Laser Spot Size Measurements and Resulting Developed Toner Features

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Abstract

Laser spot size is critical to developed dot resolution in electrophotographic printing. Spot size measurements are correlated with actual discharged areas on a photoconductor surface as measured by developed toner image size. The resulting developed dot is then used to determine the optimum parameter for converting energy intensity measurements to actual developed toner features. Due to the effects of fringe fields on the discharged photoconductor surface, holes imaged into developed areas have different laser energy to developed area conversion rates than do dots in non-discharged areas, with holes requiring a larger unexposed area to reproduce the desired features. The 50% peak intensity metric was found to be superior to the 13.5% peak intensity metric.

Overview

Laser spot size is one of several key interrelated variables impacting print quality in EP systems. Print quality in EP printing as well as most other printing processes is most difficult when printing shadows (high coverage half tones) and highlights (low coverage half tones). Multiple attributes of the electrophotographic process contribute to the difficulty of these types of features. At the interface between the charge generation layer and the charge transport layer (CTL) there are significant energy losses due to the injection efficiency [1]. Free electrons are produced which drain off to the metal core. The holes which pass into the charge transport layer then migrate to the surface of that layer with some amount of image diffusion and result in a discharged area on the photoconductor surface. Some of the energy which enters the charge transport layer will remain trapped, further reducing and modifying the charge profile for development [2]. For these reasons the direct conversion from the optical spot delivered to the photoconductor and the discharged area to be developed are not identical. From the optics perspective, optical spot size is commonly measured at 50% of the peak intensity or at $1/e^2$ (13.5%) of the peak intensity, although the metric could be defined in other ways [3,4]. In EP, each of these metrics seeks to identify that critical part of the energy profile that best correlates with the actual print output.

If all laser spot shapes are ideal Gaussian then any intensity threshold, including 13.5% and 50%, can be used to completely describe the whole spot shape. Non-ideal spot profiles should present different actual developed areas and the threshold chosen to describe the spot would impact the correlation to developed dot size. If irregularities such as shoulders or lobes are present in the laser profiles near the size metric threshold, then a great impact can be observed. Additionally, an arbitrary spot size metric threshold will not be a good indicator of hole size with a sum of tail overlap that accumulates to a value near or above the toner development threshold. To address this question energy profiles from laser spots as registered on a rotating slit laser beam profiler were compared to the resulting developed toner image on a photoconductor. Since the development vector for toner in this situation is a significant contributor to developed toner dot size, the vector was adjusted to insure that the nominal operating point of the system resulted in the desired optical density of the half tone area. The goal of the work was to determine which spot size metric most closely resembles the developed high coverage and low coverage half tone sizes for electrophotographic printing situations. Fringe -field effects from discharged photoconductors make the appropriate spot size metric different for the two printing situations.

Laser Spot Size Measurements

Laser spots for electrophotographic systems do not have a binary energy output. Instead the laser energy hits the target, a photoconductor, with two spatial dimensions and an energy density dimension, generally in a Gaussian distribution. The high energy of the center of the laser spot rolls off to very low energy at the tails of the Gaussian curve. Toner does not develop onto the photoconductor in the same pattern. There is not a high density of toner at the center of the developed dot trailing out to an extreme edge of a few scattered developed toner particles. Instead the system acts much more like there is a threshold level of energy needed for toner development. Below that level no toner or only incorrectly charged toner develops and above that level full toner development is achieved. Fringe fields from the rapidly changing surface potential tend to pull toner together, and depending on toner properties, the toner developed on the photoconductor can be spread out loosely or pulled up into a tight packet.

To predict the width of the toner packet for product engineering development efforts, and to control product quality in

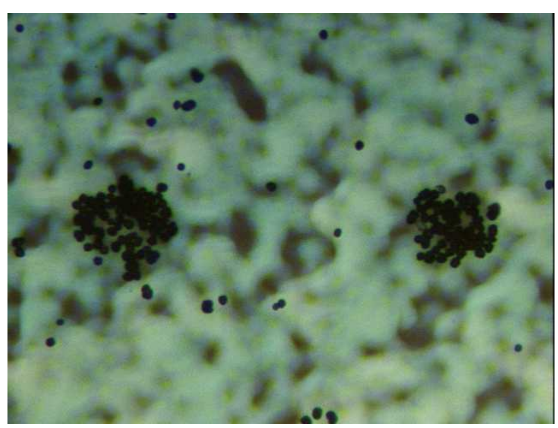

Figure 1*. Example of two single pel dots showing relatively uniform distribution of toner within each developed toner area, not a Gaussian distribution similar to the light energy distribution.*

production, laser spot intensity is measured as a function of distance from the peak laser intensity. The peak intensity is normally the center of the spot. At some energy level below the peak, the development threshold is considered to have been reached and the spot size is measured. Irregular laser shapes can make this determination more difficult, but for a Gaussian spatial distribution of energy this threshold is set by convention at either 50% of the intensity peak or at 13.5% of the intensity peak. The 50% intensity point for an ideal Gaussian curve represents the point on the curve of highest intensity rate of change, an inflection point for the first derivative. The 13.5% level represents $1/e^2$, an area which includes most of the intensity of the spot, but aims to exclude the tails that tend to have a lower signal to noise ratio.

The first step in this analysis was to characterize a Gaussian laser printhead to establish a baseline energy intensity as a function of scan and cross scan distance from the location of peak intensity. The measurement is made by either statically shining a laser spot at a rotating slit measurement device or dynamically shining the laser at a CCD array. In a static situation the laser spot is generally symmetrical in both the scan and cross scan axes. In a dynamic measurement the spot is measured while scanning over the CCD array, as would happen in an actual electrophotographic printer system. In this case the integration of the energy as a function of time yields a more oblong spot shape which can be backed out to estimate the static profile.

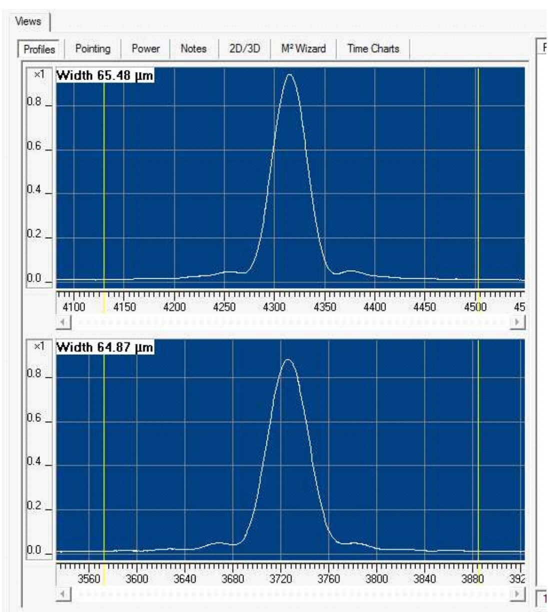

Figure 2. Example of static laser energy density profiles in scan and cross scan axes. Spot sizes in this example are given at a 13.5% threshold.

Development on the Photoconductor

After measuring the photon distribution itself, measuring the well formed pattern of developed toner on the photoconductor is a clear indicator of resulting discharge area and the next downstream process at which useful results can be easily obtained. A special print pattern was developed for this analysis that created multiple patterns of single pels being turned on and off to make 1 pel through 4 pel dots and holes though all combinations of location on a 2x2 grid. The pattern was repeated multiple times across the scan axis to check for edge vs. center effects.

The amount of toner developed onto the photoconductor, and therefore the dot size measured are a strong function of the developer roll and charge roll voltages. To address this issue a printer system already in production was used and these values were set to their mid-values and held there for all measurements. These values represent the level at which the downstream components would nominally have been operated to get the ideal dot size. The measurements were taken with black toner at rated speed and at lab ambient. To take measurements a special printer function was used that allows the printer to be stopped with minimal coasting. The printer was stopped in this fashion while printing the test pattern and measurements of developed dots and holes could then be made from the developed portion of the photoconductor surface.

Results

Undeveloped “hole” sizes are smaller for the same amount of laser intensity than are developed dots. This is shown in figure 3 below, which is a comparison of a 2x2 pel dot of developed toner next to a 2x2 pel “hole” or lack of laser discharge on the photoconductor. The smaller hole is in part due to the summing of energies of the eight overlapping laser spot tails surrounding the undeveloped holes. Holes are formed by the lack of laser energy density leaving undeveloped areas.

One convenient model is to describe the hole size by the proportion of an equivalent peak spot intensity, an inverse laser spot, that relates to the hole size. Undeveloped holes required about 50% of equivalent laser peak intensity in the scan axis and 70% of peak intensity in the cross scan axis to reach a toner development threshold. Developed dots on the other hand need about 25% of peak intensity in the scan axis and 40% of peak intensity in the cross scan axis to reach the development threshold. One consequence of this difference in spot vs. hole development threshold is that the shoulders, lobes and other harmonics of non-Gaussian spots tend to be more predominate at lower energy densities. The energy densities of these non-Gaussian features are closer to the development threshold for individual dots than the threshold for individual holes and therefore impact individual dots more than the individual holes.

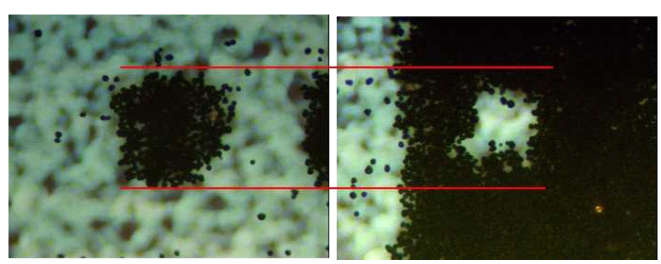

Figure 3. Example of 4 pel (2x2) dot and hole showing difference in development threshold. Both images are at the same magnification

Multiple field effects contribute to the threshold edge demonstrated in figure 3. Laser spot intensity distributions are generally Gaussian and not constant (top hat), therefore tails of nearby laser spots often overlap and combine to influence the charge density and developed toner image. Additionally, the toner itself is charged and is repelled by toner at a distance but attracted by toner at close range due to the fact that the charge resides on the surface of the toner, not at a point in the center. The toner therefore also creates an edge field which interacts with the fringe fields of the developed image and pulls the toner together. In the non-developed holes, the overlapping tails of the discharged laser spot appear dominant, as these features are significantly smaller than the dots created by the geometrically opposite laser energy profile.

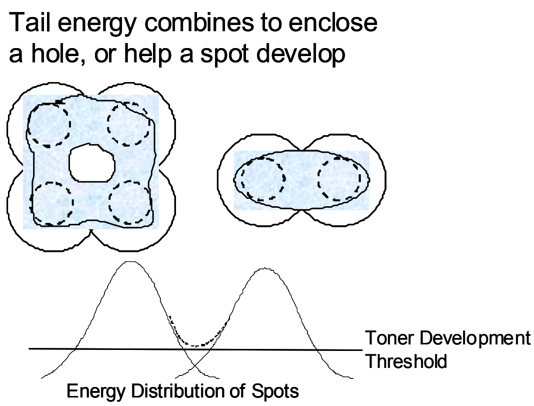

***Figure 4**. Example of a tail distribution of laser spots impacting development of "holes" and "dots". The pattern shown is an alternating, laser on for one pel, laser off for one pel, in one / two axes. The tail fields are additive, and if the development threshold is exceeded tail fields can extend the developed area.*

Single pel dots required 38% of laser peak intensity in scan axis and 46% of peak intensity in cross scan axis to develop the toner image. The scan direction for dots and holes has a threshold with a lower proportion of peak intensity because the laser spot is moving through in the scan direction and the energy is integrated over time increasing the energy density. For this reason the process direction is the more accurate dimension to compare peak intensity to actual developed dot size.

When a single pel location is left undeveloped by the laser and the surrounding locations were lased, the 8 adjacent pel locations all had some power from their tails on that pel "hole" location. This cumulative effect of the surrounding pels causes single pel holes to be smaller or in some instances non-existent. In these conditions, single pel holes did not develop well and so measurements could not be taken, even when the geometrically opposite energy profile developed dots were clearly visible.

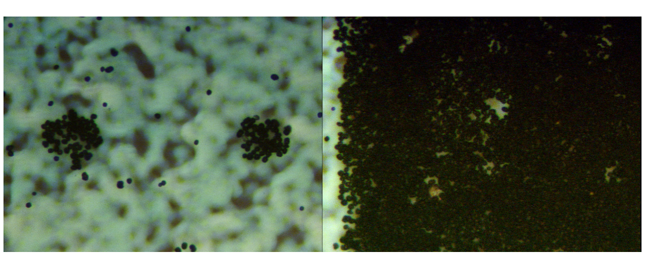

***Figure 5**. Example of two single pel dots on left and very little of a single pel hole on the right. Both images are at the same magnification.)*

When adjacent pel locations are lased the tails of the distributions overlap causing a higher energy density on the photoconductor drum than would be seen by lasing a single pel, therefore a lower percentage of peak laser spot power is required to develop toner. Comparing a single pel dot to a 2 x 2 pel pattern in the scan axis, the single pel requires 38% and the 2 x 2 pattern requires a lesser 25% because of the overlapping tails.

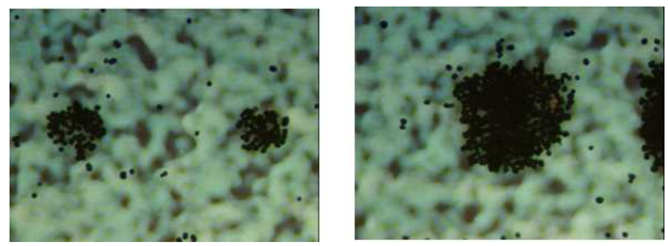

***Figure 6**. Example of two single pel dots on left and a 2 x 2 (4 pel) dot on the right. Both images are at the same magnification.*

Using the cross scan direction measurement, 40% intensity for dots and 70% intensity for holes suggests that a higher energy level measurement, like the 50% cutoff is more appropriate for current electrophotographic systems. Similarly in the less ideal scan direction the values were 38% and 50% for dots and holes respectively, and again the 50% metric is superior. This finding indicates that laser spot features at lower energy levels may not contribute significantly to print artifacts. It also highlights system energy inefficiencies in converting laser energy to developed area. Additionally, a different metric for printed dots and unprinted holes might be more useful to electrophotographic optics designers allowing them to better address difficult development scenarios.

Summary

This work compares the sizes of developed toner patterns on a photoconductor to common spot size metrics. Laser spot intensity profile was measured for the printhead, and then these measurements were compared to the developed dot size and hole size in the scan and process direction on the photoconductor. The resulting study showed that due to fringe field effects from the imaged spots, the size differed between "hole" and "dot" patterns and further variation due to pel orientation was also noted. The 50% peak intensity metric was found to be a much better indicator than the 13.5% peak intensity metric. This has implications to optics design and to printhead manufacture.

References

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Author Biography

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