

Charging Method

In general, the charging devices used in electrophotography make use of corona discharge. Since this method cannot be used in a vacuum, a charging system based on electron-beam irradiation was adopted. Secondary electrons are emitted when an electron beam hits a dielectric [5]. Directly after the commencement of electron-beam irradiation, an electric charge begins to rapidly accumulate, and as time progresses, primary electrons begin to decelerate due to the negative charging potential of the sample.

Figure 4 shows the secondary electron emission characteristics [3]. The horizontal axis typically expresses accelerating voltage, but here, it expresses landing voltage V_L in order to take into consideration the influence of electric charge accumulation. At landing voltage V_L corresponding to $V_{\delta=1}$, no charging occurs and the system maintains a balanced state. When secondary-electron emission coefficient δ is less than 1, negative charging occurs, and when δ is greater than 1, positive charging occurs.

Accumulated charge density Q is given by

$$dQ \;/\; dt \;=\; Ip\left(1-\delta_t\right), \tag{1}$$

where Ip is incident current of primary electrons and δ_t means that a secondary-electron emission coefficient changes with time [6]. Assuming δ_t to be approximated by the linear function shown in Fig. 4, δ_t is represented by

$$\delta_t = -a \times \left(V_L - V_{\delta=1}\right) + 1, \tag{2}$$

where parameter a is positive.

Now, substituting Eq. (2) into Eq. (1) yields

$$Vs(t) = (Vacc - V_{\delta=1})\{1 - \exp(-\alpha t)\} \quad (3)$$

where $\alpha = a \cdot Ip / C$ and $Vs(0) = 0$.

Charging potential $Vs(t)$ was theoretically derived from the charging mechanism. $Vs(t)$ rises rapidly but becomes saturated. $Vs(t)$ can be expressed as an exponential function. Saturated charging potential depends on the accelerating voltage.

In the proposed method, we purposely make use of this charge-up phenomenon, which should generally be avoided. By intentionally setting the accelerating voltage to greater than $V_{\delta=1}$, the electrons accumulate in the photoconductor, causing the sample to charge up. As a result, the photoconductor can be negatively and uniformly charged.

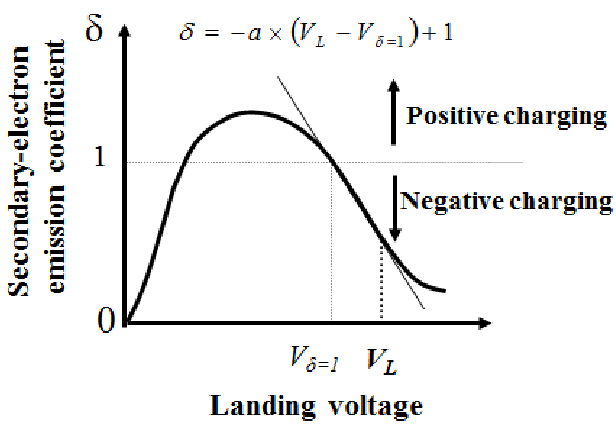


Figure 4. Secondary-electron emission characteristics.

Experimental Results

The beam diameter measurement results by the developed LSU are shown in Fig. 5. The horizontal axis shows the distance from the photoconductor position in the optical axis direction and a vertical axis shows the beam spot size measuring result of a main-scanning direction. In the main-scanning direction, the twin beam has almost overlapped.

Figures 6 and 7 show the measurement results of the latent image formed by scanning laser beam exposure under the 600 dpi condition. The sample was an OPC with a film thickness of 30 µm.

The exposure light source was an LD with a wavelength of 655nm. The laser beam was a spot size with a H60 × V80 µm elliptical beam. The LD signal had a duty cycle of 50% and the charging potential was –800 V.

Latent images of both 1-dot and 2-dot repetition patterns were observed, as shown in Fig. 6. The 2-dot patterns of Fig. 6(b) were exposed under the conditions using the same polygonal surface. This was made possible by using the twin beam to form various latent image patterns (i.e., isolated 2-dot or 2-line patterns).

The measurement results of the isolated 1-dot and 1-dot repetition patterns are shown in Fig. 7. All other exposure conditions excluding the dot-pattern were constant. The horizontal axis represents exposure energy density and the vertical axis represents the circle equivalent diameter of a latent image. These results show that the latent image area of an isolated dot is larger than that of a dot repetition when the LD light intensity is equal.

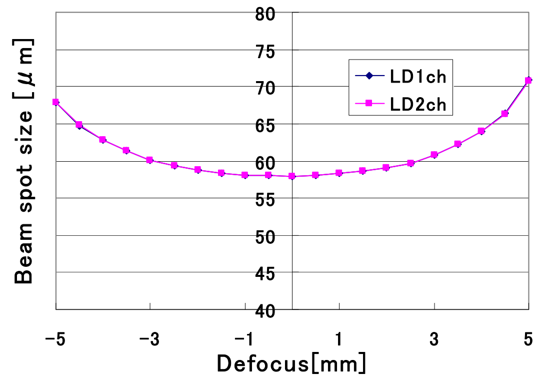


Figure 5. Measurement results of beam spot size of main-scanning direction.

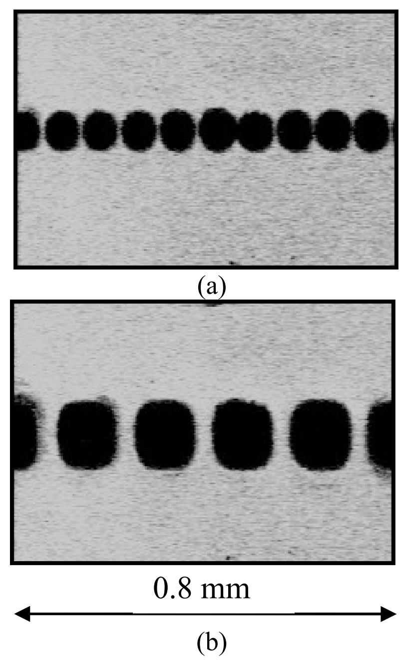


Figure 6. Measurement results of dot patterns formed by scanning laser beam: (a) 1 by 1 and (b) 2 by 2.

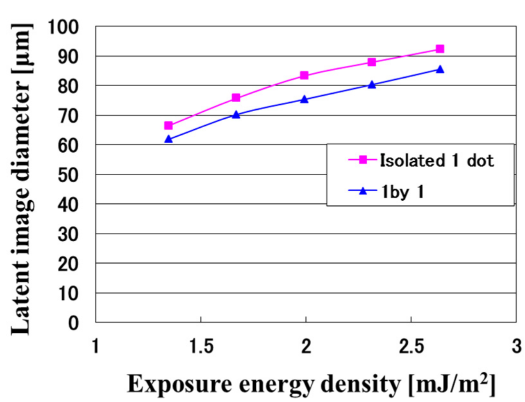


Figure 7. Measurement results of latent image size for dot-patterns.

We experimented to investigate the influence of the beam profile to a latent image. In general, a beam diameter is defined as $1/e^2$, i.e., 13.5% of main-lobe intensity, since the $1/e^2$ width is important in the mathematics of Gaussian beams. However, the beam profile does not strictly have a pure Gaussian beam profile in actual electrophotography but rather a side-lobe profile. Figure 8 shows the beam profile designed by the special aperture. Type 1 and Type 2 have the same main-lobe diameter, but the side-lobe peak of Type 2 is different from that of Type 1. We checked whether a latent image can be visualized when the side-lobe intensity is less than $1/e^2$ of the main-lobe intensity.

Figures 9 show the latent image measurements of the side-lobe intensity. The side-lobe peaks were 7.8% and 12.3% of the main-lobe peak. When the side-lobe peak was 12.3%, the latent image could be remarkably visualized, and even if it was just 7.8%, it could still be visualized somewhat. We found that the latent image is sensitive to the exposure energy when the side-lobe peak is greater, which ultimately degraded the reproducibility of a latent image. This highlights the importance of using high quality printing to carry out the optimization design of the side-lobe.

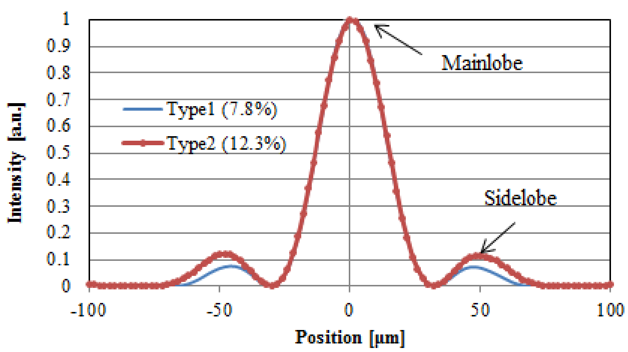
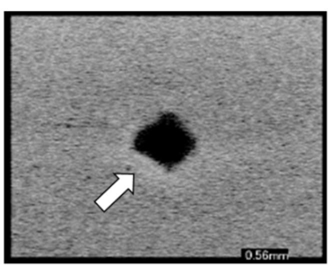
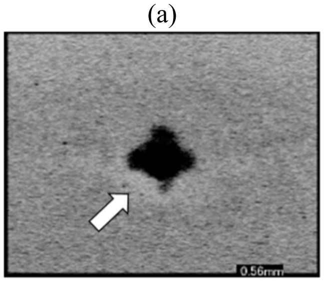


Figure 8. Side-lobe beam profile used for the experiments.



(a)



(b)

Figure 9. Electrostatic latent images: side-lobe peaks of (a) 7.8% and (b) 12.3% of main-lobe peak. Beam spot size was H45 × 50 μm. Charging potential was –600 V.

Conclusions

We have devised a scanning exposure method in a vacuum and have developed an electrostatic latent image measuring system equipped with a laser scanning unit. The laser scanning unit is arranged outside a vacuum chamber. The vibration and electromagnetic field interference of a polygon motor do not affect the orbit of the electron beam because the polygon motor is kept away from the electron optics system. A pair of laser LDs is used as the light source of the laser scanning unit, enabling it to scan a maximum of two lines in the sub-scanning direction. Arbitrary latent image patterns can easily be formed by using the laser scanning unit. The laser scanning unit also includes a shutter, which shields against offset emission by the bias current of the LD. The proposed system was able to obtain measurement results that provide valuable information on latent image characteristics for exposure conditions, including LD power, side-lobe intensity, exposure starting position, and various dot patterns.

This system has great potential for use in the optimized design of electrophotography because it can clarify the cause-and-effect relationship between exposure, photoconductor conditions and latent image formation.

References

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Author Biography

Hiroyuki Suhara received his Master of science and engineering degree from Waseda university in 1989 and started working at Ricoh the same year. He is currently working in the Imaging Engine Development Division, and is engaged in the research and development of methods for measuring optical elements and methods for analyzing electrophotographic process mechanism. His fields of expertise are optical interferometry and applied charged particle optics.