Thermal Banding Analysis in Wide Format Inkjet Printing

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Abstract

A print quality problem encountered in wide-format inkjet printing is a type of solid-area non-uniformity referred to as "thermal banding." Thermal banding can be observed, for example, in a print in which a gray or colored border surrounds an area with little or no printing. Although the same tone is specified for all sides of the border, the print density of the top and bottom borders is relatively high, while the density of the side borders between the top and bottom bands is clearly lower. Current theory holds that thermal banding is related to the temperature inside the inkjet head. As the head prints a solid area, it heats up, causing larger drops to be produced. The large drops increase the print density. When a white or mostly-white area is produced, the head cools since little or no jetting occurs. The cool head produces smaller drops and lower print density results. This paper discusses thermal banding and shows how the problem can be quantified using a commercially-available, camera-based image analysis system. The efficacy of head temperature compensation schemes will also be quantified and discussed.

Introduction

Perhaps one of the most challenging test images to print is, paradoxically, one of the simplest; a large area filled with a uniform gray or mid-tone color. This is particularly true for digital printing systems. Laser printers (electrophotographic) have problems such as ghosting that are most noticeable in halftones[1]. They also have problems with banding due to mechanical tolerances causing subtle variation in halftone dot size or position[2]. Thermal transfer and dye sublimation printers have difficulties maintaining heating uniformity across the printhead width, causing variations in tones across the page width. Inkjet printers have jetting straightness problems (resulting in banding) that are most noticeable in a uniformly gray field[3]. In a visually busy image, these problems may go unnoticed (Hence the reason most print samples produced by printer marketing departments are very busy). But these problems frequently become both noticeable and objectionable if there is a large area of uniform color in a sample print.

For each printer type, to achieve good uniformity, the devil is really in the details. A good understanding of the technical details of the printing system is needed along with knowledge of the parameters that can be adjusted or parts that can be tweaked to achieve improved uniformity. These changes cannot adversely affect other needed aspects of product performance such as print speed or cost.

In this paper, a printing uniformity problem that can affect inkjet printers will be discussed. The problem is known as thermal banding and is primarily noticed in uniform gray areas that are printed near areas of black and white printing (this will be described in detail later). The problem is probably widely known in the inkjet printer industry, but little, if any discussion of the problem has been available in the open literature. In this paper, the nature of the problem, how it manifests itself, how it can be quantified, and what printing parameters reduce its severity, will be discussed.

Problem Description and Target Design

Examination of many different types of wide format inkjet test images (pictorial and graphic) revealed some areas that were supposed to be uniform in tone to have unwanted tonal variations. This examination led to the development of a test target designed to illustrate the problem. This target is shown in Figure 1 and sample prints are shown in Figure 2 and Figure 3

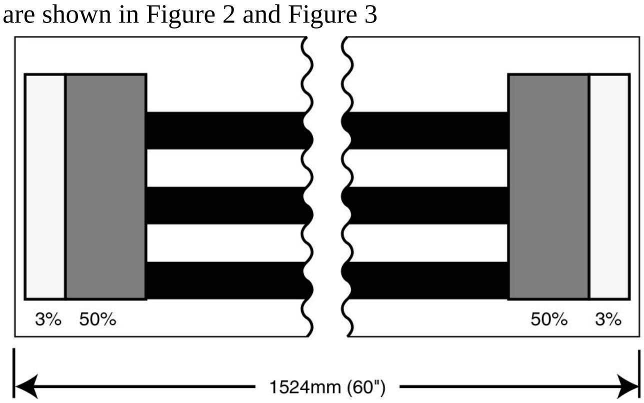

Figure 1: Test target designed to aid in quantifying the severity of thermal banding. The head prints when traveling from left to right (unidirectional) then advances the page up and prints again.

The middle section of the test target consists of long horizontal white and black stripes. On the left and right edges of the prints are vertical stripes of 50% dot coverage outside of which are vertical stripes of 3% dot coverage.

The 50% area is used to check for variations in density. The 3% area is used to check for dot size variation.

Figure 2: Sample scanned image of printed sample with thermal banding problem. (no thermal compensation employed)

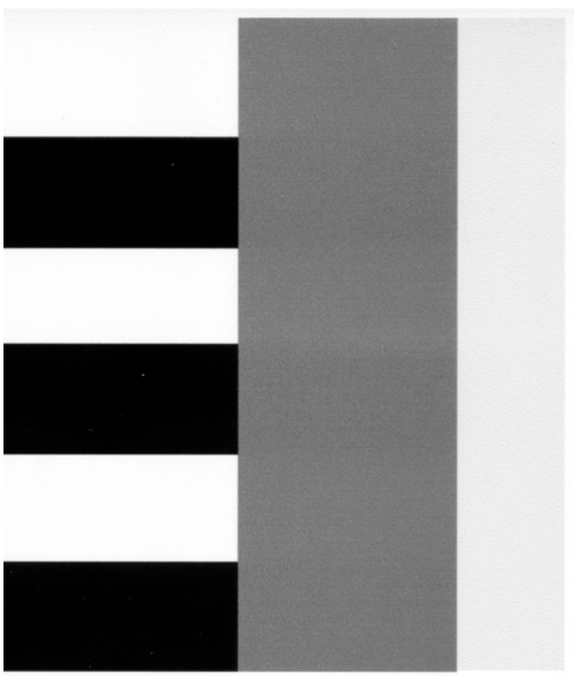

Figure 3: Sample scanned image of printed sample when thermal compensation is employed.

The thermal banding effect is shown by the differences between Figure 2, which has high thermal banding, and Figure 3, which has very little thermal banding. The 50% area following a black stripe is significantly darker than after a white stripe. This is not an optical illusion, as we will show later with instrumental measurements. Note that this sample was generated employing exaggerated printing conditions in order to illustrate the defect.

Table 1: Printing Conditions

Sample	Thermal Compensation	UNI/BI	speed
Sample 1	ON	BI	1
Sample 2	ON	BI	10
Sample 3	OFF	BI	10
Sample 4	OFF	BI	1
Sample 5	OFF	UNI	1
Sample 6	OFF	UNI	10
Sample 7	ON	UNI	10
Sample 8	ON	UNI	1

Test and Measurement Method

A simple matrix experiment was devised to demonstrate the factors affecting thermal banding. The experiment consisted of printing the test target shown in Figure 1 under a range of printing conditions on an experimental ENCAD wide-format thermal inkjet printer. The test conditions are shown in Table 1. Eight samples were printed. The thermal compensation refers to the use of heaters inside the print head to aid in the control of the ink temperature. The UNI/BI refers to whether unidirectional (printing only when the head moves from left to right) or bi-directional printing was used. The print head speed was adjusted to either 1 or 10 (arbitrary units).

Analysis of the severity of the thermal banding was determined using a commercially available automated image analysis system (IAS-1000, QEA, Inc.). A reflectance profile was measured in the 50% dot coverage area on the right side of the page. The profile averaged together a 5mm wide region in the center of the 50% stripe. The measurements were made on the right side of the page only, because this area represents the worst case (with one exception to be noted later in the paper).

In addition to the reflectance profile measurements, dot size measurements were made. The measurements were made at twelve locations within the 3% area following each of the three black and three white stripes, i.e. two measurements made after each stripe. The area examined by each measurement was 5×4mm.

Results

Severe thermal banding was produced under certain test conditions. In some samples the reflectance in the gray area following a black stripe was as much as ten reflectance units darker than following a white stripe, as shown in Figure 4. This was the result of significant increase in dot size as shown in Figure 5.

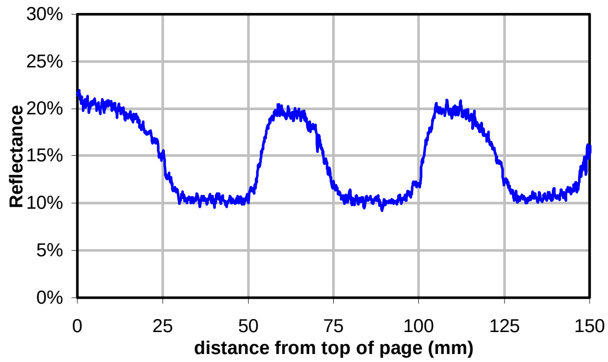

Figure 4: Typical reflectance profile from the 50% dot coverage area. Location 0mm is the top of the 50% area. Data is from Sample 6.

The testing demonstrated a significant difference in banding severity among the samples, as can be seen in the data in Table 2. In this table, good uniformity (low banding) is indicated by smaller differences between the diameter of the dots following the white and black stripes. It is also indicated by smaller differences in reflectance values following a white stripe versus a black stripe.

To reveal the main effects of the printing parameters (speed, print mode, heater condition), the data from prints with the same printing parameters were averaged together. The averaged data is shown in Figure 6. This is a common technique used in DOE (design of experiments) and Taguchi testing.

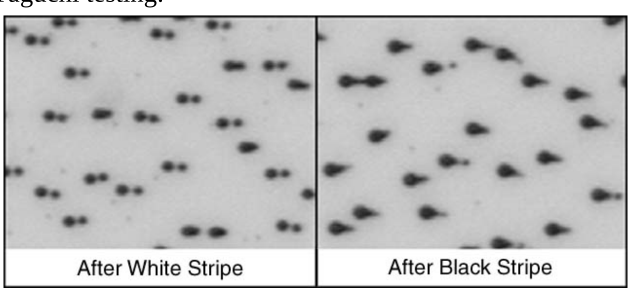

Figure 5: Images of dots from the 3% dot coverage region after printing a white horizontal stripe (left) and a black horizontal stripe (right).

Utilizing the heaters in the printhead to control the printhead temperature has the largest effect on thermal banding. The results demonstrate that the use of the heaters reduces the reflectance difference from an average of 5.8% to 1.7%. More consistent ink temperature leads to more consistent ink viscosity and drop volume.

Table 2: Averaged dot diameter measurements from the 3% area and averaged reflectance measurements from the 50% area.

	heater	Mode	speed	White dia. (µm)	Black dia. (µm)	diff. dia. (µm)	Reflect. After White	Reflect. After Black	Refl. diff.
1	ON	BI	1	88.6	91.3	2.7	14.9%	13.6%	1.2%
2	ON	BI	10	94.5	95.9	1.4	12.7%	11.1%	1.6%
3	OFF	BI	10	87.7	94.9	7.2	15.9%	11.4%	4.5%
4	OFF	BI	1	81.9	89.9	8.0	18.8%	14.7%	4.1%
5	OFF	UNI	1	81.9	92.5	10.6	18.9%	13.1%	5.9%
6	OFF	UNI	10	79.1	97.4	18.3	19.3%	10.5%	8.8%
7	ON	UNI	10	97.1	99.6	2.5	12.5%	9.9%	2.6%
8	ON	UNI	1	89.1	92.1	3.0	15.4%	14.0%	1.4%

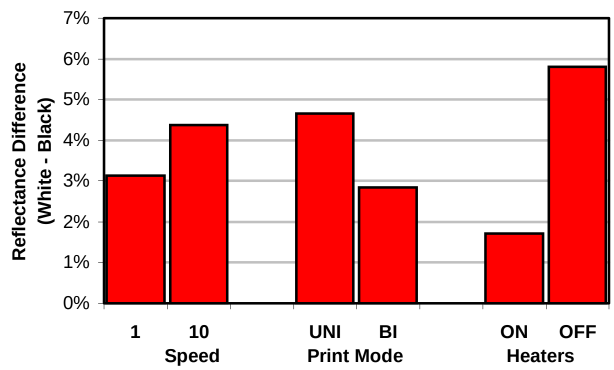

Figure 6: Main effects of changing printing parameters.

The second most important factor was the printing mode: unidirectional versus bi-directional printing. The root cause of this difference is not immediately obvious. Lets look at the reflectance values for samples 3 and 6 (Table 2). After the white stripe, the 50% area for the uni-directional printing is lighter (19.3%) than that produced during bi-directional printing (15.9%). After the black stripe, the unidirectional printing is darker (10.5%) than the bi-directional printing (11.4%). The unidirectional printing produces a larger difference in reflectance in both cases.

This difference is caused by printing history. During uni-directional printing, the 50% area after the black stripe is always printed after printing 100% black for a distance of 1270mm (50inches). During bi-directional printing, this is true only half the time. During the other half of the printing cycle, the head first prints 50mm of 50% dot coverage and 25mm of 3% coverage; after which, it reverses direction and prints the area in reverse order. This causes the temperature of the printhead to decrease slightly, producing smaller drops which leads to lighter prints.

Now consider the situation after a white stripe has been printed. During unidirectional printing the 50% area is always printed after printing nothing for a distance of 1270mm(50inches). During bi-directional printing this is the case only half of the time. During the second half of the printing cycle, the head first prints 50mm of 50% dot coverage and 25mm of 3% coverage; after which, it reverses direction and prints the area in reverse order. This causes the temperature of the printhead to increase slightly, producing larger drops which leads to higher density.

Another point about unidirectional versus bi-directional printing is an issue of symmetry. In unidirectional printing, the right side of the page exhibits more thermal banding than the left. In bi-directional printing, the thermal banding is about equal on both sides of the page. In the case of our experimental apparatus, it matters which side of the image is being measured for thermal banding. In the case of this study, only the right side is being quantified because it exhibits the highest degree of thermal banding.

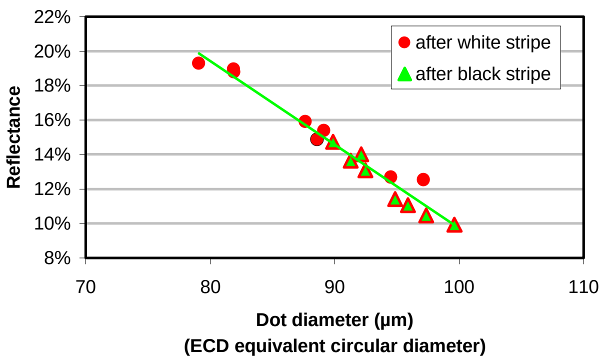

Figure 7: Relationship between dot diameter in 3% area and reflectance in 50% area.

The least important factor, in terms of its effect on thermal banding, was print speed. At higher speed, more energy per unit time is consumed in the head to fire the nozzles. This results in higher head temperature during black stripe printing under high speed (10) compared with low speed (1). After printing a white stripe, the head cools to about ambient temperature regardless of print speed, resulting in similar print density after printing a white stripe, compare reflectance values after the white stripe for samples 5 and 6 in Table 2. Printing at high speed produces a higher temperature after printing a black stripe compared with low speed printing. This results in higher print density following a black stripe at high print speed compared with low speed. Again compare samples 5 and 6 in Table 2.

As expected, there is a strong correlation between the drop diameter measured in the 3% area and the reflectance value measured in the 50% area, see Figure 7.

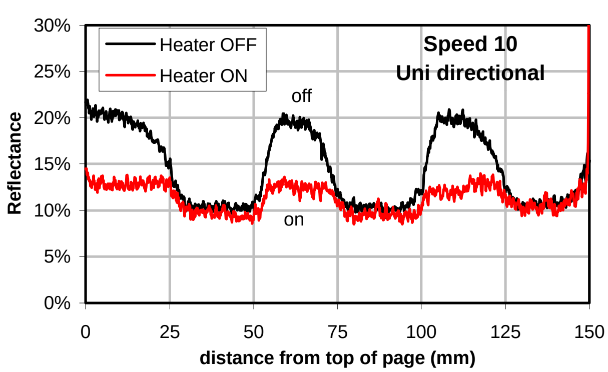

Figure 8: Reflectance profiles with and without using heaters.

The effectiveness of the employment of the printhead heaters is illustrated in Figure 8. Even under the worst printing conditions, unidirectional printing, speed 10, the reflectance difference is limited to about 2.6%. While 2.6% reflectance difference might still be noticeable in a print, bear in mind that this test print is the most extreme test condition; long horizontal black and white stripes at just the right width to aggravate the effect. For most real prints, the effect will probably be unnoticeable.

Conclusions

Thermal banding, a source of large area print non-uniformity in wide format thermal inkjet printers, has been described. A test target has been developed that highlights the problem. A range of printing conditions were utilized in order to study their effect on thermal banding. The most important factor in reducing thermal banding was the use of the printhead heaters. The use of these heaters reduced reflectance differences in a gray area from an average of 5.8% to 1.7% reflectance.

References

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Biography

Dr. John C. Briggs joined QEA in January 1998. He is responsible for new product development and application research. He is the author of numerous technical papers on digital printing and print quality. Previously at Iomega Corporation, he was a key contributor to the design and development of the Zip™ drive. Dr. Briggs holds eleven patents. He received his BS, MS, and PhD degrees in Mechanical Engineering from the Massachusetts Institute of Technology.