One-pass Printing Challenges in Large Format Printers

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Abstract

In the search of breakthrough productivity, HP has developed a new print technology capable of printing an image in a single continuous paper movement. This is possible thanks to an array of nozzles covering the full paper width. However, the big challenge of this technology is the print quality. Scanning Printer technology has been in use for long enough that most of its inherent problems have been understood and solved. PageWide technology is relatively new and there are a lot of printing challenges to solve. This paper will cover the aspects affecting print quality in one pass printing such as the impact of distance between modules, printhead to paper spacing and media drive, with focus on the position of the drop on the media. These critical parameters have been modeled and used to predict the position error of any single drop on the paper.

Introduction

The new HP PageWide XL is a family of large format Inkjet color printers for technical graphics and reproduction services. It offers the capability to print high quality images at high speeds and a low cost of operation. To achieve its high productivity it has a static array of nozzles that covers the entire page, the paper moves continuously under the printbar while the printheads fire drops on demand to print the image.

The human eye is very sensitive to slight perturbations in a regular pattern. For this reason, everything that differs from the nominal behavior will be translated into an image quality defect. As PageWide technology prints a page in just one pass, it's critical that all the elements involved in the printing perform at the highest level of accuracy and reliability. There are multiple sources of error in a print system, some of them can be addressed through different types of compensation, but there are others that need to be controlled through the printer architecture and the components specification.

We need to take into account that if the system specs are too tight this will be translated into an extra cost to the printer, but if they are too relaxed it will be impossible to compensate the possible errors and the printer will suffer from image quality defects. For this reason, it's very important to have a fundamental understanding of how the different parts of the system interact together to provide the desired image quality.

This paper is focused on the analysis and modeling of the components affecting image quality. This information is relevant to define key operational parameters of the printer to get the best image quality.

Figure 1 HP PageWide XL Printer

Image quality of one-pass printing

PageWide technology produces very accurate dots on the page because the printbar is static and the paper moves relatively slow below it. This gives enough time for the drop to land in the target position and produce round dots. On the contrary, Scanning technology move the modules back and forth while printing at high speed, this produce twin or elongated dots on the paper.

Furthermore, Scanning technology moves the media between passes while the printhead changes direction, this produces slight errors in the position of the paper and printhead adding some random noise to the position of the dots. Figure 2 shows a comparison of dot quality between PageWide and Scanning. Under the same printing conditions of media and ink, PageWide dots are more accurate in shape and position, while Scanning are more random.

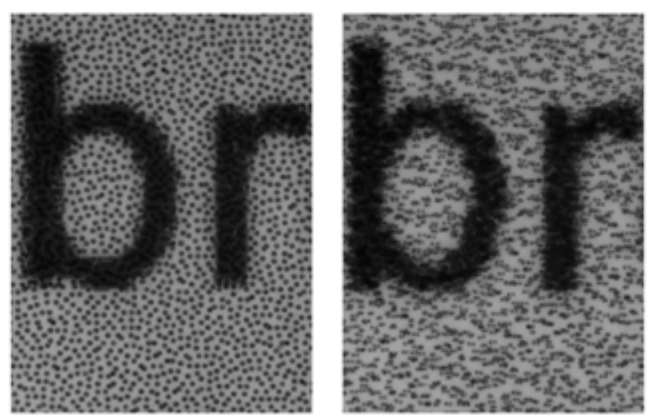

Figure 2 Microscopic pictures of dots printed with PageWide (left) and Scanning (right) technology.

The high accuracy of PageWide dots is translated into better quality of some image attributes, such as thin, sharp and straight lines and less grainy areas. In terms of image quality, PageWide technology is capable of producing better technical graphics and maps than Scanning technology.

On the other hand, the absence of arbitrariness in dot shape and position makes slight defects more visible. A failed nozzle could leave an unprinted dot row along the media feed direction. And a change in drop weight modifies the optical density producing banding. For this reason, multi-pass is capable of producing more uniform area fill.

PageWide print system configuration

The HP PageWide XL printer has a 40 inch-long printbar which holds the nozzle array. The printbar is made up of 8 modules stacked together. Each module uses multiple, staggered chips called dice. Every die has 4 colors (CMYK) distributed in trenches. The printbar can move up and down to accommodate the automatic maintenance performed to assure good nozzle health. When the printbar is in the printing position it has a fixed distance to the media. The media drive consists of perforated belts backed up by a print platen. The vacuum fan provides precise media hold-down and control of the printhead to media spacing.

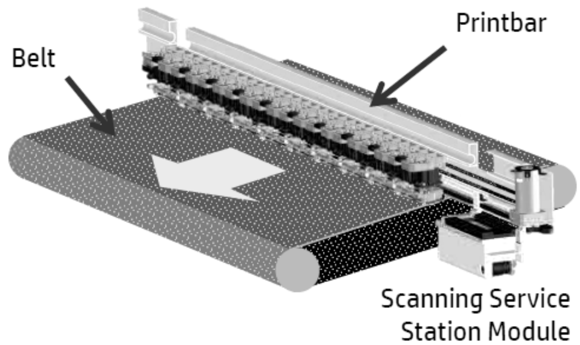

Figure 3 PageWide printer configuration

Stitching zone

The adjacent modules overlap in order to add robustness to manufacturing tolerances. In the overlap area there is nozzle redundancy. The portion of the image printed by these nozzles will be referred to as a stitching zone.

A stitching mask is used to determine how the overlapping nozzles fire to produce the optimum print quality. The simplest stitching mask uses a sharp linear pattern, one module print up to a certain point and the adjacent module prints from that point. Another common type of stitching mask is one that combines nozzles from both modules; one example is a checker board type. There are multiple enhancements of this type of masks to achieve better quality. One of them is to use nozzles from both modules but in random positions, as shown in Figure 6.

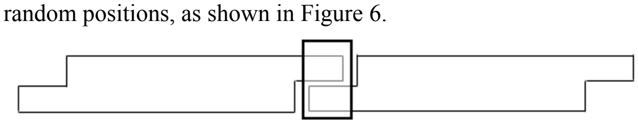

Figure 4 Stitching zone

Printheads in the print bar have positional errors due to mechanical tolerances. The modules can have positional errors in three directions: in the printbar direction (PBD), in the media advance direction (MAD) and in the printhead to paper direction (PPD). In order to minimize these errors, the position of every die in every module is measured and corrected along and across the image. This is an automatic process done by printing interference patterns and scanning those using a three-channel densitometer integrated in the printer. Even though the printhead alignment calibration is very accurate, the correction units are discrete and the resolution is limited to the nozzle spacing.

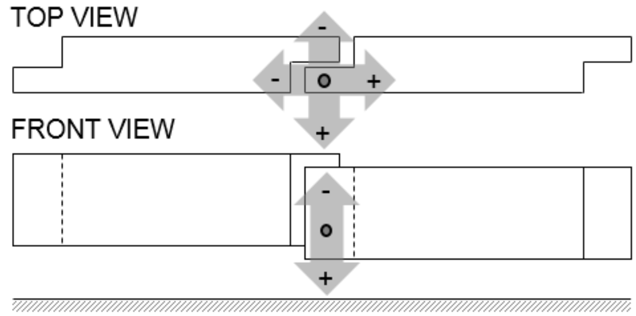

Figure 5 Position errors of modules

In the presence of slight misalignment between modules defects are visible in the stitching zone.

Figure 6 shows how the image quality is affected by certain module position errors when two different types of stitching masks are applied. To reach a good print quality a good optimization of the masks is needed in this sensitive area.

Apart from the residual error after module alignment, there are other situations where the stitching zone can be affected. In the following sections we describe the analysis of how the printing engine systems affects the module stitching zone.

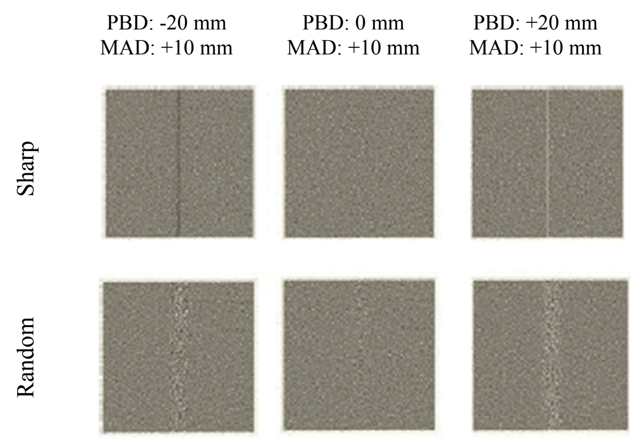

Figure 6 Simulation of stitching errors

Distance between modules

The relative position between modules is of high importance to avoid defects in the stitching zone. Wider distances between modules make the system more sensitive to errors in the relative direction of the media advance and the printbar. The types of defect produced in this situation are alternate lighter and darker streaks at the module stitching zone as shown in Figure 7.

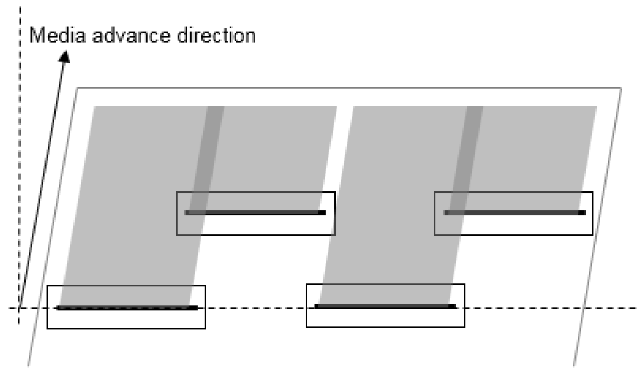

Figure 7 Diagram of Image quality defect due to lateral paper movement

According to several tests done during the investigation, a gap of +/-15 microns can be visible at a normal viewing distance of 30 cm.

Figure 8 shows the behavior and interactions between the distance of the modules and the media advance error. The desired operational range is below the curves shown and the specifications should be set based on this.

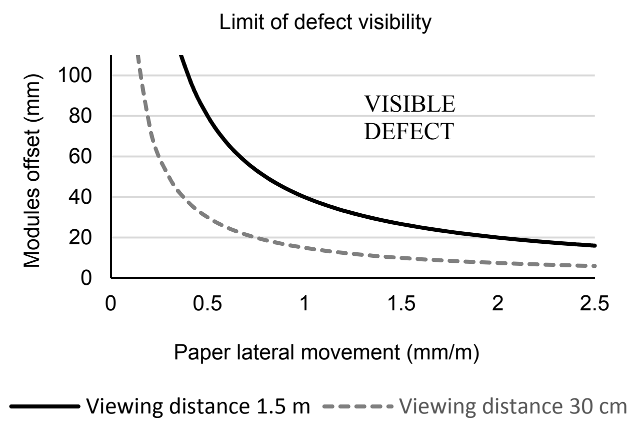

Figure 8 Graphic of limit of visibility due to later paper movement

To achieve better image quality the distance between modules should be reduced to a minimum. The S-shape of the HP PageWide XL modules allows them to fit together in a very compact print zone, compared with other configurations which force the modules to be far away from each other.

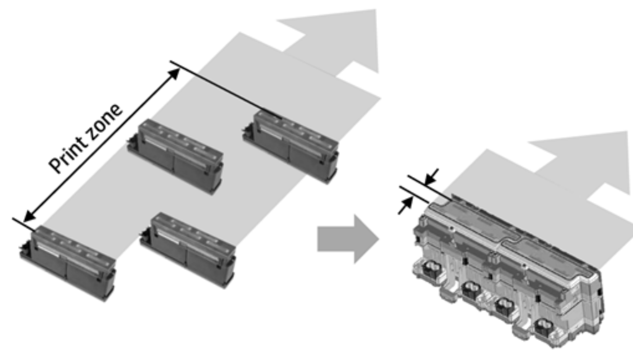

Figure 9 Difference between print zone distances

Also, the media advance control uses pulleys which have guiding grooves for the belts to suppress lateral motion.

With the combination of these two features the interaction is minimized and the output quality optimized. In addition, the stitching mask to work in this situation has to be designed to hide both a gap and overlap in the stitching zone.

Media drive

The media drive is responsible for transporting the paper below the printheads. The paper has to move at a precise constant speed to avoid banding from media velocity variations in the print zone. At a fixed drop ejection frequency, if media velocity decreases dots in the paper get closer, when the speed increases, dots in media gets further from each other. This defect can cause visible banding when viewed by the human eye.

In order to minimize the dot placement error, the digital signal to indicate when the ink drops must be fired (firing pulse) is synchronized with the actual media position and speed. The firing pulse is indirectly read by a rotary encoder placed in one of the pulleys of the media drive system. More important than having a constant speed of paper it's knowing exactly how the paper actually moves and generate the firing pulse signal following properly its movement.

Media speed variation occurs for several reasons and its characteristics depend directly on the hardware used in the media drive system. Pulley eccentricity produces a speed variation that is repeated at every turn, this generates a low frequency speed variation. Also, transmission gear teeth or natural frequencies of the system produce high frequency vibrations that are transmitted to the media. Some of these speed variations are measured by the encoder and can be counteracted by the predictive algorithms used in firing pulse generation, but others are unknown and not reported by the encoder. These unknown speed variations cause errors in the ink drop placement impacting the image quality. To understand properly this effect, the dot placement error caused by residual speed errors has been modeled and simulated.

Figure 10 shows how the media speed error is translated to dot position error on the media. The dot position error is modeled as a sinusoidal function with a certain amplitude and period. Notice that at a certain instant in time, the dot position error between trenches has an offset equal to the distance between them.

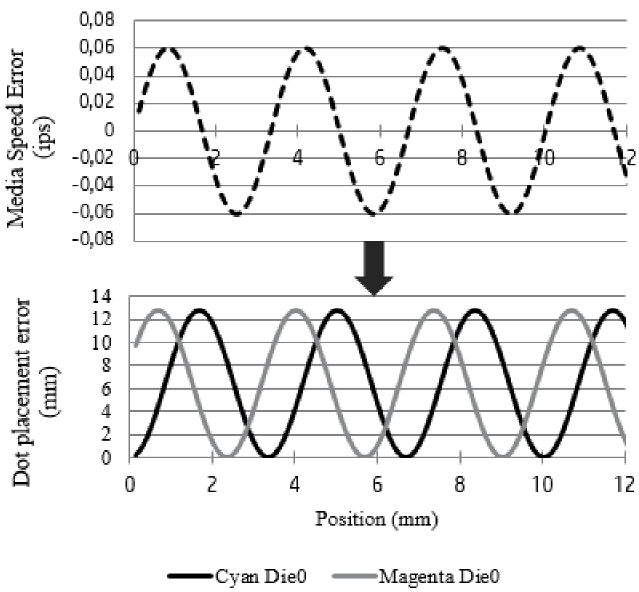

Figure 10 Drop position error model

The results show that the visibility of the defects not only depends on the magnitude of the dot position error, but also that there is a relationship between the amplitude and frequency of the error model. Very small dot position errors of just microns can be visible if the frequency of repetition is high. Figure 11 shows a simulation of a uniform area fill printed with different error models. For a fixed period, when the amplitude of the error increase, the banding is more visible. But, for the same amplitude of error, if the period increases the defects is less visible.

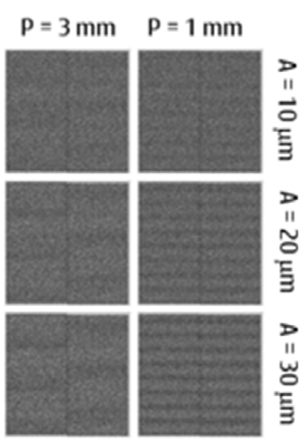

Figure 11 Simulation of banding due to vibration

According to the above results, low frequency media speed errors should not show print quality defects, because the error is distributed uniformly across a longer area. But, the stitching zone needs special attention and errors could still be visible if they are not well optimized.

In the case of high frequency errors, the physical position of the trenches in the die is also affecting the visibility of the banding. Having a fixed color configuration in a die with its corresponding distance between colors, say YCMK as shown in figure 12, and a sinusoidal media velocity error with a certain frequency, the output quality (dot position error) is highly affected depending on whether the error of the position of each color is in phase or contra phase. To print a color that needs two different inks, C and M, since a distance physically separates the trenches, they could not fire in the same moment of time. Because of that, to print in the same position, each trench is firing at a different time, and consequently the media velocity error at which each trench will print would be different too.

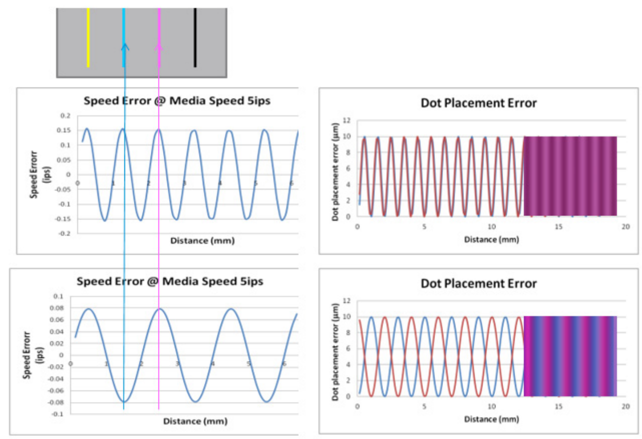

Figure 12 Different type of banding depending on media speed error frequency

Studies of visibility of the dot placement errors showed a relationship between the amplitude and the period of media advance error as the one represented in the figure 13. Desired operation range is found below the curve.

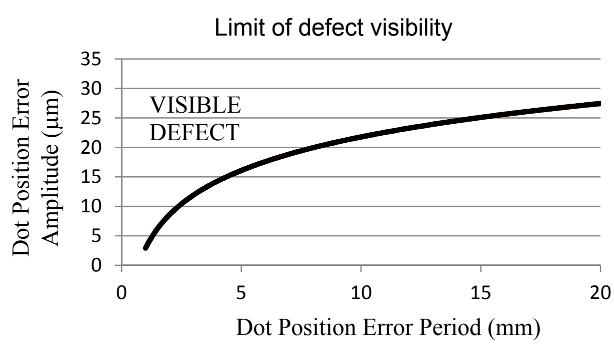

Figure 13 Graphic of limit of visibility due to media speed error

HP PageWide XL has minimized the errors through both mechanic design with a high-precision media transport, and the use of an analog encoder, signal-processing electronics, and sophisticated algorithms that predict when the belt will be at the next dot position. This information is used to synchronize drop ejection from the printheads.

Printhead to paper spacing

Maintaining precise spacing between the printheads and the media is important both for dot placement accuracy and to prevent the media from touching the printhead. When the drop is fired it takes a certain time to reach the media, this time depends on the drop velocity and the distance between the pen and the paper. Any deviation from the nominal drop trajectory produces an error in the dot placement. If the flying distance of the drop is higher, considering a fixed trajectory, the error in position will be bigger.

There are several causes for a drop trajectory deviation. The ones originated due to modules fabrication are managed through image processing by distributing the dots in the paper to hide the small error in position.

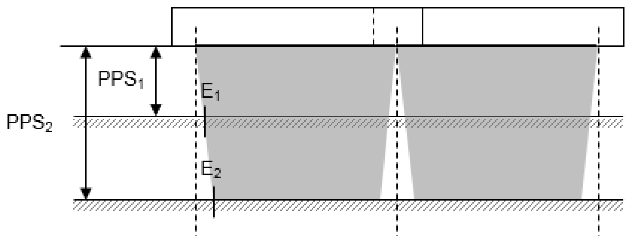

Figure 14 Drop trajectory error

The bigger defect on dot position is caused by the air flow produced by the ink jet itself. At high speed the amount of ink fired per minute is very high, consequently the jet of drops in the extreme nozzles change the trajectory due to aerodynamic effects. A computer model showed that the jet coming out of the nozzles could create a horizontal vortex, which causes a pressure drop and pulls the drops inwards. The drops tend to go towards the center of the die, making the gap between modules bigger. This affects the stitching zone in a similar way as a wrong module alignment. Above all, the amount of error depends on the ink flow, so it's dynamic as shown in Figure 15. The final amount of error depends on the area fill printed, the speed and the distance from the printhead to the media.

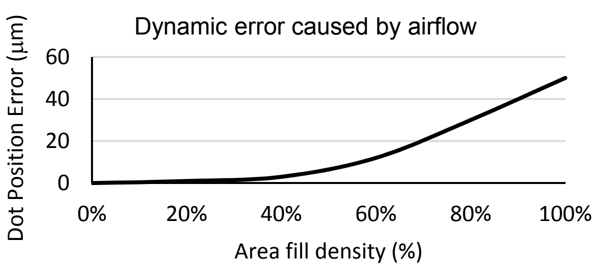

Figure 15 Dynamic error caused by airflow

In this case the management of the stitching zone should be dynamic. By modeling the behavior it's possible to compensate the gap by spitting more ink with the adjacent nozzles. Finally, it's critical to maintain precise spacing between the printheads and the media all along the printbar to assure that the dynamic compensation is correct.

Conclusions

In a PageWide printer, the printbar stays static and the paper moves at a constant speed below the nozzles. This enables high productivity and also high quality dots on paper, with round shape, constant size and accurate position. This quality of dots helps to achieve top quality lines and less grain in light area fills. On the other hand, high dot accuracy makes the one-pass printing more sensitive to small dot placement errors or missing dots.

The modeling and simulation techniques utilized throughout this study, based on predicting the dot position error, have been proven to be an effective set of tools to achieve fundamental understanding of the integrated print system. This information is critical to do a good design and optimize the image processing algorithms to achieve high print quality.

The zones where the modules overlap are especially challenging. These areas have nozzle redundancy to avoid gaps due to mechanical tolerances and it has been demonstrated that an optimized use of these nozzle is essential to minimize print quality defects in these areas.

A deep analysis of the main print system components has shown the most critical parameters to be as follows:

- The distance between print modules.
- The ability to precisely control the belt advance including prediction of belt position.
- The precision of spacing between the printheads and the paper all along the printbar.

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Isabel Borrell received her M.S in Mechanical Engineering from the Escola Tècnica Superior d'Enginyers Industrials de Barcelona (UPC). She joined Hewlett-Packard in 2000 and since then she has worked in the development of the writing systems of a variety of large format inkjet printers. Most recently she has contributed to the new HP PageWide XL printer platform.

Xavier Fariña holds a Mathematics degree from the Universitat de Barcelona. He is currently working as a software engineer in HP, designing and implementing algorithms for image processing.