Image Quality and Modeled Pixel Placement Errors Caused by Paper Feed Roll Tolerances

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Abstract

In the development of printing systems, tolerances on feed rolls are a cost-quality trade-off. Tighten the tolerances and the manufacturing costs increases. Loosen the tolerances and the quality degrades. Following the framework put forth by Engeldrum's Image Quality Circle, the paper details a model of paper feed roll tolerances effects on paper advance and image quality defects. It shows how the multi-scanline writing systems such as ink jet printers are more sensitive to larger tolerances than the single scanline writing printing systems used in electrophotography. The model also shows the relationship between the feed roll tolerances and system imaging/design parameters on paper advance errors. And lastly, simulations of images containing pixel placement errors caused by the feed roll tolerances are shown.

Introduction

The development of a printing device and its image quality are dependent on many factors, one of which is the placement accuracy of the pixels within an image. The introduction of pixel placement errors can come from many sources. This is exemplified by the plethora of work published on pixel placements errors such as banding and it's perception.[1-5] However, one source of pixel placement errors which is rarely discussed in the literature, is the manufacturing tolerances on the paper feed or advance roll. These manufacturing tolerances require a trade-off between cost and quality: Tighten the tolerances and the manufacturing costs increases; loosen the tolerances and the quality degrades.[6]

Engeldrum's Image Quality Circle,[7] IQC, gives us a framework to conceptualize how feed roll tolerances effect the perception of image quality defects. First we have a set of technology variables; in the case of the feed roll it is the roll run out (the variation of the roll's radii over all angles) or the bias (errors in the location of the rotational center of the roll). These technology variables effects IQC's Physical Image Parameters by causing pixel placement errors associated with the distance the printing media is moved by the feed roll. And when the print is viewed, defects such as image noise, banding, raggedness, and streakiness are perceived, thus creating the impact on the IQC's Customer Perceptions. This paper details the development of a computer simulation model of each these aspects of the Image Quality Circle for paper feed roll tolerances.

The Model

In developing a model of pixel placement errors caused by the paper feed roll, the following assumptions are made:

1. Pixel placement errors are solely the cause of the feed roll tolerances
2. The pixel placement errors have a low spatial frequency

The model developed adds a sinusoidal error to the radius of the roll. The radius at any given angle can be defined as:

$$r'(i) = r_0 + a\left[\sin(\phi + \theta_i) + b\right] \tag{1}$$

Where, $r'(i)$ and r_0 represent the roll's radius at angle θ_i, with and without the error respectively, a is the amplitude of the sinusoidal error introduced, ϕ is the phase offset of the error, θ_i is the instantaneous angular location on the feed roll, and b is a bias term used to shift the center of rotation of the roll.

The distance that a feed roll moves the printed media, L, is the arc length between two successive points on the roll. These two points are determined by the nominal angle that is required to produce the nominal advance using the nominal feed roll radius. Thus the advance on a feed roll with a radial profile characterized by Eq. (1), is the arc length, L, between two successive samples, $r'(i)$ and $r'(i+1)$ or θ_A and θ_B, respectively. By integrating Eq. (1) over θ and evaluating the result between θ_A and θ_B, the advance distance, L, can be written as:

$$\begin{aligned} L = {} & r\theta_B - a\cos(\phi)\cos(\theta_B) + a\sin(\phi)\sin(\theta_B) + ab\theta_B \\ & - r\theta_A + a\cos(\phi)\cos(\theta_A) - a\sin(\phi)\sin(\theta_A) - ab\theta_A \end{aligned} \tag{2}$$

Model Implementation

A computer model was implemented using National Instrument's LabVIEW version 6.1 for Microsoft

Windows. The model calculated the placement error for every advance of the media based on the parameters chosen. Once the placement errors were calculated, images were simulated and rendered in PostScript using the advance errors calculated in LabVIEW.

Results

Technology Selection

The impact of paper feed roll tolerances have been found to be different dependent on the marking technology used by the printing system. Figure 1, shows the difference between a system that writes or prints a single scanline of the image at a time, such as used in Electrophotographic printers, and, a system that writes multiple scanlines at a time such as Ink Jet printers.

It is seen by Figure 1, that the same roll produces an error that is over 50 times greater in a multiple scanline writing system than a system that writes a single scanline at a time. Thus it is concluded that multiple scanline systems are more sensitive than those writing a single scanline at a time. Due to this higher sensitivity to feed roll tolerances, the remainder of the paper will concentrate on multiple scanline writing systems.

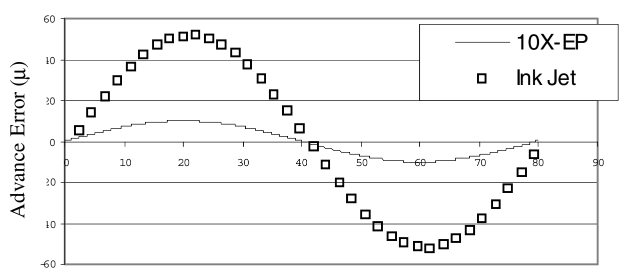


Figure 1, Relative advance errors of a feed roll with 300 microns amplitude error and 0 bias placed in a 600 DPI Electrophotographic system (shown at 10 times the error) and a 600 DPI Ink Jet system printing in two passes

The Effects of Bias

The effect of the bias term was also investigated. Figure 2, shows the effect of bias on the pixel placement errors caused by the bias tolerance. These results depict the pixel placement error produced by a 600 DPI printer having a one-inch diameter feed roll having 100 µ sinusoidal amplitude error. The three lines from the topmost line down represent a bias of 1.0, 0.0 and –1.0. The net effect of the bias is to systematically introduce a scale magnification error, which for this example, is approximately ±600 µ for every rotation of the feed roll depending on the sign of the bias. Thus as the bias approaches one, the advance errors are all over-advances. As it approaches negative one, the distribution of paper advances are all under advances. Thus when the bias is zero, errors are evenly distributed between over and under advances. As the bias term only shifts the distribution, the remainder of the paper will be constrained to work with biases of zero.

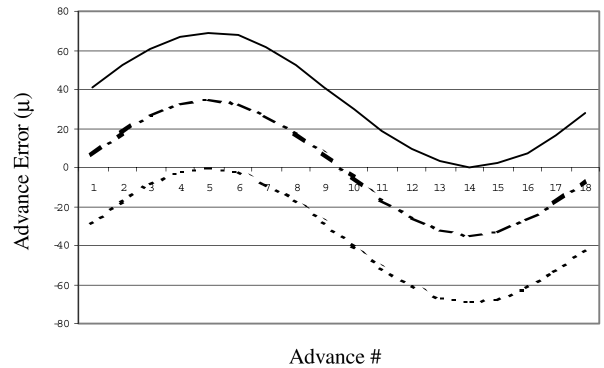


Figure 2. The effects of bias on the paper advance error.

Sinusoidal Amplitude Error

The last of the technology variables to investigate is the Amplitude of the sinusoidal error, *a*, in Equation (1). To investigate these effects, three parameters to the model were varied. The varied parameters were: The nominal feed roll diameter; The number of print passes required to form the image; And the error's sinusoidal amplitude, *a*. The standard deviations of the paper advance distributions are used to characterize each tested condition. The results are shown below in Table 1.

Table 1, Advance Error (σ) from varying the system parameters of the number of passes, nominal feed roll diameter and sinusoidal error amplitude, a.

		Passes Required to Form the Image			
Roll Diameter	A (µ)	1	2	4	8
1”	100	22.7	12.5	6.2	3.1
	200	50.4	24.9	12.4	6.1
	250	63.0	31.1	15.5	7.7
	300	75.6	37.4	18.6	9.2
	400	100.7	49.8	24.8	12.3
	500	125.9	62.3	30.9	15.4
2”	100	12.5	6.2	3.1	1.5
	200	24.9	12.4	6.1	3.1
	250	31.1	15.5	7.7	3.8
	300	37.4	18.6	9.2	4.6
	400	49.8	24.8	12.3	6.1
	500	62.3	31.0	15.4	7.7
3”	100	8.3	4.1	2.0	1.0
	200	16.5	8.2	4.1	2.0
	250	20.7	10.2	5.1	2.6
	300	24.8	12.3	6.1	3.1
	400	33.1	16.4	8.2	4.1
	500	41.4	20.5	10.2	5.1

To see the relationship of these parameters, a least squares model was used to predict the relationship of these parameters to the standard deviation. The resultant equation was determined using linear regression having an r^2 value of 0.98 and a residual standard error equal to 3.478 microns on 64 degrees of freedom.

$$\sigma = -0.0744a - 45.6923\varphi - 35.2282\omega + 0.1199a\omega + 75.611\varphi\omega + 0.1554a\varphi \tag{3}$$

where σ represents the one standard deviation value of the distribution of advance errors in microns for a given set of parameters: *a* is the amplitude of the sinusoidal error associated with the roll's radii; φ, is the reciprocal of the number of passes used to print; ω, is the reciprocal of the roll's diameter in inches.

Image Quality Artifacts

System Emulation

Finally, the "nesses" of the Image Quality Circle were examined. The perceptions of the defects are presented here using simulated images. Images were generated based on a 600 DPI printer having a 60 and 80-micron spot size. Advance errors calculated by the model above generated the errors. These were then incorporated into a PostScript printing model and rendered at 9600 DPI into a bitmap. For the purpose of this paper we investigated the feed roll tolerances effects on checkerboard patterns and eight pixel lines. Additionally, only a multiple scanline printing system was simulated due to its higher sensitivity to feed roll tolerances than those systems writing one scanline at a time.

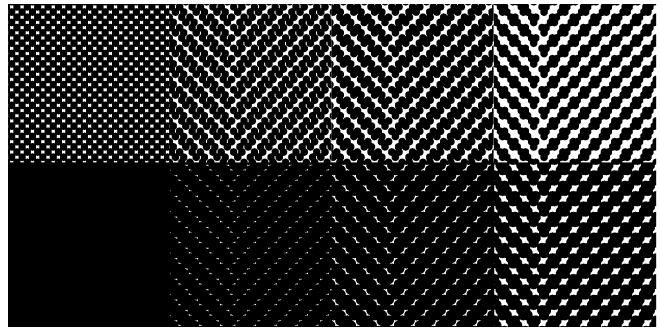
The simulated printing system had the additional characteristics of: The ability to print 104 scanlines at a time; with a nominal scanline spacing of 42.3 microns; And the ability to print in multiple passes to create the image.

Checkerboard Pattern

A checkerboard pattern was simulated changing the roll diameter and keeping the sinusoidal amplitude error constant. Figure 3, shows the results of a simulated checkerboard pattern printed in four passes (each image is rotated 90 degree).

This figure shows eight simulated images in a grid. The rows of the grid represent different spot sizes (60 μ, in the top row and 80 μ, in the bottom row). Each row is comprised of four images, a perfect rendition (a), a three-inch (b), two-inch (c) and one-inch (d) diameter rolls each with 300 μ sinusoidal amplitude error. The σ, standard deviation, of the each of the patches are 0.0, 6.1, 7.7 and 18.6 microns for patches (a), (b), (c) and (d) respectively.

As seen by Figure 3, the errors in the paper advance introduce defects into the microstructure of the image. Two defects stand out. The first is a periodic pattern that appears to change direction at the location where the advance and the start of the printing array coincide. A streak begins to also becomes more noticeable as the roll diameter decreases at this junction. By increasing the spot size the defects are masked and become less noticeable.



(a) (b) (c) (d)

Figure 3. 50% Checkerboard Pattern Quality (rotated 90 degrees). Simulated micrographs. The top row printed with a 60 μ while the bottom used an 80μ spot. (a) Perfect, (b) three inch roll diameter, (c) two inch roll diameter and (d) one inch roll diameter all having 300 μ sinusoidal amplitude error on the radii

Lines

The image quality associated with lines degrades as the feed roll tolerances increase. The effect of increases in the feed roll tolerance on a line produces an increase in jagged edges as seen in Figure 4.

(a) (b) (c) (d) (e) (f)

Figure 4, Line Edge Quality of Lines Parallel to the Advance Direction (here rotated 90degrees). Simulated 600 DPI printer using a 3 inch diameter feed roll and (a) 100, (b) 200, (c) 250, (d) 300, (e) 400 and (f) 500 micron error amplitude.

The progression depicted by this figure was created by increasing the roll's sinusoidal amplitude error from 100 microns to 500 microns while holding the nominal roll diameter constant at three inches. The σ, standard deviation, of the each of these lines are 2.0, 4.1, 5.1, 6.1, 8.2 and 10.2 for lines (a), (b), (c), (d), (e) and (f) respectively. The resultant image quality defects caused by the introduction of these sinusoidal amplitude errors are increases in periodic structure along a lines edge or its jaggedness.

Conclusions

This paper describes the development of a simulation model of paper feed roll tolerances following the framework put forth by Engeldrum's Image Quality Circle. It shows how the technology variables, the tolerances on the feed roll, affect the physical imaging parameters, the paper advance errors. And then how the final link in the imaging chain, the customer perceptions are affected by defects induced by the physical imaging parameters.

Physical image parameters were investigated from several perspectives. Depending on the printing system's marking technology the magnitude of the advance errors can be over 50 times greater for systems that write multiple scanlines at a time (i.e. ink jet) versus those systems that write one scanline at a time (electrophotography). The model showed that the introduction of a shift in the rotational axis (adding a bias) shifts the distribution of advance errors introducing magnification errors down the printed page. These magnification errors were shown to be as much as two percent shrinkage or growth coincident with the sign of the bias. In addition, the model predicts that as the amplitude of the sinusoidal error tolerance on the feed roll increases, pixel placement error tended to increase. However by changing other system parameters such roll diameter, the pixel placement errors can be reduced.

Customer perceptions were shown via simulated micrographs of the image microstructure of checkerboard and line test patterns. Shown in these images are how placement errors caused by paper feed roll tolerances introduce image quality defects such as periodic structure, streaks and edge jaggedness.

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Biography

Steven J. Bloomberg founded CISTech in 2001. CISTech is a consulting and R&D firm specializing in the application of imaging and color science to the novel usage of imaging systems. Prior to forming CISTech, Mr. Bloomberg was with the Xerox Corporation for 15 years having responsibilities in the design and development of the imaging chain used within their electrophotographic and ink jet products, as well as, developing a image quality metrics and measurement facilities. He holds four patents in the field of image processing and has authored several papers on pixel placement errors and image quality. In 1986 Mr. Bloomberg received a Bachelor of Science degree in Imaging Science from the Center for Imaging Science at Rochester Institute of Technology.